Mission of the Engineering School

The Fu Foundation School of Engineering and Applied Science, as part of a world-class teaching and research university, strives to provide the best in both undergraduate and graduate education. We are preparing engineering leaders who will solve the problems of the new century, fostering scientific inquiry but never losing sight of its human implications. The School’s programs are designed to produce well-educated engineers who can put their knowledge to work for society. This broad educational thrust takes advantage of the School’s links to a great liberal arts college and to distinguished graduate programs in law, business, and medicine.

Through a synergy of teaching and research, we seek to educate a distinguished cadre of leaders in engineering and applied science who will thrive in an atmosphere of recently emerging technologies.
The great scientist-engineer Theodore Von Karmán said that “scientists discover the world that exists; engineers create the world that never was.” That clear-cut distinction between science and engineering might have been true in the mid twentieth century, but it is not true now. Engineering and applied science and their analytical precepts are an integral part of endeavors that were formerly thought of as pure science.

Since the 1990s, there has been a blending of pure science, with its applications, and engineering where the project technical objectives, not the discipline, drives the research initiatives. In addition, the realization now exists that the analytical tools of engineering practice and research can be applied successfully to a broad range of professions, especially in business and finance. In many ways, engineering has become the new liberal art, providing a firm intellectual foundation for many different types of careers.

Columbia Engineering’s program of study, both undergraduate and graduate, is designed to meet the new reality of the world in which we live. Our School has long recognized the need for collaboration among and between scientific and technological disciplines to solve some of the world’s most intractable problems. We have also fostered connections with Columbia’s other major professional schools in areas of overlapping interest. Because of this foresight, our School will continue to serve as a dynamic hub for the intellectual and scientific forces of the University.

On the undergraduate level, we offer you Columbia’s famed Core Curriculum and the opportunity to minor in an ever-growing range of liberal arts subjects, from English and history to philosophy and music. In addition to the variety of academic options, research opportunities abound. Last year, there were more than 260 research projects available for undergraduates alone. The research opportunities are even more numerous for graduate students.

On all levels of study, Columbia Engineering provides the tools of modern technology and rigorous academic programs to allow you to pursue your goals, whether they are interdisciplinary, business-oriented, or within traditional engineering fields. We welcome you to take full advantage of the opportunities our world-class teaching and research university offers.

Gerald A. Navratil
Interim Dean

Morton B. Friedman
Vice Dean
About the School and University
HISTORY OF THE SCHOOL

A COLONIAL CHARTER
Since its founding in 1754, as King's College, Columbia University has always been an institution both of and for the city of New York. And with an original charter directing it to teach, among other things, "the arts of Number and Measuring, of Surveying and Navigation . . . the knowledge of . . . various kinds of Meteors, Stones, Mines and Minerals, Plants and Animals, and everything useful for the Comfort, the Convenience and Elegance of Life," it has also always been an institution of and for engineers.

ENGINEERS FOR AN INDUSTRIAL REVOLUTION
An early and influential graduate from the school was John Stevens, Class of 1768. Instrumental in the establishment of U.S. patent law, Stevens procured many patents in early steamboat technology, operated the first steam ferry between New York and New Jersey, received the first railroad charter in the U.S., built a pioneer locomotive, and amassed a fortune, which allowed his sons to found the Stevens Institute of Technology.

THE GILDED AGE
As the city grew, so did the school. King's College was rechartered as Columbia College in 1784, and relocated from the Wall Street area to what is now Midtown in 1857. Students began entering the new School of Mines in 1864. Trained in mining, mineralogy, and engineering, Columbia graduates continued to make their mark both at home and abroad.

A MODERN SCHOOL FOR THE MODERN ERA
The School of Mines became the School of Mines, Engineering, and Chemistry in 1896, and its professors—now called the Faculty of Applied Science—including this time Michael Idvorsky Pupin, a graduate of the Class of 1883. As a professor at Columbia, Pupin did pioneering work in carrier-wave detection and current analysis, with important applications in radio broadcasting; invented the "Pupin coil," which extended the range of long-distance telephones; and taught classes in electromechanics.

A modern student of Pupin's was Irving Langmuir. Graduating in the Class of 1903, Langmuir enjoyed a long career at the General Electric research laboratory, where he invented a gas-filled tungsten lamp; contributed to the development of the radio vacuum tube; extended Gilbert Lewis's work on electron bonding and atomic structure; and did research in monolayering and surface chemistry, which led to a Nobel Prize in chemistry in 1932.

THE NUCLEAR AGE
As the United States evolved into a major twentieth-century political power, the University continued to build onto its undergraduate curriculum the broad range of influential graduate and professional schools that define it today. Renamed once again in 1926, the School of Engineering prepared students for careers not only as engineers of nuclear-age technology, but as engineers of the far-reaching political implications of that technology as well.

After receiving a master's degree from the School in 1929, Admiral Hyman George Rickover served during the Second World War as head of the elec-
trical section of the Navy’s Bureau of Ships. A proponent of nuclear sea power, Rickover directed the planning and construction of the world’s first nuclear submarine, the 300-foot-long Nautilus, launched in 1954.

THE TECHNOLOGICAL AGE
Today, The Fu Foundation School of Engineering and Applied Science, as it was named in 1997, continues to provide leadership for scientific and educational advances. Even Joseph Engelberger, Class of 1946, the father of modern robotics, could not have anticipated the revolutionary speed with which cumbersome and expensive “big science” computers would shrink to the size of a wallet.

In 1986 the Engineering School was one of the first schools in the country to use videotapes as tools for distance learning. Today Columbia Video Network continues to be in the forefront of distance learning at the graduate level through its online education programs. Named as one of Forbes Magazine’s “Best of the Web,” CVN offers the opportunity for students anywhere in the world to enroll in certificate programs or obtain a master’s or professional degree from Columbia Engineering via the World Wide Web.

THE NEW CENTURY
No one could have imagined the explosive growth of technology and its interdisciplinary impact. The Engineering School is in a unique position to take advantage of the research facilities and talents housed at Columbia to form relationships among and between other schools and departments within the University. The new Biomedical Engineering Department, with close ties to the Medical School, is but one example. Interdisciplinary centers are the norm, with cross-disciplinary research going on in environmental chemistry, materials science, medical digital libraries, digital government, new media technologies, and GK-12 education. The School and its departments have links to the Departments of Physics, Chemistry, Earth Science, and Mathematics, as well as the College of Physicians and Surgeons, the Graduate School of Journalism, Lamont-Doherty Earth Observatory, and Teachers College. The transforming gift of The Fu Foundation has catapulted the School into the forefront of collaborative research and teaching and has given students the opportunity to work with prize-winning academicians, including Nobel laureates, from many disciplines.

THE NEW RESEARCH
For the past several years, Columbia has been first among the handful of research universities that earn the largest patent income from inventions created by its faculty. The University is the only academic institution that holds patents in the patent pool for the manufacture of MPEG-2, the technology that enables DVDs and high definition TV. Another exciting patent that holds great promise is a laser-based method to create a single crystal film for a variety of devices, from solar cells to thin-film transistors for flat panel displays for computers. Within a short time, it may be possible to put an entire computer on a sheet of glass or plastic, thanks to the innovations taking place in Engineering School labs.

A FORWARD-LookING TRADITION
But, for all its change, there is still a continuous educational thread that remains the same. The Fu Foundation School of Engineering and Applied Science still remains an institution of manageable size within a great university. Committed to the educational philosophy that a broad, rigorous exposure to the liberal arts provides the surest chart with which an engineer can navigate the future, all undergraduates must complete a modified but equally rigorous version of Columbia College’s celebrated Core Curriculum. It is these selected courses in Western Civilization and other major cultures that best prepare a student for advanced coursework; a wide range of eventual professions; and a continuing, life-long pursuit of knowledge, understanding, and social perspective. It is also these Core courses that most closely tie today’s student to the alumni of centuries past. Through a shared exposure to the nontechnical arts, all Columbia engineering students—past, present, and future—gain the humanistic tools needed to build lives not solely as technical innovators, but as social and political ones as well.
A COLLEGE WITHIN THE UNIVERSITY

A unique educational opportunity, Columbia University’s Fu Foundation School of Engineering and Applied Science (SEAS) offers programs to both undergraduate and graduate students who undertake a course of study leading to the bachelor’s, master’s, or doctoral degree in engineering and applied science. Combining the advantages of a small college with the extensive resources of a major research university, students at the School pursue their academic interests under the guidance of outstanding senior faculty members who teach both undergraduate and graduate level courses. Encouraged by the faculty to undertake research at all levels, students at the School receive the kind of personal attention that only Columbia’s exceptionally high faculty-student ratio affords.

THE NEW YORK ADVANTAGE

Besides the faculty, the single greatest facility at a Columbia student’s disposal is without doubt the City of New York. Within easy reach by walking, bus, subway, or taxi, New York’s broad range of social, cultural, and business communities offer an unparalleled opportunity for students to expand their horizons or deepen their understanding of almost any human endeavor imaginable. With art from small SoHo galleries to major Uptown museums; music from Harlem jazz clubs to the Metropolitan Opera; theatre from performance art in the East Village to musicals on Broadway; food from French on the Upper East Side to Asian in Chinatown; and sports teams from the Jets to the Yankees, New York is the crossroads of the world.

New York is fast becoming a major player in high-tech research and development, where Fortune 500 companies traded on Wall Street seek partnerships with high-tech start-up ventures in Tribeca. And as more and more companies discover the advantages of locating in New York’s greater metropolitan area, they join such long-standing facilities as AT&T Laboratories, Bell Communications Research, Exxon Research, IBM Research Laboratories, International Paper, NYNEX, and many other major companies involved in high-tech R&D. As part of the research community themselves, Columbia students have exceptional opportunities for contact with industry both on and off campus. Senior representatives of these companies often visit Columbia to lecture as adjunct faculty members or as special speakers, and undergraduate and graduate students frequently undertake research or internships with these and other companies, oftentimes leading to offers of full-time employment after graduation.

In addition to its ties to private industry, Columbia also has a historically close relationship with the public sector of New York, stretching back to the eighteenth century. No other city in the world offers as many impressive examples of the built environment—the world’s most famous collection of skyscrapers, long-span bridges, road and railroad tunnels, one of the world’s largest subway and water supply systems. Involved in all aspects of the city’s growth and capital improvements over the years, Columbia engineers have been responsible for the design, analysis, and maintenance of New York’s enormous infrastructure of municipal services and communications links, as well as its great buildings, bridges, tunnels, and monuments.

THE UNIVERSITY AT LARGE

Columbia University occupies two major campuses, as well as additional special-purpose facilities throughout the area. Besides the main campus located on the Upper West Side in Morningside Heights, further uptown in Washington Heights is the Health Sciences campus, which includes Columbia’s medical school (the College of Physicians and Surgeons), the Mailman School of Public Health, the New York State Psychiatric Institute, and other health professions programs. The Health Sciences Division is an equal partner with New York-Presbyterian Hospital in the Columbia-Presbyterian Medical Center, the world’s first academic medical center. The medical center opened in 1928 when Columbia’s health-related schools and Presbyterian Hospital (which has since merged with New York Hospital to become New York-Presbyterian Hospital) moved to the Washington Heights location. The Engineering School’s new Biomedical Engineering Department has offices on both the Morningside and Health Sciences campuses.
Beyond its schools and programs, the measure of Columbia’s true breadth and depth must take into account its seventy-odd internationally recognized centers and institutions for specialized research, which study everything from human rights to molecular recognition, as well as the close affiliations it holds with Teachers and Barnard Colleges, the Juilliard School, the American Museum of Natural History, and both the Jewish and Union Theological Seminaries. Columbia also maintains major off-campus facilities such as the Lamont-Doherty Earth Observatory in Palisades, N.Y., and the Nevis Laboratories in Irvington, N.Y. Involved in many cooperative ventures, Columbia also conducts ongoing research at such facilities as Brookhaven National Laboratory in Upton, N.Y., and the NASA Goddard Institute for Space Studies located just off the Morningside campus.

THE MOMINGSIDE HEIGHTS CAMPUS
The Fu Foundation School of Engineering and Applied Science is located on Columbia’s Morningside campus. One of the handsomest urban institutions in the country, the thirty-two acres of the Morningside campus comprise over sixty buildings of housing; recreation and research facilities; centers for the humanities and social and pure sciences; and professional schools in architecture, business, the fine arts, journalism, law, and other fields.

THE FU FOUNDATION SCHOOL OF ENGINEERING AND APPLIED SCIENCE
The Fu Foundation School of Engineering and Applied Science occupies three laboratory and classroom buildings at the north end of the campus, including the Schapiro Center for Engineering and Physical Science Research. Because of the School’s close proximity to the other Morningside facilities and programs, Columbia engineering students have ready access to the whole of the University’s resources.

Comprising multiple programs of study, with facilities specifically designed and equipped to meet the laboratory and research needs of both undergraduate and graduate students, the School is the site of an almost overwhelming array of basic and advanced research installations, from the Columbia Center for Electron Transport in Molecular Nanostructures to the Columbia Genome Center. Details about specific programs’ laboratories and equipment can be found in the sections describing those programs.

SEAS COMPUTING FACILITIES
The Botwinick Multimedia Learning Laboratory is the School’s state-of-the-art facility for computer-aided design (CAD). It is equipped with forty-five Dell Precision workstations, custom tailored for 3D modeling and animation, as well as a Sun Enterprise level server that serves the lab’s 300-plus users per semester. The lab offers students the latest modeling software products used in the industry—Alias|Wavefront Studio|Tools, Maya, Pro-Engineer—as well as Adobe Photoshop and After Effects.

All first-year students take a course in the Botwinick Multimedia Learning Laboratory that explores fundamental engineering design in a three-dimensional virtual environment. Students work in teams to research, develop, and finally design innovative new products. In addition, all undergraduate students from the University have a chance to take advanced courses in modeling and animation.

CENTRAL COMPUTING RESOURCES
Columbia University Information Technology (CUIT)
www.columbia.edu/cuit

Contact the CUIT Helpdesk for Technical Support
E-mail: askCUIT@columbia.edu
By phone: 212-854–1919
Monday–Thursday: 8:00 a.m.–11:00 p.m.
Friday: 8:00 a.m.–7:00 p.m.
Saturday: 10:00 a.m.–6:00 p.m.
Sunday: 3:00 p.m.–1:00 p.m.

In person (some consultations may require an appointment):
CUIT Client Service Center
102 Philosophy Hall
Monday–Friday: 10:00 a.m.–6:00 p.m.
services, including computer accounts, e-mail, telephone and cable TV service, and course management and student information applications. CUIT manages the Columbia wireless network and the high-speed campus Ethernet network, which is available to all students in residence hall rooms. CUIT also manages an array of computer labs, terminal clusters, ColumbiaNet kiosk stations, and electronic classrooms, and provides a variety of technical support services via the CUIT Helpdesk. CUIT services include the following:

- **Computer account IDs** provide access to Columbia’s secure online information resources, campus computer labs, and printing on CUIT printers. All Columbia students, faculty, and staff are assigned an ID account (called University Network ID or UNI). uni.columbia.edu.
- **Columbia’s Web site** provides access to hundreds of online services and resources, including extensive academic, scholarly, and administrative resources, a myriad of library catalogs and references, the Directory of Classes, registration information, campus publications, and events listings. www.columbia.edu
- **Technical support** is available through the CUIT Helpdesk, which provides assistance to the Morningside campus online, by phone, or in person. (See beginning of this section for hours and contact information.)
- **Courseworks@Columbia** is the University course management system. It allows instructors to develop and maintain course Web sites easily, distribute class materials, link to online reserves, administer quizzes and tests, communicate with students, and promote online discussions. courseworks.columbia.edu
- **Electronic classrooms** provide multimedia capabilities such as computer and projection systems, DVD and CD-ROM players, VCRs, and audio systems. www.columbia.edu/cuit/classrooms
- **Public computer kiosks** are available in various locations around the Morningside campus for accessing Columbia’s Web site resources and e-mail. www.columbia.edu/cuit/facilities/cnet
- **Computer labs and clusters** provide students, faculty, and researchers with access to a range of software. Some locations have part-time consultants to provide lab help. www.columbia.edu/cuit/facilities/labs
- **Printing facilities** are available throughout the Morningside campus and Barnard College, including CUIT computer labs, libraries, residence halls, and other computer clusters and electronic classrooms. Printing is provided by the NINJa printing system on high-speed, high-volume printers. www.columbia.edu/cuit/facilities/printers
- **Computer security resources** are available online, including links to download antivirus and anti-spyware software. The site also provides information on how to protect your system when working online. www.columbia.edu/cuit/security
- **Electronic Data Service (EDS)**, run jointly by CUIT and the Libraries, provides computing support for researchers with data-intensive applications, including special accounts, statistical software, and finding and selecting appropriate data. www.columbia.edu/cuit/eds
- **Telephone and cable TV service** is available to students living in University residence halls. www.columbia.edu/acis/telecom/students
THE COLUMBIA UNIVERSITY LIBRARIES

The Columbia University Libraries system is the nation’s sixth largest academic library system, with 9.7 million volumes, 65,650 serials, as well as extensive collections of electronic resources, manuscripts, rare books, microforms and other nonprint formats. The collections and services are organized into 25 libraries, supporting specific academic or professional disciplines. The Library’s Web site at www.columbia.edu/cu/lweb is a gateway to the print and electronic collections and services.

The Ambrose Monell Engineering Library, located within the Engineering School complex, has a collection of more than 252,000 volumes and over 1 million technical reports on microform. It currently subscribes to approximately 825 periodicals. Via LibraryWeb, the Engineering Library provides access to full-text electronic journals; a collection of many specialized databases in engineering and the sciences, e.g., Compendex, Inspec, Web of Science, ACM Digital Library, and IEEE Electronic Library; several handbooks and encyclopedias; and e-book packages such as Safari Books Online, Books 24x7, and NetLibrary. On site, the Library offers access to Scifinder Scholar, Gmelan, and Beilstein databases.

CENTER FOR CAREER EDUCATION

Center for Career Education
Columbia University
East Campus, Lower Level
Mail Code 5727
2960 Broadway
New York, NY 10027

Delivery: 70–74 Morningside Drive
Phone: 212-854-5609
Fax: 212-854-5640
E-mail: cce@columbia.edu
www.careereducation.columbia.edu

The Columbia University Center for Career Education helps students and alumni develop the key competencies necessary to make informed decisions and take the necessary steps to achieve their career goals. The Center establishes connections and facilitates interaction among undergraduate students, graduate students, alumni, employers, and organizations to generate opportunities that help students pursue their personal and professional objectives.

The Center for Career Education provides career development opportunities for students beginning with the first year at Columbia and involving a series of coordinated programs, a sequence of workshops and seminars, and individual one-to-one counseling. Career development is a lifelong process that includes self-assessment, curricular exploration through choice of major, competency development, networking, informational interviewing, internships, summer work experience, study abroad, preparation for the job search and for the graduate/professional school application process, and planning for productive careers. Above all else, it is a generative process, which provides a foundation for achieving goals throughout life.

The Center maintains a Web site (www.careereducation.columbia.edu) that contains information on career search strategies and tools, upcoming events, career fairs, full- and part-time job listings, and internships. The Center encourages both students and alumni to visit the Center and register to use Columbia’s job database early in order to maximize the level of resources and assistance they can receive.

Individual career counseling is available to assist all students and alumni the Center serves with a variety of interests, including self-assessment, career exploration, and career search tools and strategies. Through the Career Resource Center, students are able to research employers, graduate schools, opportunities abroad, and more.

The Center recognizes the special interests of graduate students in the University with programs and workshops that focus on both academic and non-academic careers. The Center maintains a dossier service, managed by Interfolio, for graduate students and alumni who hold graduate degrees. A dossier consists of letters of reference and other credentials that speak to a candidate’s scholarship, research interests, and teaching experience. A dossier is specifically used in applying for teaching positions at either the secondary level or the college level and for graduate/professional school and fellowship applications. Students can register online for the service at www.interfolio.com. It is recommended that candidates for teaching positions open a credentials file in the late summer or early autumn of the year preceding their availability for employment. Undergraduate students or alumni with undergraduate degrees from SEAS should contact the Center for Student Advising for dossier management.

The Center manages full-time, part-time, and internship opportunities for students throughout the year in two capacities. On-campus recruiting is conducted throughout the academic year and allows students to submit their resumes and cover letters online to any of the opportunities from employers who have chosen to recruit on campus. These opportunities are listed in the online recruiting database and are easily searchable. There are also full-time, part-time, and temporary on- and off-campus employment opportunities advertised year round through a general job-posting database. While at Columbia, students are encouraged to take advantage of internships that offer opportunities to gain first-hand knowledge of a career field.

The Center offers international internship opportunities through two programs, Columbia Experience Overseas (CEO) and Encouraging Dynamic Global Entrepreneurs (EDGE). The CEO program offers Columbia students high-quality internship experiences in a diverse array of industries in London and Hong Kong through alumni and employer partnerships. EDGE Scotland is a summer program in entrepreneurship and enterprise leadership offered in collaboration with Scottish Enterprise Dunbartonshire and the University of Glasgow, with support from the European Union, the Scottish Executive, and others. It takes place in Dunbartonshire, an economically underdeveloped area of Scotland. Student consulting teams are challenged to solve real-world business problems by analyzing business climate, identifying opportunities for innovation, and proposing solutions and initiatives to create a more entrepreneurial and economically vibrant culture. The EDGE Guatemala program, run in partnership with New Development Solutions, focuses on social entrepre-
neurship. Students design smart, scalable, and highly integrated business models for their constituents in rural communities. The Center also offers an arts internship program called Columbia Arts Experience. Selected students participate in a New York–based internship in the arts at organizations such as the Sundance Channel, Lincoln Center Film, Alliance for the Arts, and others.

The Center for Career Education also fosters entrepreneurship through Columbia Student Enterprises (CSE). The Columbia Student Enterprises program is a unique opportunity to learn about and develop valuable entrepreneurship and enterprise leadership skills through managing and working for student-run enterprises. The program consists of student-managed businesses such as the Columbia Bartending Agency and School of Mixology, Inside NY, CU Snacks, and the Columbia University Tutoring and Translation Agency. The participants of the program receive training and develop transferable business skills applicable to all industries. The program also promotes student initiatives in business and increases services on campus, enhancing the quality of student life and creating job opportunities for Columbia University students.

To gain a complete understanding of all Center for Career Education programs and resources, please visit the Center in the lower level of East Campus. For additional information and questions, please call 212-854-5609.

Statistics for Class of 2007 Graduates
Pursuant to New York State Education Department regulations 53.3 (d) sec. (6) and sec. (7), the School publishes the following statistics:

Survey of Graduates
These statistics reflect information gathered by the Center for Career Education from a survey of undergraduates who graduated in the spring of 2007. This was the most current information available at the time this bulletin was published. For more up-to-date information, contact the Center for Career Education at 212-854-4934.

Of those seniors graduating from SEAS in the Class of 2007 who responded to this survey:
- 51.0% have accepted job offers
- 10.3% have applied for jobs and are awaiting or deciding between job offers
- 29% will be attending graduate school
- 2.1% have not started looking for a job
- 3.4% are taking the year off
- 4.1% other

THE INTERNATIONAL STUDENTS AND SCHOLARS OFFICE (ISSO)
International Students and Scholars Office
Columbia University
Mail Code 5724
2960 Broadway
New York, NY 10027
Phone: 212-854-3587
e-mail isso@columbia.edu

The International Students and Scholars Office (ISSO) offers many services for international students as well as American citizens and permanent residents who have received their education in another country. Services for international students include preadmission counseling, document and other immigration-related services, the International Orientation program, social and cultural activities, and a program for the spouses of students. The ISSO also provides credential analysis services to the admissions offices of the University. The ISSO is open year-round, and international students are urged to make use of its services during their stay at the University and are also invited to visit the ISSO Web site at www.columbia.edu/cu/issso, with comprehensive information for both prospective and current students.

The staff of the International Students and Scholars Office is available for personal advisement and for help in learning about the campus and New York City. The ISSO is an essential source of information regarding immigration and Department of State regulations that affect students studying in the United States. The staff can also assist with many other non-academic matters. The ISSO provides information about cultural activities in the New York area and has reduced-rate tickets for plays, concerts, and other events.

Students are required to check in with the ISSO within a week of their arrival at Columbia. The office’s street address is 524 Riverside Drive in International House North, just north of 122nd Street. The orientation program for new international students arriving for the September term takes place during orientation week, usually the last week in August or the first week in September. For further information, consult the International Students and Scholars Office using the contact information above.
Undergraduate Studies
The undergraduate programs at The Fu Foundation School of Engineering and Applied Science (SEAS) not only are academically exciting and technically innovative but also lead into a wide range of career paths for the educated citizen of the twenty-first century. Whether you want to become a professional engineer, work in industry or government, or plan to pursue a career in the physical and social sciences, medicine, law, business, or education, SEAS will provide you with an unparalleled education.

SEAS firmly believes that students gain the most when engineering is brought up front, early in the four-year curriculum. Therefore, first-year students use the networked, high-performance workstations and multimedia software of the Botwinick Multimedia Learning Laboratory as part of their technical core requirements. Here students apply fundamental principles of engineering design to modeling advanced engineering and applied science problems. Later in the four-year program, students often use the Laboratory’s symbolic, numeric, and graphical computing power in ever deepening integration with classroom, laboratory, and research work of their chosen engineering program.

While pursuing their own interests, undergraduate students are encouraged to participate in a broad range of ongoing faculty research projects encompassed by the Undergraduate Research Involvement Program (URIP). An annual URIP publication sent to students describes faculty projects in which students may participate, lists necessary qualifications, and details whether the student’s participation will be voluntary, for academic credit, or for monetary compensation.

In addition to in-depth exploration of engineering and applied science, SEAS undergraduates explore the humanities and social sciences with Columbia College students through intellectually challenging Core Curriculum courses taught by the Faculty of Arts and Sciences. These courses in art, literature, music, major cultures, and economics, among others, provide students with a broad, intellectually disciplined, cultural perspective on the times they live in and the work they do.

**Policy on Degree Requirements**

The Committee on Instruction and faculty of The Fu Foundation School of Engineering and Applied Science review degree requirements and curricula matters each year, and the bulletin reflects these faculty recommendations and curricular changes in its yearly reprinting. School policy requires students to fulfill all general degree requirements as stated in the bulletin of the first year of their matriculation into the School. Students declare their major during the first semester of their sophomore year. Requirements for the major or minor are in accordance with the bulletin during the year in which the student declares the major or minor.

**The First Year—Sophomore Program**

Students entering The Fu Foundation School of Engineering and Applied Science are encouraged to consider the wide range of possibilities open to them, both academically and professionally. To this end, the first and second years of the four-year undergraduate program comprise approximately 66 semester points of credit that expose students to a cross-fertilization of ideas from different disciplines within the University. The sequence of study proceeds from an engagement with engineering and scientific fundamentals, along with humanities and social sciences, toward an increasingly focused training in the third and fourth years designed to give students mastery of certain principles and arts central to engineering and applied science.

**Liberal Arts Core for SEAS Students: 27-Point Nontechnical Requirement**

This requirement provides a broad liberal arts component that enhances the SEAS professional curriculum to help students meet the challenges of the twenty-first century. Our students are destined to be leaders in their professions and will require sophisticated communication, planning, and management skills. The SEAS Committee on Instruction established the school’s nontechnical requirement so that students would learn perspectives and principles of the humanities and social sciences as part of a well-rounded and multiperspective education. Through discussion, debate, and writing, students improve their ability
to engage in ethical, analytic, discursive, and imaginative thinking that will prove indispensable later in life.

- SEAS students must take 16 to 18 points of credit of required courses in list A and 9 to 11 elective points chosen from the approved courses in list B. The total combined number of non-technical points (from lists A and B, below) must add up to at least 27. Neither list can be modified by advising deans or faculty advisers.
- Advanced Placement (AP) credit in appropriate subject areas can be applied toward the 9-point elective nontechnical requirement.

If electing Major Cultures sequence, students must take two courses from the Major Cultures List of Approved Courses (www.college.columbia.edu/DocRep/academics/core/major_cult.pdf) for a letter grade.

- Students must begin the Major Cultures requirement with a course chosen from List A.
- The second course, completing the requirement, may be chosen from List A again or from List B or C.
- If the second course is from List A, it may be drawn from any of the five civilizations.
- If the second course is from List B or C, it must be drawn from the same civilization as the List A course.

A. Required Nontechnical Courses (16–18 points of credit)

These courses must be taken at Columbia.

<table>
<thead>
<tr>
<th>Course</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ENGL C1010 University writing</td>
<td>3</td>
</tr>
<tr>
<td>2. One of the following two-semester sequences: HUMA C1001-C1002 Masterpieces of Western literature and philosophy (All students registering for this course should be prepared to discuss the first six books of the Iliad on the first day of class.) or COCI C1101-C1102 Introduction to contemporary civilization in the West</td>
<td></td>
</tr>
<tr>
<td>or any Major Cultures sequence (2 courses) from List A of the Major Cultures Requirement or a List A and a List B or C course in the same culture</td>
<td>6–8</td>
</tr>
<tr>
<td>3. One of the following two courses: HUMA W1121 Masterpieces of Western art or HUMA W1123 Masterpieces of Western music</td>
<td>3</td>
</tr>
<tr>
<td>4. ECON W1105 Principles of economics (This course can be satisfied through Advanced Placement; see the Advanced Placement chart on page 14.)</td>
<td>4</td>
</tr>
</tbody>
</table>

B. Elective Nontechnical Courses (9–11 points of credit)

The following course listing by department specifies the courses that either fulfill or do not fulfill the nontechnical requirement.

(Professional, workshop, lab, project, scientific, studio, music instruction, and master's-level professional courses do not satisfy the 27-point nontechnical requirement.)
ECONOMICS
All courses except:
W3211 Intermediate microeconomics
W3213 Intermediate macroeconomics
W3412 Introduction to econometrics
W3025 Financial economics
W4020 Economics of uncertainty and information
W4211 Advanced microeconomics
W4213 Advanced macroeconomics
W4261 Introduction to accounting and finance
W4280 Corporate finance
W4412 Advanced econometrics
W4415 Game theory
W4918 Seminar in applied econometrics
W4930 Seminar in mathematical modeling in economics
BC1001 Introduction to macroeconomics
BC1002 Introduction to microeconomics
BC2411 Statistics for economics
BC3018 Econometrics
BC3033 Intermediate macroeconomic theory
BC3035 Intermediate microeconomic theory

EDUCATION: All courses

ENGLISH AND COMPARATIVE LITERATURE
All courses

FILM STUDIES
All courses except:
lab courses, and
W3850 Senior seminar in screenwriting
W4005 The film medium: script analysis

FRENCH AND ROMANCE PHILOLOGY
All courses

GERMANIC LANGUAGES: All courses

GREEK: All courses

HISTORY: All courses

HISTORY AND PHILOSOPHY OF SCIENCE
All courses

ITALIAN: All courses

LATIN: All courses

LATINO STUDIES: All courses

MATHEMATICS: No courses

MEDIEVAL AND RENAISSANCE STUDIES
All courses

MIDDLE EASTERN AND ASIAN LANGUAGE
AND CULTURES: All courses

MUSIC
All courses except performance or instrument instruction classes (which do not count toward the 128 credits required for graduation)

PHILOSOPHY
All courses except:
F1401 Elementary logic
V3411 Introduction to symbolic logic
W4137 Non-classical logic
G4431 Introduction to set theory
G4424 Modal logic
CSPH G4801 Mathematical logic, I
CSPH G4802 Incompleteness results in logic
Courses in logic

PHYSICAL EDUCATION: No courses

PHYSICS: No courses

POLITICAL SCIENCE: All courses

PSYCHOLOGY
No lab courses. Only:
W1001 The science of psychology
W2235 Thinking and decision making
W2240 Human communication
W2280 Introduction to developmental psychology
W2610 Introduction to personality
W2620 Abnormal behavior
W2630 Social psychology
W2640 Introduction to social cognition
V2680 Social and personality development
W3615 Children at risk

RELIGION: All courses

SEAS:
Only:
SCNC W3010 Science, technology and society
BMEN E4010 Ethics for biomedical engineers
EEHS E3900 History of telecommunications

SLAVIC LANGUAGES: All courses

SOCIOLOGY:
All courses except:
SOGI V3212 Statistics and methods

SPANISH AND PORTUGUESE: All courses

SPEECH: No courses

STATISTICS: No courses

URBAN STUDIES: All courses

VISUAL ARTS: No more than one course, which must be at the 3000 level or higher

WOMEN AND GENDER STUDIES: All courses

WRITING: All courses

Technical Course Requirements
The prescribed First-Year-Sophomore Program curriculum requires students to complete a program of technical course work introducing them to five major areas of technical inquiry: engineering, mathematics, physics, chemistry, and computer science.

All first-year SEAS undergraduate students take ENGI E1102: Design fundamentals using the advanced computer technologies (4 points), in the Botwinick Multimedia Learning Laboratory. In this course, students learn the basics of engineering design along with professional and teamwork skills through participation in community service projects for real clients in local communities.

While students need not officially commit to a particular branch of engineering until the third semester, most programs recommend, and in some cases may require, that particular courses be taken earlier for maximum efficiency in program planning. For information concerning these requirements, students should turn to the individual program sections in this bulletin.

Professional-Level Courses for First- and Second-Year Students
First- and second-year students are required to take at least one professional-level course chosen from the list below. The faculty strongly encourages students to schedule two of these courses. (The Botwinick Multimedia Learning Laboratory course in computer and engineering design technology, ENGI E1102, which is required of every first-year student, is not included in this list.)

Each course is designed to acquaint SEAS students with rigorous intellectual effort in engineering and applied science early in their academic careers. If a student chooses to take the second professional-level course, such a 1000-level course may, at the discretion of each department, be used as an upper-level technical elective normally satisfied by 3000-level or higher courses.

The courses stipulate minimal prerequisites. Each course serves as an introduction to the area of study in addition to teaching the subject matter. Each course is taught by regular department faculty and thus provides a double introduction to both subject area and faculty.

The courses are:

APPH E1300y Physics of the human body
The human body analyzed from the basic principles of physics: energy balance in the body, mechanics of motion, fluid dynamics of the heart and circulation, vibrations in speaking and hearing, muscle mechanics, vision, gas exchange and transport in the lungs, structural properties and limits, and other topics.
APAM E1601y Introduction to computational mathematics and physics
Mathematics and physics problems solved by using computers. Topics include elementary interpolation of functions, solution of nonlinear algebraic equations, curve-fitting and hypothesis testing, wave propagation, fluid motion, gravitational and celestial mechanics, and chaotic dynamics.

BMEN E1001x Engineering in medicine
The present and historical role of engineering in medicine and health care delivery. Engineering approaches to understanding organismic and cellular function in living systems. Engineering in the diagnosis and treatment of disease. Medical imaging, medical devices: diagnostic and surgical instruments, drug delivery systems, prostheses, artificial organs.

CHEN E1040y Molecular engineering and product design
Examines the ways in which chemical and biological sciences are interpreted through analytical design and engineering frameworks to generate products that enhance human endeavor. Culture of chemical engineering and the wide variety of chemical engineering practices, through lectures by department faculty and practicing chemical engineers, trips to industrial facilities, reverse engineering of chemical products, and a chemical design competition.

CIEN E1201y Design of buildings, bridges, and spacecraft
Basic principles according to which many structures are designed, constructed, and maintained in service. How strength and safety are treated and the role of the computer at this design stage. Performance requirements, such as noise and motion limitations. Classic and new materials of construction, their important features, and laboratory demonstration of properties. Management of both design and construction projects, and follow-up assessment monitoring and control.

EAE E1100y A better planet by design
Sustainable development and management of Earth resources (water, minerals, energy, and land) are now recognized globally as an essential goal. A "systems analytic" approach to understanding feedbacks and interactions between human activity and the environment is introduced. Elements of integrated assessment, modeling, forecasting and decision analysis are illustrated by means of case studies of current resource and environment concerns.

ELEN E1201x and y Introduction to electrical engineering, with laboratory in circuit design
Exploration of selected topics and their application. Electrical variables, circuit laws, nonlinear and linear elements, ideal and real sources, transducers, operational amplifiers in simple circuits, external behavior of diodes and transistors, first order RC and RL circuits. Digital representation of a signal, digital logic gates, flipflops.

GRAP E1115x and y Engineering graphics
Visualization and simulation in virtual environments; computer graphics methods for presentation of data. 3-D modeling; animation; rendering; image editing; technical drawing.

MECE E1001x Mechanical engineering: micro-machines to jumbo jets
The role of mechanical engineering in developing many of the fundamental technological advances on which today's society depends. Topics include airplanes, automobiles, robots, and modern manufacturing methods, as well as the emerging fields of micro-electro-mechanical machines (MEMS) and nanotechnology. The physical concepts that govern the operation of these technologies will be developed from basic principles and then applied in simple design problems. Students will also be exposed to state-of-the-art innovations in each case study.

MSAE E1001y Atomic-scale engineering of new materials
An introduction to the nanoscale science and engineering of new materials. The control and manipulation of atomic structure can create new solids with unprecedented properties. Computer hard drives, compact disc players, and liquid crystal displays (LCDs) are explored to understand the role of new materials in enabling technologies. Group problem-solving sessions are used to develop understanding.

Physical Education
Two terms of physical education (C1001-C1002) are a degree requirement for students in The Fu Foundation School of Engineering and Applied Science. No more than 4 points of physical education courses may be counted toward the degree. A student who intends to participate in an intercollegiate sport should register for the appropriate section of C1005: Intercollegiate athletics. Intercollegiate athletes who attend regularly receive 1 point of credit up to the maximum of 4. Those who are advised to follow a restricted or adapted activity program should contact Professor Torrey in the Department of Physical Education and Intercollegiate Athletics. The physical education program offers a variety of activities in the areas of aquatics, dance, fitness, martial arts, individual and dual lifetime sports, team sports, and outdoor education. Most activities are designed for the beginner/intermediate levels. Advanced courses are indicated on the schedule. The majority of the activities are offered in ten time preferences. However, there are early-morning conditioning activities, Friday-only classes at Baker Field, and special courses that utilize off-campus facilities during weekends and vacation periods. The courses offered by the department for each term are included in the online Directory of Classes, and a description of the scheduled activities for each time preference is posted in the Physical Education Office, 336 Dodge Physical Fitness Center, and is included on the Department of Physical Education and Intercollegiate Athletics Web site (www.gocolumbialions.com). Students may register for only one section of physical education each term.

Music Instruction Courses
Music instruction and performance courses do not count toward the 128 points of credit required for a B.S. degree. Please note that this includes courses taken at Teachers College, Columbia College, and the School of the Arts.

Visual Arts Courses
Students are allowed to take courses in the Visual Arts Department for general credit to be applied toward the B.S. degree. However, no more than one visual arts course, which must be taken at the 3000 level or higher, may count toward the non-technical elective requirement.

Advanced Placement
Prior to entering Columbia, students may have taken the College Entrance Examination Board’s Advanced Placement Examinations in a number of technical and nontechnical areas. Students may be assigned to an advanced-level course in mathematics, chemistry, or physics. A maximum of 16 points may be applied.

In the required pure science areas, the number of advanced placement academic credits awarded to students of engineering and applied science varies from the levels awarded for liberal arts programs, notably in mathematics, physics, chemistry, and computer science. The benefit of advanced placement is acceleration through certain First Year–Sophomore Program requirements and thus the opportunity of taking specialized courses earlier.

Each year the school reviews the CEEB advanced placement curriculum...
and makes determinations as to appropriate placements, credit, and/or exemption. Please see the Advanced Placement Credit Chart at left.

International Baccalaureate (IB)

Entering students may be granted 6 points of credit for each score of 6 or 7 on IB Higher Level Examinations if taken in disciplines offered as undergraduate programs at Columbia. Students should consult their adviser for further clarification.

STUDY ABROAD

Study abroad represents a significant enhancement to your engineering education. Students engaged in international study discover insights into other cultures, develop new perspectives, and learn to reflect on how their own culture has shaped their understanding of the world.

With proper planning, SEAS undergraduate students can study abroad. Most do so in the spring semester of their sophomore year or in their junior year. In general, students take technical and nontechnical electives while abroad, although completing required courses is possible in some circumstances. It is essential that students begin planning during their first year by meeting with Scott Carpenter, assistant dean of academic affairs and study abroad, in 105 Carman (sc2764@columbia.edu). Dean Carpenter helps students clarify their goals for international study, make the right preparations for their program, and integrate their study-abroad courses into the Columbia curriculum. Students also gain approval from their departmental advisers to ensure that their work abroad meets the requirements of their majors.

Eligibility Requirements

In order to participate in a semester- or year-long study abroad program, students must:

- have at least a 3.0 GPA
- be making good progress toward finishing the Core Curriculum
- have at least intermediate proficiency level or higher in the local language, if it is not English
• take a language or literature course in the designated language the semester before going abroad
• have completed a course pertaining to the country or region where they intend to study

Please note, for programs in countries where the language of instruction is not English, students must take all course work in the local language.

To obtain approval for study abroad, students must be cleared by Dean Carpenter by October 15 for spring programs and March 15 for fall and academic-year programs. A review of each student’s academic and disciplinary records is conducted as part of this process. Students on academic or disciplinary probation are not permitted to study abroad during the term of their probation. Students must also register with the Office of Global Programs for study abroad by November 15 for spring programs and April 15 for fall and academic-year programs.

Study-abroad students remain enrolled at Columbia and tuition is paid to Columbia. Students participating in Columbia-approved programs pay housing costs directly to their host or sponsoring institution. Students receiving financial aid at Columbia will remain eligible for financial aid when they study abroad with Columbia’s approval. Students who wish to be considered for financial aid while studying abroad should consult the Office of Financial Aid and Educational Financing (407 Lerner).

Program Information
Choosing the right program is an important step in planning to study abroad. Study-abroad programs vary widely in size, geographical location, academic philosophy, language requirements, living arrangements, and opportunities for research and internships. Students must establish a set of goals for the study-abroad experience, taking into account their foreign-language skills and adaptability to new environments, as well as their research objectives and professional aspirations.

Students should visit the Office of Global Programs Web site to review various lists of approved program options and consult with OGP staff for specific information: www.ogp.columbia.edu/pages/columbia_students/SEAS/programs/index.html. Students must have their program choice approved by the Office of Global Programs (204 Lewisohn).

Summer study-abroad programs allow students to earn credits for language instruction and nontechnical electives. Students can participate in Columbia-approved summer programs for transfer credit or on Columbia-sponsored programs for direct credit. The Columbia-sponsored summer programs include the Chinese Language Program in Beijing, the Business Chinese and Internship Program in Shanghai, the Italian Cultural Studies Program in Venice, and the Columbia University Programs in Paris at Reid Hall.

Noncredited internships abroad—the EDGE and CEO programs—are coordinated by the Center for Career Education. Please visit the following Web site for more information: www.cce.columbia.edu/findajob/cce-internship/entrepreneurship.

Academic Credit
Students in Columbia-sponsored programs receive direct Columbia credit, and the courses and grades appear on your academic transcript. These include Reid Hall, Paris; the Berlin Consortium for German Studies; the Kyoto Center for Japanese Studies; and the Tsinghua University program in Beijing.

Credit from approved programs is certified as transfer credit toward the Columbia degree upon successful completion of the program verifiable by academic transcript. Students must earn a grade of C or better in order for credits to transfer. Course titles and grades for approved programs do not appear on the Columbia transcript and the grades are not factored into the student’s GPA.

Faculty from the SEAS academic departments have the responsibility to assess all work completed abroad and make decisions about how these courses fit into major requirements. It is imperative that students gain course-by-course approval from their department prior to departure on a study-abroad program.

COMBINED PLAN PROGRAMS
The Fu Foundation School of Engineering and Applied Science maintains cooperative program relationships with institutions nationwide, and with other Columbia University undergraduate divisions. These programs allow students to complete the equivalent of the First Year–Sophomore Program and transfer directly to a field of specialization in the School, beginning their study at the School as junior-level students. A list of participating Combined Plan institutions follows on this page.

The Combined Plan (3-2) Program within Columbia University
Students who follow this program apply through their own school at Columbia College, Barnard College, or the School of General Studies for admission. Under this plan, the pre-engineering student studies in the appropriate college for three years, then attends The Fu Foundation School of Engineering and Applied Science for two years and is awarded the Bachelor of Arts degree and the Bachelor of Science degree in engineering upon completion of the fifth year. This five-year program is optional at Columbia, but the School recommends it to all students who wish greater enrichment in the liberal arts and pure sciences.

The Combined Plan with Other Affiliated Colleges
There are over one hundred liberal arts colleges, including those at Columbia, in which a student can enroll in a Combined Plan program leading to two degrees. Every affiliated school has a liaison officer who coordinates the program at his or her home institution. Inasmuch as each liberal arts college requires the completion of a specified curriculum to qualify for the baccalaureate from that institution, students interested in this program should inform the liaison officer as early as possible, preferably in the first year.

The 3-2 Combined Plan Program B.A./B.S. at The Fu Foundation School of Engineering and Applied Science is designed to provide students with the opportunity to receive both a B.A. degree from an affiliated liberal arts college and
a B.S. degree from SEAS within five years. Students complete the requirements for the liberal arts degree along with a pre-engineering course of study in three years at their college and then complete at Columbia. Combined Plan students are required to complete all SEAS requirements within four consecutive semesters. Please note that no change of major is guaranteed.

Guaranteed admission into The Fu Foundation School of Engineering and Applied Science’s undergraduate Combined Plan Program is offered to applicants who have met the following requirements:

1. have been enrolled at an affiliated school for at least the past two years;
2. have received an overall GPA and a pre-engineering GPA of 3.0 or higher;
3. have received three favorable recommendations, from the Combined Plan liaison and both a science and a math instructor at the home institution;
4. have successfully completed the course load stipulated by the articulation agreement between the home institution and Columbia, which includes (a) the science and math prerequisite courses listed in the Pre-Combined Plan Curriculum Guide and (b) the major and distribution requirements prescribed by the home institution.

Admission to SEAS at the end of the junior year is guaranteed for those students who have a grade-point average of 3.0 or better; are recommended by the liaison officer; and have completed the appropriate preparation successfully.

Another available option is the 4-2 B.S. degree program. This is designed to allow students to graduate from their liberal arts college with a B.A. degree and then transfer to SEAS to complete a B.S. degree in two years. Students should have followed a related course of study at their liberal arts college.

Requirements for guaranteed admission to the 4-2 B.S. degree program are the same as above, with the additional requirement that if the applicant has already graduated from the affiliated school, he or she must apply to the Combined Plan Program within one year of graduating.

For further information on the 3-2 B.A./B.S. program and the 4-2 B.S. program, you are encouraged to e-mail your questions to: combinedplan@columbia.edu. You may also call 212-854-2522 or contact Combined Plan Coordinators, Office of Undergraduate Admissions, 212 Hamilton Hall, Mail Code 2807, 1130 Amsterdam Avenue, New York, NY 10027.

The 4-2 M.S. program is designed to allow students to complete an M.S. degree at SEAS in two years after completion of a B.A. degree at one of the affiliated schools. This program will allow students the opportunity to take under-graduate engineering courses if necessary. Please contact the Office of Graduate Student Services, The Fu Foundation School of Engineering and Applied Science, 524 S. W. Mudd, Mail Code 4708, 500 West 120th Street, New York, NY 10027. You may also e-mail questions to seasgradmit@columbia.edu.

The following colleges are affiliated with SEAS in the Combined Plan; admission requirements and other information may be obtained from them or by contacting the Office of Undergraduate Admissions. For more information, go to www.studentaffairs.columbia.edu/admissions/engineering/combined.

The Combined Plan—Affiliated Colleges and Universities

Adelphi University, Garden City, NY
Albertson College, Caldwell, ID
Albion College, Albion, MI
Alfred University, Alfred, NY
Allegheny College, Meadville, PA
Arcadia University, Glenside, PA
Augustana College, Sioux Falls, SD
Austin College, Sherman, TX
Baldwin-Wallace College, Berea, OH
Bard College, Annandale-on-Hudson, NY
Barnard College, New York, NY
Bates College, Lewiston, ME
Beloit College, Beloit, WI
Bethany College, Bethany, WV
Birmingham-Southern College, Birmingham, AL
Bowdoin College, Brunswick, ME
Brandeis University, Waltham, MA
Carleton College, Northfield, MN
Carroll College, Helena, MT
Centenary College of Louisiana, Shreveport, LA
Centre College, Danville, KY
Claremont McKenna College, Claremont, CA
Clark University, Worcester, MA
Colgate University, Hamilton, NY
College of Notre Dame, Baltimore, MD
College of the Holy Cross, Worcester, MA
College of William and Mary, Williamsburg, VA
Colorado College, Colorado Springs, CO
Columbia College, New York, NY
Davidson College, Davidson, NC
Denison University, Granville, OH
DePauw University, Greencastle, IN
Dillard University, New Orleans, LO
Doane College, Crete, NE
Drew University, Madison, NJ
Earlham College, Richmond, IN
Eckerd College, St. Petersburg, FL
Elon College, NC
Fairfield University, Fairfield, CT
Fordham University, Bronx, NY
Franklin and Marshall College, Lancaster, PA
Georgetown University, Washington, DC
Gettysburg College, Gettysburg, PA
Grinnell College, Grinnell, IA
Hamilton College, Clinton, NY
Hartwick College, Oneonta, NY
Hastings College, Hastings, NE
Hendrix College, Conway, AR
Hobart and William Smith Colleges, Geneva, NY
Hofstra University, Hempstead, NY
Illinois Wesleyan University, Bloomington, IL
Jacksonville University, Jacksonville, FL
Juniata College, Huntingdon, PA
Kansas Wesleyan University, Salina, KS
Knox College, Galesburg, IL
Lawrence University, Appleton, WI
Lewis and Clark College, Portland, OR
Loyola University Chicago, Chicago, IL
MacMurray College, Jacksonville, IL
Marietta College, Marietta, OH
Miami University, Oxford, OH
Middlebury College, Middlebury, VT
Millaps College, Jackson, MI
Morehouse College, Atlanta, GA
Muhlenberg College, Allentown, PA
Nebraska Wesleyan University, Lincoln, NE
Oberlin College, Oberlin, OH
Occidental College, Los Angeles, CA
Pacific Lutheran University, Tacoma, WA
Pitzer College, Claremont, CA
Providence College, Providence, RI
Queens College, Flushing, NY
Randolph-Macon College, Ashland, VA
Reed College, Portland, OR
Rollins College, Winter Park, FL
St. John Fisher College, Rochester, NY
St. Lawrence University, Canton, NY
Sarah Lawrence College, Bronxville, NY
School of General Studies, Columbia University, New York, NY
Scripps College, Claremont, CA
Seattle Pacific University, Seattle, WA
Simon’s Rock College of Bard, Great Barrington, MA
Spelman College, Atlanta, GA
State University of New York, Fredonia, NY
THE JUNIOR–SENIOR PROGRAMS

Students may review degree progress via DARS (Degree Audit Reporting System) as presented on Student Services Online. Required courses not completed by this time are detailed as deficiencies and must be completed during summer session or carried as overload courses during the final two years of study.

Having chosen their program major, students in their third and fourth year are assigned to an adviser in the department in which the program is offered. In addition to the courses required by their program, students must continue to satisfy certain distributive requirements, choosing elective courses that provide sufficient content in engineering sciences and engineering design. The order and distribution of the prescribed course work may be changed with the adviser's approval. Specific questions concerning course requirements should be addressed to the appropriate department or division. The Vice Dean’s concurrent approval is required for all waivers and substitutions.

Tau Beta Pi

The Tau Beta Pi Association, a national engineering honor society, was founded in 1885 “to mark in a fitting manner those who have conferred honor upon their Alma Mater by distinguished scholarship and exemplary character as undergraduates in engineering, or by their attainments as alumni in the field of engineering, and to foster a spirit of liberal culture in engineering colleges.” Columbia’s chapter, New York Alpha, is the ninth oldest and was founded in 1902. Many Columbia buildings have been named for some of the more prominent chapter alumni: Charles Fredrick Chandler, Michael Ildvorsky Pupin, Augustus Schemerhorn, and, of course, Harvey Seeley Mudd.

Undergraduate students whose scholarship places them in the top eighth of their class in their next-to-last year or in the top fifth of their class in their last college year are eligible for membership consideration. These scholastically eligible students are further considered on the basis of personal integrity, breadth of interest both inside and outside engineering, adaptability, and unselfish activity.

Taking Graduate Courses as an Undergraduate

With the faculty adviser’s approval, a student may take graduate courses while still an undergraduate in the School. Such work may be credited toward one of the graduate degrees offered by the Faculty of Engineering and Applied Science, subject to the following conditions: (1) the course must be accepted as part of an approved graduate program of study; (2) the course must not have been used to fulfill a requirement for the B.S. degree and must be so certified by the Dean; and (3) the amount of graduate credit earned by an undergraduate cannot exceed 15 points. Undergraduates may not take CVN courses.

The Bachelor of Science Degree

Students who complete a four-year sequence of prescribed study are awarded the Bachelor of Science degree. The general requirement for the Bachelor of Science degree is the completion of a minimum of 128 academic credits with a minimum cumulative grade-point average (GPA) of 2.0 (C) at the time of graduation. The program requirements, specified elsewhere in this bulletin, include the First Year–Sophomore course requirements, the Junior-Senior major departmental requirements, and technical and nontechnical elective requirements. Students who wish to transfer points of credit may count no more than 65 transfer points toward the degree, and must satisfy the University’s residence requirements by taking at least 60 points of credit at Columbia.

The bachelor’s degree in engineering and applied science earned at Columbia University prepares students to enter a wide range of professions. Students are, however, encouraged to consider graduate work, at least to the master’s degree level, which is increasingly considered necessary for many professional careers.

The Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET), an organization formed by the major engineering professional societies, accredits university engineering programs on a nationwide basis. Completion of an accredited program of study is usually the first step toward a professional engineering license. Advanced study in engineering at a graduate school sometimes presupposes the completion of an accredited program of undergraduate study.

The following undergraduate programs are accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology: chemical engineering, civil engineering, Earth and environmental engineering, electrical engineering, industrial engineering, and mechanical engineering. For a complete listing of all programs registered with the State of New York, including ABET programs, see page 20.

The 4-1 Program at Columbia College

Students who are admitted as first-year students to The Fu Foundation School of Engineering and Applied Science, and subsequently complete the four-year program for the Bachelor of Science degree, have the opportunity to apply for admission to either Columbia College or Barnard College and, after one additional year of study, receive the Bachelor of Arts degree.

The program will be selective, and admission will be based on the following factors: granting of the B.S. at SEAS at the end of the fourth year; fulfillment of the College Core requirements by the
end of the fourth year at SEAS; a minimum GPA of 3.0 in the College Core and other courses; and the successful completion of any prerequisites for the College major or concentration.

Interested students should contact their Advising Center for further information.

Minors
Undergraduates in The Fu Foundation School of Engineering and Applied Science may choose to add minors to their programs. This choice should be made as early as possible, but not later than the fall of their sophomore year, when they also decide on a major.

In considering a minor, students must understand that all minors are not, and cannot, be available to all students. In when they also decide on a major.

The successful completion of a minor chosen, as well as the course

STEMs may choose to add minors to

School of Engineering and Applied

made as early as possible, but not later

than the fall of their sophomore year,

and other courses; and the successful

mum GPA of 3.0 in the College Core

scheduling difficulties. The potential for

ingm inorsshouldexpecttoencounter

depends on the student’s major and

schedules and availability, which may

change from year to year. The list of

minors, as well as their requirements, appear in the section “Undergraduate Minors,” beginning on page 186.

PROGRAMS IN PREPARATION
FOR OTHER PROFESSIONS
The Fu Foundation School of Engineering and Applied Science prepares its students to enter any number of graduate programs and professions outside of what is generally thought of as the engineering field. In an increasingly technological society, where the line between humanities and technology is becoming increasingly blurred, individuals with a thorough grounding in applied mathematics and the physical and engineering sciences find themselves highly sought after as professionals in practically all fields of endeavor.

Engineering students interested in pursuing graduate work in such areas as architecture, business, education, journalism, or law will find themselves well prepared to meet the generally flexible admissions requirements of most professional schools. Undergraduate students should, however, make careful inquiry into the kinds of specific preparatory work that may be required for admission into highly specialized programs such as medicine.

Pre-Med
Engineering students seeking admission to dental, medical, optometric, osteopathic, or veterinary schools directly after college must complete all entrance requirements by the end of the junior year, and should plan their program accordingly. Students should consult with their adviser and the Office of Preprofessional Advising to plan an appropriate program. Students should also connect with the Office of Preprofessional Advising to learn more about extracurricular and research opportunities related to premed studies.

It is necessary to apply for admission to health professions schools a little over one year in advance of the entry date. If candidates are interested in going directly on to health professions school following graduation, they should complete all requirements and the Medical College Admissions Test (MCAT) by the summer following the junior year. It is, however, entirely acceptable to delay application and entrance to these schools several years beyond graduation, if desired.

Candidates planning for an application to medical or dental school will also need to be evaluated by the Premedical Advisory Committee prior to application. A Premedical Advisory Committee application is made available each year in December. Please consult with the Office of Preprofessional Advising for more information regarding this process.

The Engineering School’s curriculum covers many of the premedical courses required by medical schools. However, in addition to completing the mathematics, chemistry, and physics courses required by the First Year–Sophomore Program, most medical schools ask for a full year of organic chemistry, a full year of biology, and a full year of English.

The following courses are required by medical schools:

One year of calculus for some schools
One year of physics, with lab
One year of general chemistry, with lab
One year of biology, with lab
(BME labs will qualify)
One year of organic chemistry, with lab
One year of English
Biochemistry or additional biology
(required by some schools)

Pre-Law
Students fulfilling the curriculum of The Fu Foundation School of Engineering and Applied Science are well prepared to apply to and enter professional schools of law, which generally do not require any specific pre-law course work. Schools of law encourage undergraduate students to complete a curriculum characterized by rigorous intellectual training involving relational, syntactical, and abstract thinking. A sound liberal education is best for most pre-law students. While selecting courses, keep in mind the need to hone your writing skills, your communication skills, and your capacity for logical analysis.

Courses in history, political science, economics, statistics, and anthropology help students understand the structure of society and the problems of social ordering with which the law is concerned. The study of philosophy, literature, fine arts, foreign languages, and other cultures imparts familiarity with traditions of universal thought and trends that influence legal developments nationally and internationally. The examination of human behavior through sociology and psychology will aid a prospective law student in understanding the types and effects of behavior to which the law relates.

The systematic ordering of abstractions and ideas in logic and the sciences contributes much to a pre-law student’s ability to analyze, understand, and rationally organize his or her thoughts. Finally, it is useful in some fields of law for a student to have a fundamental knowledge of technology, engineering, computers, and accounting.

New York State Initial Certification in Adolescence Education Grades 7–12 for Teachers of Mathematics and the Sciences or in Childhood Education Grades 1–6
The Barnard Education Program provides courses leading to certification to teach in New York State (with reciprocal
agreements with forty-one other states) at either the elementary or secondary level. Students gain experience and develop skills in urban school classrooms. Interested students should apply for admission to the program and supply an essay and letters of recommendation no later than the first Monday in October of the junior year. These forms may be downloaded from the Barnard College Office of Education Web site or picked up in the 336 Milbank Hall office. Coursework required includes courses in psychology and education, including practicum and student teaching, totaling 23–26 points of credit depending on level of certification sought (please see the Web site for specific courses).

Certification to teach mathematics requires 36 points in mathematics. Pure science courses required are: 36 points in the sciences, of which 15 must be in the area of the certification sought: chemistry, biology, physics, or Earth science.

Application deadline is the first Monday in October of the student’s junior year. Students who plan to study abroad during their junior year should apply during the fall semester of their sophomore year. Students should decide on their interest in teacher certification by the end of the first year in order to start course work in the sophomore year.

Barnard College Education Program 
336 Milbank Hall 
212-854-7072

JOINT PROGRAMS

School of Law
Each year The Fu Foundation School of Engineering and Applied Science may nominate two highly qualified juniors for a joint program with the Columbia University School of Law, enabling students to complete the requirements for the degrees of Bachelor of Science and Doctor of Jurisprudence in six years instead of seven. Students should speak to the Office of Pre-Professional Advising in the fall semester to express their interest and prepare to take the LSAT by February of their junior year. The application process is conducted March through April.

School of International and Public Affairs
The Fu Foundation School of Engineering and Applied Science and the School of International and Public Affairs at Columbia offer a joint program enabling a small number of students to complete the requirements for the degrees of Bachelor of Science and Master of International Affairs in five years instead of six. Not only an excellent academic record but also maturity, fluency in an appropriate foreign language, and pertinent experience will determine admission to this program. Applications are processed in the junior year by the Center for Student Advising.

REGISTERED PROGRAMS

The New York State Department of Education requires that this bulletin include a listing of registered programs, both undergraduate and graduate (see chart on page 20). Enrollment in other than registered or otherwise approved programs may jeopardize a student’s eligibility for certain student aid awards.

The letter “X” or the name of a degree on the chart indicates that a program is registered with the New York State Department of Education.
### Programs Registered with the New York State Department of Education

<table>
<thead>
<tr>
<th>Program Title</th>
<th>HEGIS code</th>
<th>B.S.</th>
<th>M.S.</th>
<th>Professional</th>
<th>M.Phil.</th>
<th>Eng.Sc.D.</th>
<th>Ph.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Mathematics</td>
<td>913</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied Physics</td>
<td>919</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Biomedical Engineering</td>
<td>905</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Chemical Engineering</td>
<td>906</td>
<td>X</td>
<td>X</td>
<td>Chemical Engineer</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>908</td>
<td>X</td>
<td></td>
<td>Civil Engineer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Civil Engineering and Engineering Mechanics</td>
<td>908</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Combined Plan w/Affiliated College; Dual B.S. (M.S.)/B.A.</td>
<td>999</td>
<td>X</td>
<td>X</td>
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<td></td>
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<tr>
<td>Computer Engineering</td>
<td>999</td>
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<tr>
<td>Computer Science</td>
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<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td></td>
<td>909</td>
<td>X</td>
<td></td>
<td>Computer Systems Engineer</td>
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<tr>
<td>Computer Science/Business: Dual M.S./M.B.A.</td>
<td>701</td>
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<tr>
<td>Earth and Environmental Engineering</td>
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</tr>
<tr>
<td>Electrical Engineering</td>
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<td>X</td>
<td>Electrical Engineer</td>
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<td></td>
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<tr>
<td>Engineering Mechanics</td>
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<td>Mechanics Engineer</td>
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<tr>
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<td>X</td>
<td>Financial Engineer*</td>
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<tr>
<td>Industrial Engineering</td>
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<td>Industrial Engineer</td>
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<td></td>
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<td>Industrial Engineering/Business: Dual M.S./M.B.A.</td>
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<td></td>
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<tr>
<td>Materials Science and Engineering</td>
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<tr>
<td>Mechanical Engineering</td>
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<td>X</td>
<td>Mechanical Engineer</td>
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<td>X</td>
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<td>Medical Physics</td>
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<tr>
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<td>Metallurgical Engineer</td>
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<tr>
<td>Mining Engineering</td>
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<td></td>
<td>Engineer of Mines</td>
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<td></td>
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</tr>
<tr>
<td>Mining Engineering and Applied Geophysics</td>
<td>918</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Operations Research</td>
<td>913</td>
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<td>X</td>
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<tr>
<td>Operations Research: Engineering and Management Systems</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

*State approval pending.
ADMISSION AS A FIRST-YEAR STUDENT

Each autumn The Fu Foundation School of Engineering and Applied Science enrolls approximately 300 highly qualified men and women, chosen from a wide range of applicants. All become full, active participants in a rich and diverse university setting. Therefore, the Admissions Committee is interested in achievements not only in mathematics and science, but also in other fields: English, the social sciences, languages, and the arts. Considerable value is placed on personal qualities and attributes like diversity of interests, special abilities, maturity, motivation, curiosity, and independence. Secondary school records and recommendations are carefully evaluated to ascertain the content and difficulty of the applicant’s preparatory studies and the degree to which this preparation correlates with standardized tests. Of importance also is the candidate’s participation in extracurricular or community activities. Here the emphasis is placed on the depth and significance of involvement rather than on the number of activities. For its final selection, the School seeks students with unique achievements and talents as well as diverse economic, social, and geographic backgrounds.

Accordingly, the School of Engineering and Applied Science prescribes no standardized course of study for secondary school students applying for first-year admission. The School does, however, strongly recommend the following academic preparation:

- 4 years of mathematics (preferably through calculus)
- 1 year of physics
- 1 year of chemistry
- 4 years of English

and recommends as well:

- 3 years or more of a foreign language
- 3 or 4 years of history and social studies

The Application Process

Students are strongly encouraged to apply online. You may also download a paper copy of the application. Information about both the online application and the downloadable application will be available by September 1, 2008, at www.studentaffairs.columbia.edu/admissions/applications. If you do not have access to the Internet, please call the Office of Undergraduate Admissions at 212-854-2522 to request an application.

Part 1 of the application should be filled out and submitted as early as possible along with the $70 application fee or an official fee waiver request.

All parts of the application must be postmarked no later than the first business day following January 1. (See below for Early Decision deadlines.)

Decision letters are mailed out in early April.

The Early Decision Program

Candidates for whom Columbia is the first choice may apply under the Early Decision Program. In order to qualify for this program, all application materials must be postmarked by November 1.

In mid-December, Early Decision applicants receive notice of their acceptance, denial, or deferral to regular decision status. Applicants admitted under the Early Decision program are obligated to accept Columbia’s offer of admission and must withdraw their applications at other colleges if they are provided with a financial aid package that enables them to attend Columbia.

Required Standardized Testing

Please go to www.studentaffairs.columbia.edu/admissions for our standardized testing requirements. You must register with the appropriate testing agency well in advance of the date on which you wish to be tested. Please note that scores reported to Columbia’s School of General Studies (2095) will not reach our office and will not be considered for evaluation. Columbia reserves the right not to evaluate a candidate whose scores are not reported directly by the testing agency. Please do not utilize the “rush” service in sending your test scores to Columbia. Doing so does not speed up the processing of your test scores. We obtain all testing via a secure Web site to which we are provided access by the appropriate testing
agency. Scores that are sent via the “rush” service are sent to us in paper form, which we are no longer able to process.

Applicants may submit results of the American College Testing (ACT) examinations in lieu of the SAT I, but may not substitute any other examinations for the required SAT Subject Tests.

The Test of English as a Foreign Language (TOEFL) is required of all applicants whose principal language of instruction has not been English and who have not lived in an English-speaking environment for at least five years.

Applicants must be certain when taking standardized tests to have their results reported directly to Columbia University by the testing agency. The following codes should be used when completing test registration forms:

- SAT Reasoning, SAT Subject Tests, TOEFL: use code 2111
- ACT: use code 2719

Educational Testing Service
Rosedale Road
Princeton, NJ 08541
Phone: 609-921-9000
www.ets.org

American College Testing Program
Box 313
Iowa City, IA 52243
Phone: 319-337-1270
www.act.org

Test of English as a Foreign Language
Box 899
Princeton, NJ 08451
609-771-7100
www.toefl.org

Advanced Placement
The School gives recognition to the Advanced Placement program. Appropriate placement and credit will be given to students who score according to the School’s criteria (see page 14) in the Advanced Placement examinations given in May by the College Entrance Examination Board. In addition, required courses may be waived on the basis of faculty placement conferences, permitting students with special preparation to advance in prescribed sequences. No credit is given for college courses taken prior to high school graduation, but appropriate placements may be made.

C. Prescott Davis Scholars Program
Each year, outstanding high school seniors are nominated for selection as C. Prescott Davis Scholars by the Admissions Committee. After a rigorous selection process, the Scholars are chosen to participate throughout their four undergraduate years in academic and co-curricular opportunities, including research with faculty, professional internships, and meetings with world-renowned scholars, innovators, and leaders.

Higher Education Opportunity Program (HEOP) and National Opportunity Program (NOP)
The Higher Education Opportunity Program (HEOP) is sponsored by the New York State Department of Education and Columbia University. The program is designed for New York State residents who have particular educational and economic needs with regard to admission requirements. HEOP students must be U.S. citizens or permanent residents who have lived in New York State for one year prior to enrolling in college.

HEOP’s individualized counseling and tutoring services help students meet the challenges of a major university and professional school. New students attend an intensive pre-first-year Summer Science and Humanities Institute on the Columbia campus. Students in the School’s undergraduate Higher Education Opportunity Program can follow a five-year curriculum which spreads the first and second-year requirements over three years and allows for the inclusion of several extra courses designed to provide academic support.

Because of the different pace of this program, students are considered to be making minimum satisfactory progress when they complete 24 points of credit in one academic year. HEOP students’ academic performance is otherwise evaluated by the same standards applied to all undergraduates. HEOP support is available to students wishing to pursue only the Bachelor of Science degree or Columbia’s Combined Plan Program for both the Bachelor of Arts and Bachelor of Science in five years.

The National Opportunity Program (NOP) is a replication of the Higher Education Opportunity Program and provides access to a Columbia education for students outside of New York State. Requirements for NOP are the same as those for HEOP, except for the New York State residency requirement.

For further information concerning the Engineering School’s Opportunity Programs, contact:

Opportunity Programs and Undergraduate Services
Columbia University
New York, NY 10027
Phone: 212-854-3514
www.studentaffairs.columbia.edu/asp/programs

APPLICANTS WITH ADVANCED STANDING (TRANSFER APPLICANTS)

Students with strong academic records in pre-engineering programs at two-year community colleges are eligible for sophomore or junior standing in The Fu Foundation School of Engineering and Applied Science upon transfer to Columbia. Community college students who are considering applying to the School of Engineering and Applied Science are encouraged to complete a course of study similar to the School’s First Year–Sophomore Program. Credit and placement in the School will be determined by the equivalence of the courses taken by the student to those described in this bulletin.

The School also accepts applications for transfer into the sophomore or junior year from students in four-year programs at arts and sciences colleges and engineering schools. Transfers may enter Columbia only in September and may count no more than 68 points of credit toward the Columbia degree. Transfer students must also satisfy the University’s residence requirements by taking at least 60 points at Columbia.

Transfer applicants should provide the scores of College Board Examinations as part of their application. Applicants must submit results of the SAT or the American College Testing (ACT) examinations. Results of the SAT-II
Subject Tests are required only if the tests were taken in high school.

Students in a non-English-speaking environment and whose primary language of instruction has not been English for at least five years are required to take an English proficiency examination, TOEFL or IELTS. These students must submit the results of at least one of the exams and will be required to take an English placement test on arrival, before registration.

Transfer Applications can only be completed online at the Web site of the Office of Undergraduate Admissions, at www.studentaffairs.columbia.edu/admissions/aboutapplying/transfer.php. Applications must be received by March 15 for September admission.

The Combined Plan Programs
The Combined Plan programs at The Fu Foundation School of Engineering and Applied Science are designed to provide students the opportunity to receive both a Bachelor of Arts or Bachelor of Science degree from an affiliated liberal arts college and a Bachelor of Science or Master of Science degree from Columbia. Details concerning these programs are contained in the section “The Undergraduate Programs” of this bulletin.

Secondary school students who wish to follow one of the Combined Plan programs at one of the affiliated Combined Plan schools listed on page 19 of this bulletin should apply directly to the affiliated school’s admissions office.

Third-year undergraduate students already in a Combined Plan program should apply to the Columbia University School of Engineering and Applied Science Combined Plan Program. The deadlines for applying to these programs, each of which is described in the section “The Undergraduate Programs” of this bulletin, are:

- March 15 for the 3-2 Combined Plan Program
- March 15 for the 4-2 Combined Plan B.S. Program
- February 15 for the 4-2 Combined Plan M.S. Program

For further information on the 3-2 and 4-2 B.S. programs, visit www.engineering.columbia.edu/admissions/cp. You may also contact the Office of Undergraduate Admissions by phone, at 212-854-2522, or by e-mail at combinedplan@columbia.edu. For further information on the 4-2 M.S. program, contact the Office of Graduate Student Services (see the address on the inside front cover) or phone 212-854-6438.

CAMPUS VISITS AND INTERVIEWS
Prospective students are encouraged to visit the Columbia campus throughout the year. The Office of Undergraduate Admissions hosts information sessions and campus tours through the Visitors Center, located in 213 Low Library. Group information sessions are conducted by members of the admissions staff and offer the opportunity to learn more about Columbia University’s academic and student life as well as admissions and financial aid. Campus tours immediately follow the information session and are led by a current undergraduate student. Engineering tours, designed to offer prospective students an in-depth look into The Fu Foundation School of Engineering and Applied Science, are led by current Columbia engineering students and are available every Friday at 1:00 p.m., except for holidays. Please note that the Engineering School tour is designed to supplement, but not replace, the Undergraduate Admissions information session and general campus tour. For further information and a detailed schedule of visit opportunities, please go to www.studentaffairs.columbia.edu/admissions/visiting.

Columbia does not conduct interviews on campus. Interviews are instead conducted around the country and the world by the members of the Alumni Representative Committee. The University provides the names of candidates to the Committee, which conducts interviews from October through February. Candidates will be contacted by a Committee member during this time if interviews are available. Candidates should not call or write the Admissions Office to arrange alumni interviews.
The 2008–2009 tuition and fees are estimated. Tuition and fees are prescribed by statute and are subject to change at the discretion of the Trustees.

University charges such as tuition, fees, and residence hall and meal plans are billed in the first Student Account Statement of the term, which is sent out in July and December of each year for the upcoming term. This account is payable and due in full on or before the payment due date announced in the Statement, typically at the end of August or early January before the beginning of the billed term. Any student who does not receive the first Student Account Statement is expected to pay at registration.

If the University does not receive the full amount due for the term on or before the payment due date of the first Statement, a late payment charge of $150 will be assessed. An additional charge of 1 percent per billing cycle may be imposed on any amount past due thereafter.

Students with an overdue account balance may be prohibited from registering, changing programs, or obtaining a diploma or transcripts. In the case of persistently delinquent accounts, the University may utilize the services of an attorney and/or collection agent to collect any amount past due thereafter.

Students with an overdue account balance may be prohibited from registering, changing programs, or obtaining a diploma or transcripts. In the case of persistently delinquent accounts, the University may utilize the services of an attorney and/or collection agent to collect any amount past due thereafter.

**TUITION**
Undergraduate students enrolled in The Fu Foundation School of Engineering and Applied Science pay a flat tuition charge of $18,735 per term, regardless of the number of course credits taken.

**MANDATORY FEES**
- Orientation fee: $385 (one-time charge in the first term of registration)
- Student Life fee: $541 per term
- Health Service fee: $387 per term
- International Services charge: $50 per term (international students only)
- Transcript fee: $95 (one-time charge)

**OTHER FEES**
- Application and late fees
  - Application for undergraduate admission: $70
  - Application for undergraduate transfer admission: $70
  - Late registration fee during late registration: $50 after late registration: $100

Books and course materials:
- Depends upon course

Laboratory fees:
- See course listings

Room and board (estimated): $9,900

HEALTH INSURANCE
Columbia University offers the Student Medical Insurance Plan, which provides both Basic and Comprehensive levels of coverage. Full-time students are automatically enrolled in the Basic level of the Plan and billed for the insurance premium in addition to the Health Service fee. Visit www.health.columbia.edu for detailed information about medical insurance coverage options and directions for making confirmation, enrollment, or waiver requests.

PERSONAL EXPENSES
Students should expect to incur miscellaneous personal expenses for such items as clothing, linen, laundry, dry cleaning, and so forth. Students should also add to the above expenses the cost of two round trips between home and the University to cover travel during the summer and the month-long, midyear break.

The University advises students to open a local bank account upon arrival in New York City. Since it often takes as long as three weeks for the first deposit to clear, students should plan to cover immediate expenses using either a credit card, traveler’s checks, or cash draft drawn on a local bank. Students are urged not to arrive in New York without sufficient start-up funds.

LABORATORY CHARGES
Students may need to add another $100 to $300 for drafting materials or laboratory fees in certain courses. Each student taking laboratory courses must furnish, at his or her own expense, the necessary notebooks, blank forms, and similar supplies. In some laboratory courses, a fee is charged to cover expendable materials and equipment maintenance. Students engaged in special tests, investigations, theses, or
research work are required to meet the costs of expendable materials as may be necessary for this work and in accordance with such arrangements as may be made between the student and the department immediately concerned.

** DAMAGES**

All students will be charged for damage to instruments or apparatus caused by their carelessness. The amount of the charge will be the actual cost of repair, and, if the damage results in total loss of the apparatus, adjustment will be made in the charge for age or condition. To ensure that there may be no question as to the liability for damage, students should note whether the apparatus is in good condition before use and, in case of difficulty, request instruction in its proper operation. Where there is danger of costly damage, an instructor should be requested to inspect the apparatus. Liability for breakage will be decided by the instructor in charge of the course.

When the laboratory work is done by a group, charges for breakage will be divided among the members of the group. The students responsible for any damage will be notified that a charge is being made against them.

The amount of the charge will be stated at that time or as soon as it can be determined.

** TUITION AND FEE REFUNDS**

Students who make a complete withdrawal from a term are assessed a withdrawal fee of $75. Late fees, application fees, withdrawal fees, tuition deposits, special fees, computer fees, special examination fees, and transcript fees are not refundable.

The Health Service Fee, Health Insurance Premium, University facilities fees, and student activity fees are not refundable after the change of program period.

Students who withdraw within the first 60 percent of the academic period are subject to a refund calculation, which refunds a portion of tuition based on the percentage of the term remaining after the time of withdrawal. This calculation is made from the date the student’s written notice of withdrawal is received by the Dean’s Office.

**Percentage Refund for Withdrawal during First Nine Weeks of Term**

(*prorated for calendars of a different duration*)

<table>
<thead>
<tr>
<th>Week</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st week</td>
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<tr>
<td>2nd week</td>
<td>90%</td>
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<tr>
<td>3rd week</td>
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<tr>
<td>9th week</td>
<td>40%</td>
</tr>
<tr>
<td>10th week and after</td>
<td>0%</td>
</tr>
</tbody>
</table>

For students receiving federal student aid, refunds will be made to the federal aid programs in accordance with Department of Education regulations. Refunds will be credited in the following order:

Federal Unsubsidized Stafford Loans
Federal Stafford Loans
Federal Perkins Loans
Federal PLUS Loans (when disbursed through the University)
Federal Pell Grants
Federal Supplemental Educational Opportunity Grants
Other Title IV funds

Withdrawing students should be aware that they will not be entitled to any portion of a refund until all Title IV programs are credited and all outstanding charges have been paid.
Office of Financial Aid and Educational Financing  
Columbia University  
407 Alfred Lerner Hall  
Mail Code 2802  
2920 Broadway  
New York, NY 10027  
Phone: 212-854-3711  
Fax: 212-854-5353  
E-mail: undergrad-finaid@columbia.edu  
www.studentaffairs.columbia.edu/finaid

Admission to Columbia is need-blind for all students who are U.S. citizens, U.S. permanent residents, Canadian citizens, or Mexican citizens. Financial aid is awarded only to students who demonstrate need. Columbia is committed to meeting the full demonstrated financial need of all applicants admitted as first-year students. Financial aid is available for all four undergraduate years, providing students continue to demonstrate financial need.

While transfer admission is need-blind, financial aid resources for transfer students are very limited. Therefore, The Fu Foundation School of Engineering and Applied Science is unable to meet the full need of transfer applicants, with the exception of students who enter the Combined Plan Program and those who transfer from Columbia College.

**DETERMINING ELIGIBILITY**

Columbia determines the amount each family can contribute to educational costs through an evaluation of the family’s financial information as reported on the application forms described in the section “How to Apply for Financial Aid.” The difference between the family contribution and the total cost of attendance at Columbia (including tuition, room, board, fees, books, travel, and personal expenses) represents the student’s demonstrated need.

The family contribution to the cost of attending Columbia consists of two elements: the parent contribution and the student contribution. The parent contribution is determined through an evaluation of parent income and assets, family size, and the number of family members attending college. The student contribution consists of a percentage of the student’s assets and a minimum contribution from income. Each student is expected to work during the summer and save a certain amount to contribute to educational costs.

The minimum contribution from earnings is currently:

- First year $1,850  
- Sophomore $2,050  
- Junior $2,250  
- Senior $2,350

The expected summer earnings amount is separate from the amount that students are expected to earn by working a part-time job during the academic year.

Eligibility for Columbia grant aid is normally limited to eight terms of undergraduate study. Students must reapply for financial aid each year and be registered for a minimum of 12 points during any term for which aid is requested. Changes in the family’s circumstances—for example, increased income or a change in the number of family members attending college—will result in changes in the family contribution. In addition, the individual elements in the financial aid package may vary from year to year. The amount of the federal loan will increase during the sophomore and junior years, because the federal government allows upper-class students to borrow more than first-year students. For details, see the section on student loans.

The Office of Financial Aid and Educational Financing reserves the right to revise a financial aid award if the student withdraws from school or if any information reported on financial aid applications conflicts with information on tax returns or other verification documents. If a family’s financial circumstances change after submission of the financial aid application, an appeal may be made to the Office of Financial Aid and Educational Financing, in writing, for a reconsideration of the financial aid package. An appeal may be made at any time during the year if circumstances warrant; otherwise appeals in direct response to award letters must be made in writing within two weeks of receipt of aid packages.

**Satisfactory Academic Progress**

Students must continue to make satisfactory academic progress toward the degree to remain eligible for financial aid. Satisfactory academic progress is reviewed at the end of each term by the Committee on Academic Screening. All
students are considered for financial aid purposes to be making satisfactory academic progress as long as they are allowed to continue enrollment. For details of The Fu Foundation School of Engineering and Applied Science’s process for evaluating student’s academic progress, see the section on Conduct and Discipline in this bulletin. A student who is required to withdraw because of failure to make satisfactory academic progress may appeal the decision to the Committee on Academic Screening. Upon returning to the School of Engineering and Applied Science following a required withdrawal period, a student regains eligibility for financial aid.

FINANCIAL AID AWARDS
Financial aid is awarded in the form of a “package,” consisting of a combination of the various types of financial aid for which the student is eligible. Most financial aid packages include a combination of grant and “self-help.” The self-help portion of a financial aid package consists of a part-time job during the academic year. Grants from government sources or directly from Columbia cover any remaining need beyond that covered by the self-help award.

Columbia determines the institutional, federal, and New York State financial aid programs for which each student is eligible and awards funds appropriately. In addition to applying to Columbia for assistance, all financial aid applicants are expected to apply for any other grant/scholarship aid for which they may be eligible. Students must notify the Office of Financial Aid and Educational Financing if any outside awards are received. Students who receive financial aid from Columbia grant permission to the Office of Financial Aid and Educational Financing to release relevant personal, academic, and financial information to persons or organizations outside Columbia in order to institute or to continue financial assistance that they might be eligible to receive from such sources. Students can expect that Columbia will respect their right to privacy and release information only as necessary.

The following sources of financial aid may be included in a financial aid package from Columbia.

A. Grants and Scholarships
Through the Columbia University Grant (CUG) program, need-based grants are made to full-time matriculated Columbia students without expectation of repayment. Grants are funded through a variety of University resources, including annual gifts and endowed accounts.

Federal Supplemental Educational Opportunity Grants (SEOG) are grants made under Title IV of the Higher Education Act of 1965, as amended, from funds supplied entirely by the federal government. These funds are awarded to students who demonstrate financial need and are made without expectation of repayment. The amount of an individual grant may range from $200 to $4,000 per year.

The Federal Pell Grant program is authorized by the Education Amendments of 1972. Under this program the federal government provides grants to students who qualify on the basis of financial need. Pell grants range from $890 to $4,731.

The New York State Tuition Assistance Program (TAP) provides grants to full-time, matriculated New York State residents who meet New York State’s eligibility standards. Current TAP award amounts range from $275 to $5,000.

Other grants/scholarships may be available to students from a variety of outside sources. These include, but are not limited to, awards sponsored by secondary schools, civic organizations, parental employers, corporations, and the National Merit and National Achievement Scholarship programs. Outside scholarships are used to reduce the self-help component of the financial aid package. Only after self-help has been completely eliminated will the scholarships begin to reduce any Columbia grant.

B. Student Employment
All students who receive financial aid from Columbia are expected to have a part-time job to help meet the cost of education. Most students work on or near campus, but there are many interesting and rewarding jobs throughout New York City as well.

The University’s Center for Career Education maintains an extensive listing of student employment opportunities, both for federal work-study positions and other student employment options, which do not receive federal funding.
These listings are available on the Center’s Web site: www.careereducation.columbia.edu/students/find_a_job/workstudy.php. For further information, including information on Columbia Student Enterprises, see the section “Center for Career Education” in this bulletin.

Federal Work-Study Student Employment. The Work-Study Payroll Office is dedicated to assisting Columbia students with all processes related to hiring and payment. The Federal Work-Study (FWS) program is designed to promote part-time employment for students who are in need of earnings to help finance their education and to encourage participation in community service. The goal of Columbia University’s FWS program is to provide student assistance that supports a wide range of career objectives and departmental needs within the University and the community.

C. Financing Options

In addition to Columbia’s commitment to meeting 100 percent of every student’s demonstrated financial need, Columbia is committed to assisting families in meeting their family contributions. The following financing options are available to assist families in making educational costs more affordable.

Monthly Payment Plan: Columbia offers an interest-free monthly payment plan through which parents may make five equal monthly payments each term rather than paying the term’s bill in full at the beginning of each term. The only cost associated with the plan is a nominal enrollment fee.

Parent Loans for Undergraduate Students (PLUS): Through the PLUS program, parents may borrow for a child’s educational expenses. Loans are made by banks and other commercial lenders from their own funds, with guarantees by the federal government. Under the PLUS program, parents may borrow up to the total cost of attendance less any other financial aid received. Parents need not demonstrate need to qualify; however, they must be citizens or permanent residents of the United States and must pass a standard credit check. A fee of up to 3 percent will be deducted from the loan at the time that it is disbursed. Repayment begins sixty days after the second disbursement of the loan.

HOW TO APPLY FOR FINANCIAL AID

In order to be considered for need-based institutional financial aid at any time during their four years of undergraduate study, students must apply for financial aid at the time they apply for admission. Exceptions may be granted only in the case of extenuating circumstances that result in a significant change in the family’s financial situation. Continuing students must reapply for financial aid each year. Continuing Student financial aid application forms are made available by the Office of Financial Aid and Educational Financing in mid-March. The student’s name and Columbia ID number should be printed on all documents submitted to the Office of Financial Aid and Educational Financing. Financial aid applicants whose application materials are submitted after the published deadlines cannot be guaranteed institutional financial aid.

1. Columbia Application for Financial Aid

All Columbia application materials can be accessed through www.studentaffairs.columbia.edu/finaid. First-year applicants should fill out the Columbia Application for Financial Aid for New Students, which is included in the Admission Application Booklet. The application must be returned by the following deadlines:

November 15: Columbia Application for Financial Aid for New Students: first-year application for early decision candidates

February 1: Columbia Application for Financial Aid for New Students: first-year application for regular decision candidates

May 5: Columbia Application for Financial Aid for Continuing Students

2. College Scholarship Service (CSS) PROFILE Form

First-time applicants (first-year and transfer applicants, and continuing students who are applying for financial aid for the first time) must register with CSS for the PROFILE Form by visiting CSS online at www.collegeboard.com/profile. Applicants who register online should complete the CSS Profile online (requires a secure browser and credit card). All students must include the Columbia University School of Engineering and Applied Science’s CSS code on their PROFILE Form.

CSS code for SEAS: 2111

The deadlines to submit online are:

November 15: First-year early decision
March 1: First-year regular decision
April 20: Transfer applicants
May 5: Continuing students

3. Free Application for Federal Student Aid (FAFSA)

First-year applicants should obtain a FAFSA online at www.fafsa.ed.gov, from their high school guidance office, or by calling 1-800-4FED-AID.

Transfer applicants should obtain a FAFSA online, from their current college’s financial aid office, or by calling the number above.

Continuing students should apply online each year.

All students must include the Columbia University School of Engineering and Applied Science’s school code on the FAFSA form.

FAFSA code for SEAS: E00486

Students and their parents submitting the FAFSA online should request PIN numbers from the FAFSA Web site, so that they may complete the FAFSA with an online signature. FAFSA applicants without PIN numbers may print a signature page and mail it in to the FAFSA Processor. All online FAFSA applicants should wait for and print out the confirmation page, to ensure that their online submission has been received.

Columbia recommends waiting until after federal income tax returns have been completed before completing the FAFSA form, but no later than the
following deadlines:

**February 1:** First-year candidates, both early and regular decision: paper version of FAFSA

**March 1:** First-year candidates, both early and regular decision: online

**April 1:** Transfer applicants: paper version of FAFSA

**April 20:** Transfer applicants: online

**May 5:** Continuing students: online or paper version of FAFSA

4. **Noncustodial Parent's Statement Form**

Columbia believes that the principal responsibility for meeting educational costs belongs to the family and offers financial aid only to supplement the family’s resources. If the student’s natural parents are divorced or separated, Columbia requires each parent to provide financial information as part of the student’s application for financial aid. The parent with whom the applicant lives most of the year should complete the PROFILE Form and the FAFSA. The noncustodial parent should submit an income tax return and the Noncustodial Parent’s Statement to the financial aid office.

First-year and transfer applicants and continuing students should complete the CSS Noncustodial PROFILE. The deadlines for completing this form are:

- **November 15:** First-year early decision candidates
- **March 1:** First-year regular decision candidates
- **April 20:** Transfer applicants
- **May 5:** Continuing students

5. **Business/Farm Information**

If the student or parents own all or part of a business, corporations, or partnership, or are farm tenants, a complete copy of the most recent business tax return (including all schedules) must be submitted to Columbia. Sole proprietors must submit Schedule C. The deadlines to return these documents to the financial aid office are:

- **November 15:** First-year early decision candidates
- **March 1:** First-year regular decision candidates
- **April 20:** Transfer applicants
- **May 5:** Continuing students

6. **Federal income tax returns**

Signed copies of parent and student federal income tax returns, including W-2 forms and all schedules, are required for verification of the information reported on the PROFILE Form and FAFSA. The financial aid office strongly encourages families of first-year applicants to complete their federal income taxes in February. Signed copies of federal tax returns for parents and, if applicable, for students should be submitted to the financial aid office as soon as they are completed. The preferred deadlines for submission of signed federal tax returns are:

- **March 1:** First-year candidates (early and regular decision)
- **April 20:** Transfer applicants
- **May 5:** Continuing students

**TAX WITHHOLDING FOR NONRESIDENT ALIEN SCHOLARSHIP AND FELLOWSHIP RECIPIENTS**

United States tax law requires the University to withhold tax at the rate of 14 percent on scholarship and fellowship grants paid to nonresident aliens.
which exceed the cost of tuition, books, fees, and related classroom expenses. Certain countries have entered into tax treaties with the United States, which may serve to reduce this rate of withholding. However, even when such a treaty applies, the student and the University must report the full amount of such excess to the Internal Revenue Service. If a student claims tax treaty benefits, he or she must also report this amount to his or her country of residence.

The International Students and Scholars Office has prepared a packet of tax information, which is revised annually and is available to students. International Students and Scholars Office Columbia University 524 Riverside Drive, Mail Code 5724 New York, NY 10027 Phone: 212-854-3587 Fax: 212-854-8579

The tax law is complex and may vary with regard to individual circumstances. Therefore, as the University is not in a position to offer individual tax advice, students are advised to consult with a qualified tax professional and/or the consulate of their country of residence.
Graduate Studies
Graduate programs of study in The Fu Foundation School of Engineering and Applied Science are not formally prescribed, but are planned to meet the particular needs and interests of each individual student. Departmental requirements for each degree, which supplement the general requirements given below, appear in the sections on individual graduate programs.

Applicants for a graduate program are required to have completed an undergraduate degree and to furnish an official transcript as part of the admissions application. Ordinarily the candidate for a graduate degree will have completed an undergraduate course in the same field of engineering in which he or she seeks a graduate degree. However, if the student’s interests have changed, it may be necessary to make up such basic undergraduate courses as are essential to graduate study in his or her new field of interest.

In order to complete the requirements for any graduate degree, the student must plan a program with the department of major interest and then have it approved by the Office of Graduate Student Services; the program may be modified later with the permission of the department and the Assistant Dean. No more than one term of course work or, in the case of part-time students, no more than 15 points of credit of course work, completed before the program is approved, may be counted toward the degree. Students registered in the School have a minimum requirement for each Columbia degree of 30 points of credit of course work completed at Columbia University. The student must enroll for at least 15 of these points while registered in the Engineering School. (See also the section “Special Nondegree Students” on page 35 and the chapter “Columbia Video Network.”) Students wishing to change from the Ph.D. degree to the Eng.Sc.D. degree must therefore enroll for at least 15 points while registered in the School. For residence requirements for students registered in the Graduate School of Arts and Sciences or those wishing to change from the Eng.Sc.D. degree to the Ph.D. degree, see the bulletin of the Graduate School of Arts and Sciences.

Students admitted to graduate study are expected to enter upon and continue their studies in each succeeding regular term of the academic year. Any such student who fails to register for the following term will be assumed to have withdrawn unless a leave of absence has been granted by the Office of Graduate Student Services.

While many candidates study on a full-time basis, it is usually possible to obtain all or a substantial part of the credit requirement for the master’s, professional, or doctoral degrees through part-time study.

Under special conditions, and with the prior approval of the department of his or her major interest and of the Assistant Dean, a student may be permitted to take a required subject at another school. However, credit for such courses will not reduce the 30-point minimum that must be taken at Columbia for each degree.

Competence in written and spoken English is required of every degree candidate. See pages 37–38 for English proficiency requirements.

For graduation, a candidate for any degree except a doctoral degree must file an Application for Degree or Certificate on the date specified in the Academic Calendar. Candidates for a doctoral degree must apply for the final examination. If the degree is not earned by the next regular time for the issuance of diplomas subsequent to the date of filing, the application must be renewed. Degrees are awarded three times a year—in October, February, and May.

THE MASTER OF SCIENCE DEGREE

The Master of Science degree is offered in many fields of engineering and applied science upon the satisfactory completion of a minimum of 30 points of credit of approved graduate study extending over at least one academic year.

While a suitable Master of Science program will necessarily emphasize some specialization, the program should be well balanced, including basic subjects of broad importance as well as theory and applications. The history of modern economic, social, and political institutions is important in engineering, and this is recognized in the prescribed undergraduate program of the School. If the candidate’s undergraduate education has been largely confined to pure science and technology, a program of general studies, totaling from 6 to 8 points, may be required. Supplementary
statements covering these special requirements are issued by the School’s separate departments. An applicant who lacks essential training will be required to strengthen or supplement the undergraduate work by taking or repeating certain undergraduate courses before proceeding to graduate study. No graduate credit (that is, credit toward the minimum 30-point requirement for the Master of Science degree) will be allowed for such subjects. Accordingly, Master of Science programs may include from 35 to 45 points and may require three terms for completion. Doctoral research credits cannot be used toward M.S. degree requirements.

All degree requirements must be completed within five years of the beginning of graduate study. Under extraordinary circumstances, a written request for an extension of this time limit may be submitted to the student’s department for approval by the department chairman and the Assistant Dean. A minimum grade-point average of 2.5 is required for the M.S. degree. A student who, at the end of any term, has not attained the grade-point average required for the degree may be asked to withdraw.

The 4-2 Master of Science Program
The 4-2 Master of Science Program provides the opportunity for students holding bachelor’s degrees from affiliated liberal arts colleges (see the listing under the heading “The Combined Plan—Affiliated Colleges and Universities,” on pages 16–17 of this bulletin) with majors in mathematics, physics, chemistry, or certain other physical sciences to receive the M.S. degree after two years of study at Columbia in the following fields of engineering and applied science: biomedical, chemical, civil, computer, Earth and environmental, electrical, industrial, and mechanical engineering; applied physics; applied mathematics; engineering mechanics; operations research; materials science; and computer science.

Each applicant must produce evidence of an outstanding undergraduate record, including superior performance in physics and mathematics through differential equations. The program of study will be individually worked out in consultation with a faculty adviser and will be designed to integrate undergraduate work with the field of engineering or applied science the student chooses to follow. During the first year, the program will consist primarily of basic undergraduate courses; during the second year, of graduate courses in the selected field. The student must complete at least 30 credits of graduate study to qualify for the degree.

A student whose background may require supplementary preparation in some specific area, or who has been out of school for a considerable period, will have to carry a heavier than normal course load or extend the program beyond two years.

Please contact the Office of Graduate Student Services, The Fu Foundation School of Engineering and Applied Science, 524 S. W. Mudd, Mail Code 4708, 500 West 120th Street, New York, NY 10027; you should also contact the Combined Plan liaison at your school for program information. You may, in addition, e-mail questions to seasgradmit@columbia.edu.

Joint Program with the School of Business in Industrial Engineering
The Graduate School of Business and the Engineering School offer a joint program leading to the degrees of Master of Business Administration and the Master of Science in Industrial Engineering. (See “Industrial Engineering and Operations Research.”)

Joint Program with the School of Business in Operations Research
The Graduate School of Business and the Engineering School offer a joint program leading to the degrees of Master of Business Administration and the Master of Science in Operations Research. (See “Industrial Engineering and Operations Research.”)

Joint Program with the School of Business in Earth Resources Engineering
The Graduate School of Business and the Engineering School offer a joint program leading to the degrees of Master of Business Administration and the Master of Science in Earth Resources Engineering. (See “Earth and Environmental Engineering.”)

Special Studies with the Harriman Institute
A candidate for an advanced degree in the Engineering School may combine these studies with work in the Harriman
Institute. Upon completion of the course requirements in the Institute and satisfaction of the language requirement (in any language indigenous to the former USSR), the student may qualify for the professional certificate of the Harriman Institute. The manner in which the Institute and departmental requirements are combined is to be determined by the student in consultation with departmental and Institute advisers. Advanced studies and research may, where appropriate, be supervised by faculty members from both the School and the Institute.

THE PROFESSIONAL DEGREE

An undergraduate engineering degree is prerequisite for admission to the professional degree program. The program leading to the professional degrees in chemical, civil, computer, electrical, industrial, mechanical, metallurgical and mining engineering, and engineering mechanics is planned for engineers who wish to do advanced work beyond the level of the M.S. degree but who do not desire to emphasize research.

The professional degree is awarded for satisfactory completion of a graduate program at a higher level of course work than is normally completed for the M.S. degree. Students who find it necessary to include master's-level courses in their professional degree program will, in general, take such courses as deficiency courses. A candidate is required to maintain a grade-point average of at least 3.0. A student who, at the end of any term, has not attained the grade-point average required for the degree may be asked to withdraw. At least 30 points of credit of graduate work beyond the M.S. degree, or 60 points of graduate work beyond the B.S. degree, are required for the professional degree.

The final 30 points required for the professional degree must be completed in no more than five years.

DOCTORAL DEGREES: ENG.SC.D. AND PH.D.

Two doctoral degrees in engineering are offered by the University: the Doctor of Engineering Science, administered by The Fu Foundation School of Engineering and Applied Science, and the Doctor of Philosophy, administered by the Graduate School of Arts and Sciences. The Eng.Sc.D. and Ph.D. programs have identical academic requirements with regard to courses, thesis, and examinations, but differ in residence requirements and in certain administrative details.

Requirements for the Degrees

A student must obtain the master's degree (M.S.) before enrolling as a candidate for either the Ph.D. or Eng.Sc.D. degree. Application for admission as a doctoral candidate may be made while a student is enrolled as a master's degree candidate. The minimum requirement in course work for either doctoral degree is 60 points of credit beyond the bachelor's degree.

Candidates for the Ph.D. degree must register full time and complete six Residence Units. A master's degree from an accredited institution may be accepted in the form of advanced standing as the equivalent of one year of residence (30 points of credit or two Residence Units) for either doctoral degree. An application for advanced standing must be completed during the first semester of study. Candidates for the Eng.Sc.D. degree must (in addition to the 60-point requirement) accumulate 12 points of credit in the departmental course E9800: Doctoral research instruction. A holder of the professional degree who wishes to continue work toward the Eng.Sc.D. degree will be required to complete not less than 30 additional points of credit in residence. All doctoral programs are subject to review by the Committee on Instruction of the School. In no case will more than 15 points of credit be approved for the dissertation and research and studies directly connected therewith without special approval by this Committee. Normally, a doctoral candidate specializes in a field of interest acceptable to a department of the School.

Departmental requirements may include comprehensive written and oral qualifying examinations. Thereafter, the student must write a dissertation embodying original research under the sponsorship of a member of his or her department and submit it to the department. If the department recommends the dissertation for defense, the student applies for final examination, which is held before an examining committee appointed by the Dean. This application must be made at least three weeks before the date of the final examination. A student must have a satisfactory grade-point average to be admitted to the doctoral qualifying examination. Consult the department requirements for details.

The candidate for the degree of Doctor of Engineering Science must submit evidence that his or her dissertation has been filed in compliance with requirements set by the Faculty of Engineering and Applied Science.

The defense of the dissertation constitutes the final test of the candidate's qualifications. It must be demonstrated that the candidate has made a contribution to knowledge in a chosen area. In content the dissertation should, therefore, be a distinctly original contribution in the selected field of study. In form it must show the mastery of written English which is expected of a university graduate.

Ph.D. candidates should obtain a copy of the bulletin of the Graduate School of Arts and Sciences, in which are printed the faculty requirements for the Ph.D. degree. These are supplemented by the requirements of the department of major interest.

Doctoral Research Instruction

In order that the University may recover the costs that are not defrayed by the University's income from tuition, charges for research required for the Eng.Sc.D. are assessed as given below.

Ph.D. candidates should consult the bulletin of the Graduate School of Arts and Sciences for the research instruction requirements that apply to them.

An Eng.Sc.D. candidate is required to do the following:

1. At the time the student begins doctoral research, the student is eligible to register for E9800 (3, 6, 9, or 12 points of credit). Twelve points must have been accumulated by the time the student is to receive the degree.
2. Registration for E9800 at a time other than that prescribed above is not per-
mitted, except by written permission of the Dean.

3. Although 12 points of E9800 are required for the doctoral degree, no part of this credit may count toward the minimum residence requirement of 30 points (or 60 points beyond the bachelor’s degree).

4. If a student is required to take coursework beyond the minimum residence requirements, the 12 points of doctoral research instruction must still be taken in addition to the required coursework.

5. A student must register continuously through the autumn and spring terms. This requirement does not include the summer session.

Completion of Requirements
The requirements for the Eng.Sc.D. degree must be completed in no more than seven years. The seven-year time period begins at the time the student becomes a candidate for the Eng.Sc.D. degree or a candidate for the professional degree, whichever occurs first, and extends to the date on which the dissertation defense is held.

Extension of the time allowed for completion of the degree may be granted on recommendation of the student’s sponsor and the department chairman to the Dean when special circumstances warrant. Such extensions are initiated by submitting a statement of work in progress and a schedule for completion together with the sponsor’s recommendation to the department chairman.

SPECIAL NONDEGREE STUDENTS
Qualified persons who are not interested in a degree program but who wish only to take certain courses may be permitted to register as special students, provided facilities are available.

Many graduate courses in The Fu Foundation School of Engineering and Applied Science are offered in the late afternoon and evening in order to make them available to working individuals who wish to further their knowledge in the areas of engineering and applied science. Individuals who find it difficult or impossible to attend classes on the Columbia campus may be able to receive instruction from the School through the Columbia Video Network without leaving their work sites.

Individuals interested in this program should read the section describing the CVN, which follows in this bulletin.

Special students receive grades and must maintain satisfactory attendance and performance in classes or laboratories and will be subject to the same rules as degree candidates. Should a special student decide to pursue a degree program, work completed as a special student may be considered for advanced standing, but no more than 15 points of coursework completed as a special student may be counted toward a graduate degree.

For additional information and regulations pertaining to special students, see “Graduate Admissions.”
BACKGROUND
Continuing a tradition of nearly 250 years of academic excellence and innovation, Columbia University’s Fu Foundation School of Engineering and Applied Science established the Columbia Video Network (CVN) in 1986 to meet a growing need within the engineering community for a graduate distance education program. Classes and degrees offered through CVN are fully accredited; the degrees are granted by Columbia University.

Classes available through CVN are taught on campus by Columbia University faculty in multimedia classrooms. Faculty and students meet in classrooms equipped with cameras, electronic writing tablets, and SMART™ boards. The recorded lectures are fully downloadable for study at home, office, or on the road. CVN students take the same classes, have the same homework assignments, take the same exams, and earn the same degrees as on-campus students in Master of Science or Professional Degree programs.

COURSE OFFERINGS AND DEGREE PROGRAMS
CVN makes select SEAS graduate courses available to off-campus students in autumn (September–December) and spring (January–May) terms. CVN administrators work closely with faculty representatives from each department to select the classes that best fit the needs of new and continuing students around the world. During the summer semester (and, occasionally, the autumn and spring terms), the CVN program makes prerecorded courses available.

CVN currently offers courses and Master of Science degree programs in the following disciplines:
- Applied mathematics
- Biomedical engineering
- Chemical engineering
- Civil engineering
- Computer science
- Earth and environmental engineering
- Electrical engineering
- Operations research
- Methods in finance
- Engineering management systems
- Materials science and engineering
- Mechanical engineering

For students who wish to do advance work beyond the M.S., but do not wish to emphasize research, Professional Degrees (P.D.) are also available in the following areas: computer science, electrical engineering, industrial engineering/operations research, and mechanical engineering.

STUDENT REGISTRATION
Students who have earned an undergraduate degree in engineering, mathematics, or related field can apply to take classes for credit or audit without first enrolling in a degree program at the University or taking the GRE or TOEFL exams by registering as nondegree students. CVN also offers Certificates of Professional Achievement programs in various fields, which may lead to study in a related M.S. or P.D. program.

PROGRAM BENEFITS
The CVN program allows working professionals to enroll in courses and earn graduate engineering degrees from an Ivy League university without leaving their communities, their families, or their jobs. The key component of CVN is flexibility without compromise to the high-caliber teaching, resources, and standards inherent in The Fu Foundation School of Engineering and Applied Science. CVN students are a part of the Columbia community and may take classes on campus. To further enhance the sense of community, CVN has developed a completely automated online Student Center. It provides a place where CVN students and faculty can communicate. Homework and exams are submitted and graded there, and course notes and other reference materials are available for downloading.

Professors and teaching assistants are available via e-mail or phone to address academic questions. CVN’s administrative staff is available to assist with registration procedures, technical queries, and academic advising so working professionals can devote their energies to their studies, their families, and their careers.
The basic requirement for admission as a graduate student is a bachelor's degree received from an institution of acceptable standing. Ordinarily, the applicant will have majored in the field in which graduate study is intended, but in certain programs, preparation in a related field of engineering or science is acceptable. The applicant will be admitted only if the undergraduate record shows promise of productive and effective graduate work.

Students who hold an appropriate degree in engineering may apply for admission to study for the Ph.D. degree. However, students are required to obtain the master's degree first. Applications for admission as a doctoral candidate may be made after completion of 15 points of work as a candidate for the master's degree.

Students may be admitted in one of the following six classifications: candidate for the M.S. degree, candidate for the M.S. degree leading to the Ph.D. degree, candidate for the professional degree, candidate for the Doctor of Engineering Science degree, candidate for the Doctor of Philosophy degree (see also the bulletin of the Graduate School of Arts and Sciences), or special student (not a degree candidate). Note: Not more than 15 points of credit completed as a special nondegree student may be counted toward a degree.

**APPLICATION REQUIREMENTS**

Application materials may be obtained by contacting the Office of Graduate Student Services (see address above), or from our Web site (also above). The forms obtained should be filed in accordance with instructions accompanying the application. When filing the application, the candidate should obtain one official transcript from each postsecondary institution attended and submit them in the original sealed envelope with the application forms. Consideration for admission will be based not only on the completion of an earlier course of study, but also upon the quality of the record presented and upon such evidence as can be obtained concerning the candidate's personal fitness to pursue professional work.

Additionally, candidates must provide three letters of recommendation and the results of required standardized exams. The Graduate Record Examination (general) is required for all candidates. GRE scores are valid for five years from the test date. The Test of English as a Foreign Language (TOEFL) is required of all candidates who received their bachelor's degree in a country in which English is not the official and spoken language.

TOEFL scores are valid for two years from the test date. Applicants can only apply to one degree program per admission term.

**ENGLISH PROFICIENCY REQUIREMENT**

Admitted graduate students who are required to submit official TOEFL results must attain levels of proficiency as described below. Students will not be cleared for graduation unless they satisfy the following requirements:

- M.S. and Professional Degree candidates must reach level 8 on the English Placement Test (EPT) offered by Columbia's American Language Program (ALP).
- Ph.D. and Eng.Sc.D. candidates must attain level 10 on the English Placement Test (EPT) offered by Columbia's American Language Program (ALP).

The EPT is administered in two parts. Part I is a multiple-choice exam and Part II is an essay. Students are required to take both parts, and a level 8 must be scored on Part I in order to take Part II.

The EPT must be taken at Orientation (the fee for this administration of the exam will be covered by SEAS). A student who misses this administration of the EPT must take the exam at his or her own expense at the beginning of the first semester enrolled and submit the official score to the Graduate Student Services Office. (CVN students are exempt from the EPT.)
A student who does not pass the EPT at the required level of proficiency must retake it at his or her own expense until the required level of proficiency is achieved. The ALP may regulate how often the examination is taken.

It is strongly recommended that students enroll in an appropriate ALP course if they have not achieved the required proficiency after the first examination. For more information on the administration of the EPT, please contact the Graduate Student Services Office.

**APPLICATION FEES**

A nonrefundable application processing fee of $70 is required of all degree and nondegree applicants who apply using a hard-copy or online application. Failure to submit the application fee can delay processing of application materials.

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**GRADUATE ADMISSION CALENDAR**

Applicants are admitted twice yearly, for the fall and spring semesters.

- Fall admission application deadlines: *December 1*, for Ph.D., Eng.Sc.D., and M.S. leading to Ph.D. programs, and applicants to the M.S. program in financial engineering. *February 15*, for professional, M.S. only, and non-degree applicants.
- Spring admission application deadlines: *October 1*, for all departments and degree levels.

Applicants who wish to be considered for scholarships, fellowships, and assistantships should file complete applications for fall admission.

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**ONE-TERM SPECIAL STUDENT STATUS**

Individuals who meet the eligibility requirements, who are U.S. citizens or U.S. permanent residents, and who wish to take courses for enrichment, may secure faculty approval to take up to two graduate-level courses for one term only as a one-term special student. This option is also appropriate for individuals who missed applications deadlines. Applications for special student status are available at the Office of Graduate Student Services and must be submitted during the first week of the fall or spring semester.

If a one-term special student subsequently wishes either to continue taking classes the following term or to become a degree candidate, a formal application must be made through the Office of Graduate Student Services.
The 2008–2009 tuition and fees are estimated. Tuition and fees are prescribed by statute and are subject to change at the discretion of the Trustees.

University charges such as tuition, fees, and residence hall and meal plans are billed in the first Student Account Statement of the term, which is sent out in July and December of each year for the upcoming term. This account is payable and due in full on or before the payment due date announced in the Statement, typically at the end of August or early January before the beginning of the billed term. Any student who does not receive the first Student Account Statement is expected to pay at registration.

If the University does not receive the full amount due for the term on or before the payment due date of the first Statement, a late payment charge of $150 will be assessed. An additional charge of 1 percent per billing cycle may be imposed on any amount past due thereafter.

Students with an overdue account balance may be prohibited from registering, changing programs, or obtaining a diploma or transcripts. In the case of persistently delinquent accounts, the University may utilize the services of an attorney and/or collection agent to collect any amount past due. If a student’s account is referred for collection, the student may be charged an additional amount equal to the cost of collection, including reasonable attorney’s fees and expenses incurred by the University.

TUITION
Graduate students enrolled in M.S., Professional Degree, and Eng.Sc.D. programs pay $1,248 per credit, except when a special fee is fixed. Graduate tuition for Ph.D. students is $34,364, or $17,182 per Residence Unit. The Residence Unit, full-time registration for one semester rather than for individual courses (whether or not the student is taking courses), provides the basis for tuition charges. Ph.D. students should consult the bulletin for the Graduate School of Arts and Sciences.

COMPREHENSIVE FEE/ MATRICULATION AND FACILITIES
Eng.Sc.D. candidates engaged only in research, and who have completed their twelve (12) credits of Doctoral Research Instruction (see “The Graduate Programs” in this bulletin), are assessed a Comprehensive Fee of $1,465 per term by The Fu Foundation School of Engineering and Applied Science.

Ph.D. candidates engaged only in research are assessed $1,465 per term for Matriculation and Facilities by the Graduate School of Arts and Sciences.

MANDATORY FEES
University facilities fee
• Full-time master’s programs: $303 per term
• All other full-time programs: $288 per term
Health Service fee: $387 per term
International Services charge: $50 per term (international students only)
Transcript fee: $95 (one-time charge)

OTHER FEES
Application and late fees
• Application for graduate admission paper copy: $70
  online: $70
• Late registration fee
during late registration: $50
  after late registration: $100
Books and course materials:
  Depends upon course
Laboratory fees: See course listings

HEALTH INSURANCE
Columbia University offers the Student Medical Insurance Plan, which provides both Basic and Comprehensive levels of coverage. Full-time students are automatically enrolled in the Basic level of the Plan and billed for the insurance premium in addition to the Health Service fee. Visit www.health.columbia.edu for detailed information about medical insurance coverage options and directions for making confirmation, enrollment, or waiver requests.

PERSONAL EXPENSES
Students should expect to incur miscellaneous personal expenses for such items as food, clothing, linen, laundry, dry cleaning, and so forth.

The University advises students to open a local bank account upon arrival in New York City. Since it often takes as long as three weeks for the first deposit to clear, students should plan to cover immediate expenses using either a credit card, traveler’s checks, or cash draft drawn on a local bank. Students are urged not to arrive in New York without sufficient start-up funds.
LABORATORY CHARGES
Students may need to add another $100 to $300 for drafting materials or laboratory fees in certain courses. Each student taking laboratory courses must furnish, at his or her own expense, the necessary notebooks, blank forms, and similar supplies. In some laboratory courses, a fee is charged to cover expendable materials and equipment maintenance; the amount of the fee is shown with the descriptions in the course listings. Students engaged in special tests, investigations, theses, or research work are required to meet the costs of expendable materials as may be necessary for this work and in accordance with such arrangements as may be made between the student and the department immediately concerned.

DAMAGES
All students will be charged for damage to instruments or apparatus caused by their carelessness. The amount of the charge will be the actual cost of repair, and, if the damage results in total loss of the apparatus, adjustment will be made in the charge for age or condition. To ensure that there may be no question as to the liability for damage, students should note whether the apparatus is in good condition before use and, in case of difficulty, request instruction in its proper operation. Where there is danger of costly damage, an instructor should be requested to inspect the apparatus. Liability for breakage will be decided by the instructor in charge of the course.

When the laboratory work is done by a group, charges for breakage will be divided among the members of the group. The students responsible for any damage will be notified that a charge is being made against them. The amount of the charge will be stated at that time or as soon as it can be determined.

TUITION AND FEE REFUNDS
Students who make a complete withdrawal from a term are assessed a withdrawal fee of $75. Late fees, application fees, withdrawal fees, tuition deposits, special fees, computer fees, special examination fees, and transcript fees are not refundable.

The Health Service Fee, Health Insurance Premium, University facilities fees, and student activity fees are not refundable after the change of program period.

Students who withdraw within the first 60 percent of the academic period are subject to a pro rata refund calculation, which refunds a portion of tuition based on the percentage of the term remaining after the time of withdrawal. This calculation is made from the date the student's written notice of withdrawal is received by the Office of Graduate Student Services.

Percentage Refund for Withdrawal during First Nine Weeks of Term
Prorated for calendars of a different duration, if the entire program is dropped:

<table>
<thead>
<tr>
<th>Week</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st week</td>
<td>100%</td>
</tr>
<tr>
<td>2nd week</td>
<td>90%</td>
</tr>
<tr>
<td>3rd week</td>
<td>80%</td>
</tr>
<tr>
<td>4th week</td>
<td>80%</td>
</tr>
<tr>
<td>5th week</td>
<td>70%</td>
</tr>
<tr>
<td>6th week</td>
<td>60%</td>
</tr>
<tr>
<td>7th week</td>
<td>60%</td>
</tr>
<tr>
<td>8th week</td>
<td>50%</td>
</tr>
<tr>
<td>9th week</td>
<td>40%</td>
</tr>
<tr>
<td>10th week and after</td>
<td>0%</td>
</tr>
</tbody>
</table>

Refund Policy When Dropping Individual Courses
Tuition for courses dropped by the last day of the Change of Program period is refunded in full. There is no refund of tuition for individual courses dropped after the last day of the Change of Program period. The Change of Program period is usually the first two weeks of the fall or spring semesters (please note that the first week of the semester usually begins on a Tuesday).

Please note: The prorated schedule above does not pertain to individual classes dropped (unless your entire schedule consists of only one class). The prorated schedule pertains to withdrawals. Withdrawal is defined as dropping one’s entire program.

For students receiving federal student aid, refunds will be made to the federal aid programs in accordance with Department of Education regulations. Refunds will be credited in the following order:

Federal Unsubsidized Stafford Loans
Federal Stafford Loans
Federal Perkins Loans
Federal PLUS Loans (when disbursed through the University)
Federal Pell Grants
Federal Supplemental Educational Opportunity Grants
Other Title IV funds

Withdrawal students should be aware that they will not be entitled to any portion of a refund until all Title IV programs are credited and all outstanding charges have been paid.
FINANCING GRADUATE EDUCATION

The academic departments of The Fu Foundation School of Engineering and Applied Science and the Office of Financial Aid and Educational Financing seek to ensure that all academically qualified students have enough financial support to enable them to work toward their degree. Possible forms of support for tuition, fees, books, and living expenses are: institutional grants, fellowships, teaching and research assistantships, readerships, preceptorships, on- or off-campus employment, federal work-study employment, and student loans. The Office of Financial Aid and Educational Financing works closely with students to develop reasonable financial plans for completing a degree.

Columbia University graduate funds are administered by two separate branches of the University, and the application materials required by the two branches differ slightly. Institutional grants, fellowships, teaching and research assistantships, readerships, and preceptorships are all departmentally administered funds. Questions and problems regarding these awards should be directed to your academic department. Federal Stafford loans, federal unsubsidized Stafford loans, federal Perkins loans, federal work-study employment, and New York State TAP grants are administered by the Office of Financial Aid and Educational Financing. Questions and problems with regard to awards should be directed to your financial aid adviser.

INSTRUCTIONS FOR FINANCIAL AID APPLICANTS

Forms

Prospective and continuing graduate students of The Fu Foundation School of Engineering and Applied Science must do the following to be considered for all forms of graduate financing (both departmentally administered and financial aid–administered funds):

1a. Prospective Students—complete an application for admission and submit it to The Fu Foundation School of Engineering and Applied Science’s Office of Graduate Student Services;

1b. Continuing Students—preregister for classes during the preregistration period;

2. complete a Free Application for Federal Student Aid (FAFSA) form and submit it to the U.S. Department of Education (only U.S. citizens or permanent residents must complete the FAFSA; if you are a noncitizen, you do not need to submit this form);

3. complete an Express TAP application and submit it to the New York State Higher Education Services Corporation (only U.S. citizens or permanent residents who reside in New York State must complete the Express TAP application; if you are not a New York State resident, you do not need to submit this form);

4. file a Columbia University Enrollment Status Sheet. Complete the form and submit it to the Office of Financial Aid and Educational Financing.

Application Process

Before you can complete the Free Application for Federal Student Aid (FAFSA) form, you must obtain a personal identification number (PIN) from the U.S. Department of Education. The PIN serves as your identifier and your personal electronic signature on the FAFSA. It will also allow you to access your personal information in various U.S. Department of Education systems. Apply for your PIN at www.pin.ed.gov. Approximately three business days after you request your PIN, you will receive an e-mail with instructions on how to retrieve it electronically. If you ask to be notified of your PIN by mail, it will arrive in seven to ten business days via the U.S. Postal Service.

Once you have your PIN, you must complete a FAFSA-on-the-Web application at www.fafsa.ed.gov. Columbia University prefers that you apply for financial aid online. Information collected on the FAFSA will help Columbia to determine your need for financial aid. You must give permission for the application data to be sent to Columbia University by entering the Fu Foundation School of Engineering and Applied Science Title IV school code (E00120) on the FAFSA form.

Once your FAFSA-on-the-Web application is complete, your online confirmation page will give you a link to the TAP-on-the-Web application. New York State uses the information provided on your TAP application to determine your eligibility for a Tuition Assistance Program (TAP) grant. The TAP-on-the-Web online
form will be partially completed with some information from your FAFSA. Review this data, supply any missing information, and submit the completed form. If you do not finish the online TAP-on-the-Web application, you will be mailed a paper Express TAP Application. As with the TAP-on-the-Web application, your Express TAP Application will also be partially completed with some of your FAFSA data. Verify that the partially completed data is correct, complete the remainder of the form, and return it to HESC in the envelope provided.

Preregister for classes during the preregistration period if you are a continuing student. All students must complete the Graduate Engineering Financial Aid Application available from the Office of Financial Aid and Educational Financing. The Graduate Engineering Financial Aid Application provides the University with information about your planned program, including the number of courses in which you plan to enroll.

**Deadlines**

Apply for financial aid at the same time that you apply for admissions. Your admissions application must be received by the December 1 deadline to be eligible for The Fu Foundation School of Engineering and Applied Science departmental funding (institutional grants, fellowships, teaching and research assistantships, readerships, and preceptorships). Spring admissions applicants will not be considered for departmental funding.

Incoming applicants and continuing students must complete their FAFSA form after January 1 and by May 1.

Guidelines for continuing students are available from departmental advisers in advance of the established deadline. All continuing supported students must preregister for classes during the preregistration period.

Complete the Graduate Engineering Financial Aid Application available from the Office of Financial Aid and Educational Financing by May 1.

**GRADUATE SCHOOL DEPARTMENTAL FUNDING**

The graduate departments of The Fu Foundation School of Engineering and Applied Science offer an extensive array of funding. Funding decisions, based solely on merit, and contingent upon making satisfactory academic progress, are made by the departments. As a prospective student you must apply for admission and complete the financial aid forms as stated on page 41. Continuing students must preregister for classes during the preregistration period and complete the applicable forms as stated on page 41. Outside scholarships for which you qualify must be reported to your department and the Office of Financial Aid and Educational Financing. The Fu Foundation School of Engineering and Applied Science reserves the right to adjust your institutional award if you hold an outside scholarship, fellowship, or other outside funding.

**Institutional Grants**

Institutional grants are awarded to graduate students on the basis of academic merit. Recipients must maintain satisfactory academic standing. All applicants for admission and continuing students maintaining satisfactory academic standing will be considered for these funds.

**Fellowships**

Fellowships are financial and intellectual awards for academic merit that provide stipends to be used by fellows to further their research. If you are awarded a fellowship, you are expected to devote time to your own work, and you are not required to render any service to the University or donor. You may publish research produced by your fellowship work. As a fellow, you may not engage in remunerative employment without consent of the Dean. All applicants for admission and continuing students maintaining satisfactory academic standing will be considered for these funds. Applicants should contact the department directly for information. See pages 214–216 for a complete listing of fellowships.

**Assistantships**

Teaching and research assistantships, available in many departments, provide tuition exemption and a living stipend. Duties may include teaching, laboratory supervision, participation in faculty research, and other related activities. Teaching and research assistantships require up to twenty hours of work per week. The appointments generally last from nine to twelve months. If you are participating in faculty research that fulfills degree requirements, you may apply for a research assistantship. Readers and preceptors receive partial tuition exemption and a stipend. Assistantships are awarded on the basis of academic merit. All applicants for admission and continuing students maintaining satisfactory academic standing will be considered for these funds. Applicants should contact the department directly for information.

**ALTERNATIVE FUNDING SOURCES**

**External Awards**

Because it is not possible to offer full grant and fellowship support to all graduate students and because of the prestige inherent in holding an award through open competition, applicants are encouraged to consider major national and international fellowship opportunities. It is important that prospective graduate students explore every available source of funding for graduate study.

In researching outside funding you may look to faculty advisers, career services offices, deans of students, and offices of financial aid where frequently you may find resource materials, books, and grant applications for a wide variety of funding sources. You must notify both your academic department at The Fu Foundation School of Engineering and Applied Science and the Office of Financial Aid and Educational Financing of any outside awards that you will be receiving.

**Funding for International Students**

To secure a visa, international students must demonstrate that they have sufficient funding to complete the degree. Many international students obtain support for their educational expenses from their government, a foundation, or a private agency.

International students who apply by the December 15 deadline and are admitted to a graduate program in The Fu Foundation School of Engineering
and Applied Science are automatically considered for departmental funding (institutional grants, fellowships, teaching and research assistantships, readerships, and preceptorships) upon completion of the required financial aid forms referred to above. Spring admissions applicants will not be considered for departmental funding. Continuing international students must preregister for classes during the preregistration period and complete an enrollment status form to be considered for departmental funding.

Most loan programs are restricted to U.S. citizens and permanent residents. However, international students may apply for these domestic loan programs with a cosigner who is a citizen or permanent resident in the United States. Depending on the loan program, you may need a valid U.S. Social Security number. Also depending on your country of origin, you may qualify for a private loan without need for a creditworthy U.S. citizen or permanent resident. Contact the financial aid office for more details on this loan program.

Students who study at The Fu Foundation School of Engineering and Applied Science on temporary visas should fully understand the regulations concerning possible employment under those visas. Before making plans for employment in the United States, international students should consult with the International Students and Scholars Office (ISSO), located at 524 Riverside Drive, Suite 200; 212-854-3587. Their Web site is www.columbia.edu/cu/issso/issso.html.

OTHER FINANCIAL AID—FEDERAL, STATE, AND PRIVATE PROGRAMS

Eligibility
To be considered for nondepartmental financial aid (federal Stafford loans, federal unsubsidized Stafford loans, federal Perkins loans, federal work-study employment, and New York State TAP grants), you must be a U.S. citizen or permanent resident admitted as at least a half-time student to a degree program in The Fu Foundation School of Engineering and Applied Science. If you are taking courses but are not yet admitted into a degree program, then you do not qualify for federal or state aid. In addition, to preserve your aid eligibility, you must maintain satisfactory academic progress, as defined in “The Graduate Programs” section.

To apply for funds, you must complete a Free Application for Federal Student Aid (FAFSA) form, a Graduate Engineering Financial Aid Application, and an Express TAP application (if you are a New York State resident). Loan borrowers must complete a Columbia University Loan Entrance Interview. The information supplied on the FAFSA form is used to determine your eligibility for federal aid. The Enrollment Status Sheet provides the University with information about your planned program, including the number of courses in which you plan to enroll. The Express TAP application acts as your request for New York State Tuition Assistance Program funds.

Columbia University prefers that the FAFSA be filed after January 1, but preferably before May 1, for fall enrollment. Students must give permission for the application data to be sent to Columbia University by entering The Fu Foundation School of Engineering and Applied Science Title IV school code (E00120) on the FAFSA form.

It is your responsibility to supply accurate and complete information on the FAFSA and to notify the Office of Financial Aid and Educational Financing immediately of any changes in your enrollment plans, housing status, or financial situation, including information about any institutional or outside scholarships you will be receiving.

The Graduate Engineering Financial Aid Application is available from the Office of Financial Aid and Educational Financing or can be downloaded from their Web site located at: www.engineering.columbia.edu/graduate/financing.

Determination of your financial need is based upon the number of courses for which you register. If you enroll in fewer courses than you initially reported on your Columbia University Enrollment Status Sheet, your financial aid may be reduced.

University-administered federal and state awards are not automatically renewed each year. Continuing graduate students must submit a Renewal FAFSA each year by the Columbia University deadline. Renewal depends on the annual reevaluation of your need, the availability of funds, and satisfactory progress toward the completion of your degree requirements.

New York State Tuition Assistance Program (TAP)
Legal residents of New York State who are enrolled in a full-time degree program of at least 12 points a term, or the equivalent, may be eligible for awards under this program. To apply for TAP, list the Columbia University school code (E00120) on the FAFSA form. When the FAFSA has been processed, an Express TAP application will be mailed to you. Review the information, change any incorrect items, sign the form, and return it to the address indicated.

Veterans’ Benefits
Various Department of Veterans Affairs programs provide educational benefits for sons, daughters, and spouses of deceased or permanently disabled veterans as well as for veterans and in-service personnel who served on active duty in the U.S. Armed Forces after January 1, 1955. In these programs the amount of benefits varies. Under most programs the student pays tuition and fees at the time of registration but receives a monthly allowance from Veterans Affairs.

Since interpretation of regulations governing veterans’ benefits is subject to change, veterans and their dependents should keep in touch with the Department of Veterans Affairs. For additional information and assistance in completing the necessary forms, contact 1-800-827-1000, or consult their Web site (www.va.gov).

Federal Family Education Loans
Federal Subsidized Stafford Student Loan Program
Federal Unsubsidized Stafford Loan Program
Federal Perkins Loan
Federal Graduate PLUS Loan
Detailed information regarding the above loan programs may be found on the
Columbia Comprehensive Educational Financing Plan

Columbia University has developed the Comprehensive Educational Financing Plan to assist students and parents with their financing needs. The plan is a combination of federal, institutional, and private sources of funds that we hope will meet the needs of our diverse student population, providing options to part-time, full-time, and international students. The suggested lenders listed in this plan were selected as a result of a competitive Request for Proposal (RFP) process conducted in 2005. The criteria for selection included competitive rates and terms, supportive customer service, and a flexible application and fund disbursement process.

The Columbia Comprehensive Educational Financing Plan offers payment plans, loan programs, and tuition insurance options as well as limited loan options for international students. Information regarding the Columbia Comprehensive Educational Financing Plan may be obtained through the Office of Financial Aid and Educational Financing.

Private Loans

Several private loan programs are available to both U.S. citizens and international students attending Columbia University. These loans were created to supplement federal and institutional aid. These loan programs require that you (the applicant) have a good credit standing and not be in default on any outstanding loans. International students may be eligible for a private loan with the assistance of a creditworthy U.S. citizen or permanent resident. In some cases, as an international student, you must have a valid U.S. Social Security number. Some international students from specific countries may qualify for a private loan without need for a creditworthy U.S. citizen or permanent resident. Contact the financial aid office for more details on this loan program.

Employment

Students on fellowship support must obtain the permission of the Dean before accepting remunerative employment.

Students who study at The Fu Foundation School of Engineering and Applied Science on temporary visas should fully understand the regulations concerning possible employment under those visas. Before making plans for employment in the United States, international students should consult with the International Students and Scholars Office (ISSO) located at 524 Riverside Drive, Suite 200; 212-854-3587. Their Web site is www.columbia.edu/cu/isso/isso.html.

Federal Work-Study Program

Federal work-study jobs are on-campus jobs funded by the U.S. Department of Education and the University. If you are eligible for this form of financial aid, we recommend that you inquire about work-study positions in the academic department from which you will receive your degree; but work-study jobs are available in many academic and administrative departments, laboratories, libraries, and campus dining halls. If you are employed under the work-study program, you will be paid biweekly based on the number of hours you worked, and you may earn up to the total amount specified in your financial aid award offer.

On-Campus Employment

The Center for Career Education maintains an extensive listing of student employment opportunities. The Center for Career Education (CCE) is located at East Campus, Lower Level, 212-854-5609, www.careereducation.columbia.edu.

Off-Campus Employment in New York City

One of the nation’s largest urban areas, the city offers a wide variety of opportunities for part-time work. Many students gain significant experience in fields related to their research and study while they meet a portion of their educational expenses.
Faculty and Administration
OFFICERS

Lee C. Bollinger
B.A., J.D.
President of Columbia University

Alan Brinkley
B.A., Ph.D.
Provost of Columbia University

Gerald A. Navratil
B.S., M.S., Ph.D.
Interim Dean

Morton B. Friedman
B.S., M.S., D.Sc.
Vice Dean

Anna Marie O'Neill
B.B.A.
Associate Dean

Jack McGourty
B.A., M.S., Ph.D.
Associate Dean for Undergraduate Studies

Andrew Laine
B.S., M.S., D.Sc.
Secretary

FACULTY

Alfred V. Aho
Lawrence Gussman Professor of Computer Science

Peter K. Allen
Professor of Computer Science

Dimitris Anastassiou
Professor of Electrical Engineering
Dipl., National Technical University of Athens (Greece), 1974; M.S., California, 1975; Ph.D., 1979

Gerard H. A. Ateshian
Professor of Mechanical Engineering and of Biomedical Engineering
B.S., Columbia, 1986; M.S., 1987; M.Phil., 1990; Ph.D., 1991

Daniel Attinger
Assistant Professor of Mechanical Engineering
M.S., EPFL Lausanne, 1997; Ph.D., ETH Zurich, 2001

William E. Bailey
Associate Professor of Materials Science (Henry Krumb School of Mines) and of Applied Physics and Applied Mathematics
B.S. and B.A., Brown, 1993; M.S., Stanford, 1995; Ph.D., 1999

Guillaume Bal
Associate Professor of Applied Mathematics
Diploma, École Polytechnique, 1993; Ph.D., University of Paris, 1997

Scott Banta
Assistant Professor of Chemical Engineering
B.S., University of Maryland, Baltimore, 1997; M.S., Rutgers, 2000; Ph.D., 2002

Peter Belhumeur
Professor of Computer Science

Steven M. Bellovin
Professor of Computer Science
B.A., Columbia, 1972; M.S., North Carolina (Chapel Hill), 1977; Ph.D., 1987

Keren Bergman
Professor of Electrical Engineering
B.S., Bucknell University, 1988; M.S., Massachusetts Institute of Technology, 1991; Ph.D., 1994

Raimondo Betti
Professor of Civil Engineering
B.S., Rome, 1985; M.S., Southern California, 1988; Ph.D., 1991

Daniel Bienstock
Professor of Industrial Engineering and Operations Research
B.S., Brandeis, 1982; Ph.D., Massachusetts Institute of Technology, 1985

Simon J. L. Billinge
Professor of Materials Science (Henry Krumb School of Mines) and of Applied Physics and Applied Mathematics

Jose Blanchet
Assistant Professor of Industrial Engineering and Operations Research
B.S., Instituto Tecnológico Autónomo de México, 2000; Ph.D., Stanford, 2004

Bruno A. Boley
Professor of Civil Engineering
B.C.E., College of the City of New York, 1943; M.Ac.E., Polytechnic Institute of Brooklyn, 1945; Eng.Sc.D., 1946

Allen H. Boozer
Professor of Applied Physics
B.A., Virginia, 1966; Ph.D., Cornell, 1970

Mark A. Borden
Assistant Professor of Chemical Engineering
B.S., Arizona (Tucson), 1999; Ph.D., California (Davis), 2003

Truman R. Brown
Percy K. and Vida L. W. Hudson Professor of Biomedical Engineering and Professor of Radiology (Health Sciences)
B.S., Massachusetts Institute of Technology, 1964; Ph.D., 1970

Mark A. Cane
G. Unger Vetlesen Professor of Earth and Environmental Sciences and Professor of Applied Physics and Applied Mathematics
B.A., Harvard, 1965; M.A., 1966; Ph.D., Massachusetts Institute of Technology, 1975

Luca Carloni
Assistant Professor of Computer Science
B.S., Bologna (Italy), 1995; M.S., California (Berkeley), 1997; Ph.D., 2004

Marco Castaldi
Assistant Professor of Earth and Environmental Engineering (Henry Krumb School of Mines)
B.S., Manhattan College, 1992; M.S., UCLA, 1994; Ph.D., 1997

Siu-Wai Chan
Professor of Materials Science (Henry Krumb School of Mines) and of Applied Physics and Applied Mathematics
B.S., Columbia, 1980; Sc.D., Massachusetts Institute of Technology, 1985

Kartik Chandran
Assistant Professor of Earth and Environmental Engineering
B.S., Indian Institute of Technology (Roorkee), 1995; Ph.D., University of Connecticut, 1999

Shih-Fu Chang
Professor of Electrical Engineering
B.S., National Taiwan University, 1985; M.S., California (Berkeley), 1991; Ph.D., 1993

Praveen Chaudhari
Professor of Materials Science (Henry Krumb School of Mines) and of Applied Physics and Applied Mathematics
B.S., Indian Institute of Technology, 1961; M.S., Massachusetts Institute of Technology, 1963; Ph.D., 1966
Xi Chen  
Professor of Civil Engineering  
B.E., Xi’an Jiaotong University (P.R. China), 1994; M.E., Tsinghua University (P.R. China), 1997; S.M., Harvard, 1998; Ph.D., 2001

Nicola Chiara  
Assistant Professor of Civil Engineering  
B.S., Università degli Studi di Palermo (Italy), 1995; M.S., University of Texas, 2001; Ph.D., Columbia, 2006

Maria Chudnovsky  
Associate Professor of Industrial Engineering and Operations Research  

Edward G. Coffman Jr.  
Professor of Electrical Engineering  
B.S., California (Los Angeles), 1956; M.S., 1961; Ph.D., 1966

Rama Cont  
Associate Professor of Industrial Engineering and Operations Research  

Matias Courdurier  
Assistant Professor of Applied Mathematics  
B.S., Universidad de Chile, 2001; Ph.D., University of Washington, 2007

Patricia J. Culligan  
Professor of Civil Engineering  
B.Sc., University of Leeds, 1982; M.Phil., Cambridge University, 1985; Ph.D., 1989

Gautam Dasgupta  
Professor of Civil Engineering  
B.Engr., Calcutta, 1967; M.Engr., 1969; Ph.D., California (Berkeley), 1974

George Deodatis  
The Santiago and Robertina Calatrava Family Professor of Civil Engineering  
B.S., National Technical University of Athens, 1982; M.S., Columbia, 1984; Ph.D., 1987

Emanuel Derman  
Professor of Industrial Engineering and Operations Research  
B.Sc., University of Cape Town, 1965; M.A., Columbia, 1968; Ph.D., 1973

Paul Diament  
Professor of Electrical Engineering  
B.S., Columbia, 1960; M.S., 1961; Ph.D., 1963

Paul F. Duby  
Professor of Mineral Engineering  

Christopher J. Durning  
Professor of Chemical Engineering  
B.S., Columbia, 1978; M.A., Princeton, 1979; Ph.D., 1982

Stephen A. Edwards  
Associate Professor of Computer Science  
B.S., California Institute of Technology, 1992; M.S., California (Berkeley), 1994; Ph.D., 1997

Dan Ellis  
Associate Professor of Electrical Engineering  
B.A., Cambridge University, 1987; M.S., Massachusetts Institute of Technology, 1992; Ph.D., 1996

Steven K. Feiner  
Professor of Computer Science  
B.A., Brown, 1973; Ph.D., 1985

Morton B. Friedman  
Professor of Civil Engineering  
B.S., New York University, 1948; M.S., 1950; D.Sc., 1953

Guillermo Gallego  
Professor of Industrial Engineering and Operations Research  
B.S., California (San Diego), 1980; Ph.D., Cornell, 1988

Donald Goldfarb  
Alexander and Hermine Avanessians Professor of Industrial Engineering and Operations Research  
B.Ch.E., Cornell, 1963; M.A., Princeton, 1965; Ph.D., 1966

Gavin Gong  
Assistant Professor of Earth and Environmental Engineering (Henry Krumb School of Mines)  
B.E., Cooper Union, 1991; M.S., Massachusetts Institute of Technology, 1994; Ph.D., 2003

Luis Gravano  
Associate Professor of Computer Science  
B.S., Lujan (Argentina), 1990; M.S., Stanford, 1994; Ph.D., 1997

Eitan Grinspun  
Assistant Professor of Computer Science  
B.A., Toronto (Ontario), 1997; M.S., California Institute of Technology, 2000; Ph.D., 2003

Jonathan L. Gross  
Professor of Computer Science  
B.S., Massachusetts Institute of Technology, 1964; M.A., Dartmouth, 1966; Ph.D., 1968

Carl C. Gryte  
Professor of Chemical Engineering  
B.Sc., Toronto, 1964; M.Sc., 1966; Ph.D., Polytechnic Institute of Brooklyn, 1970

X. Edward Guo  
Professor of Biomedical Engineering  
B.S., Peking University, 1984; M.S., Harvard-MIT, 1990; Ph.D., 1994

Tony F. Heinz  
David M. Rickey Professor of Optical Communications (Electrical Engineering) and Professor of Physics (Arts and Sciences)  
B.S., Stanford, 1978; Ph.D., California (Berkeley), 1982

Irving P. Herman  
Professor of Applied Physics  
B.S., Massachusetts Institute of Technology, 1972; Ph.D., 1977

Andreas H. Hielscher  
Associate Professor of Biomedical Engineering and of Radiology (Health Sciences)  
B.S., University of Hannover (Germany), 1987; M.S., 1991; Ph.D., Rice University, 1995

Elizabeth M. C. Hillman  
Assistant Professor of Biomedical Engineering and of Radiology (Health Sciences)  
M.Sc., University College London, 1998; Ph.D., 2002

Julia Hirschberg  
Professor of Computer Science  
B.A., Eckert College, 1968; Ph.D., Michigan, 1976; MSEE, Pennsylvania, 1982; Ph.D., 1985

James C. Hone  
Associate Professor of Mechanical Engineering  
B.S., Yale, 1990; Ph.D., California (Berkeley), 1998
Hayden Huang  
Assistant Professor of Biomedical Engineering  
B.S., Johns Hopkins, 1995; S.M., Massachusetts Institute of Technology, 1997; Ph.D., 2002

Woonghee Tim Huh  
Assistant Professor of Operations Research  
B.S., B.A., University of Waterloo (Ontario), 1997; M.S., Cornell, 2001; Ph.D., 2003

Clark T. Hung  
Associate Professor of Biomedical Engineering  

James S. Im  
Professor of Materials Science (Henry Krumb School of Mines) and of Applied Physics and Applied Mathematics  
B.S., Cornell, 1984; Ph.D., Massachusetts Institute of Technology, 1989

Garud Iyengar  
Associate Professor of Industrial Engineering and Operations Research  
B.S., Washington University, 1988; M.S., Stanford, 1989; Ph.D., 1994

Christopher R. Jacobs  
Associate Professor of Biomedical Engineering  
B.S., Washington University, 1988; M.S., Stanford, 1989; Ph.D., 1994

Tony Jebara  
Associate Professor of Computer Science  
B.S., McGill, 1996; M.S., Massachusetts Institute of Technology, 1998; Ph.D., 2002

Predrag Relja Jelenkovic  
Professor of Electrical Engineering  
Dipl.Ing., Belgrade University, 1991; M.S., Columbia, 1993; M. Phil., 1995; Ph.D., 1996

Jingyue Ju  
Professor of Chemical Engineering  
B.S., Inner Mongolia University, 1985; M.S., Chinese Academy of Sciences, 1988; Ph.D., Southern California, 1993

Souleymane Kachani  
Assistant Professor of Operations Research  
B.S., Ecole Centrale Paris, 1998; M.S., Massachusetts Institute of Technology, 1999; Ph.D., 2002

Gail E. Kaiser  
Professor of Computer Science  
B.S., Massachusetts Institute of Technology, 1979; M.S., 1980; Ph.D., Carnegie Mellon, 1985

Lance C. Kam  
Assistant Professor of Biomedical Engineering  
B.S., Washington University, 1991; M.S., University of Hawaii, 1994; Ph.D., Rensselaer, 1999

John R. Kender  
Professor of Computer Science  
B.S., Detroit, 1970; M.S., Michigan, 1972; Ph.D., Carnegie-Mellon, 1980

Angelos Keromytis  
Associate Professor of Computer Science  
B.S., Crete, Heraklion, 1996; M.S., Pennsylvania, 1997; Ph.D., 2001

David E. Keyes  
Fu Foundation Professor of Applied Mathematics  
B.S.E., Princeton, 1978; Ph.D., Harvard, 1984

Peter Kinget  
Associate Professor of Electrical Engineering  
Ph.D., Katholieke Universiteit Leuven (Belgium), 1996

Jeffrey T. Koberstein  
Percy K. and Vida L. W. Hudson Professor of Chemical Engineering  
B.S., University of Wisconsin, 1974; Ph.D., University of Massachusetts, 1979

Elisa E. Konofagou  
Assistant Professor of Biomedical Engineering  
B.S., Université de Paris VI (France), 1992; M.S., University of London, 1993; Ph.D., University of Houston, 1999

S. G. Steven Kou  
Associate Professor of Industrial Engineering and Operations Research  
M.A., Columbia, 1992; Ph.D., 1995

Sanat K. Kumar  
Professor of Chemical Engineering  
B.Tech., Indian Institute of Technology, 1981; S.M., Massachusetts Institute of Technology, 1984; Ph.D., 1987

Ioannis Kynnissis  
Assistant Professor of Electrical Engineering  
M.Eng., Massachusetts Institute of Technology, 1999; Ph.D., 2003

Jeffrey Kysar  
Associate Professor of Mechanical Engineering  

Klaus S. Lackner  
Maurice Ewing and T. Lamar Worzel Professor of Geophysics (Earth and Environmental Engineering, Henry Krumb School of Mines)  
B.S., Heidelberg, 1974; M.S., 1976; Ph.D., 1978

Andrew F. Laine  
Professor of Biomedical Engineering and of Radiology (Health Sciences)  
B.S., Cornell, 1977; M.S., Connecticut, 1980; M.S., Washington (St. Louis), 1983; D.Sc., 1989

Upmanu Lall  
Alan and Carol Silberstein Professor of Earth and Environmental Engineering (Henry Krumb School of Mines) and Civil Engineering  
B.Tech., Indian Institute of Technology (Kanpur), 1976; M.S., University of Texas, 1980; Ph.D., 1981

Aurel A. Lazar  
Professor of Electrical Engineering  
B.S., Bucharest Polytechnical Institute, 1971; M.S., Darmstadt Institute of Technology, 1976; Ph.D., Princeton, 1980

Edward F. Leonard  
Professor of Chemical Engineering  
B.S., Massachusetts Institute of Technology, 1953; M.S., Pennsylvania, 1955; Ph.D., 1960

Jung-Chi Liao  
Assistant Professor of Mechanical Engineering  
B.S., National Taiwan University, 1993; M.S., Massachusetts Institute of Technology, 1997; Ph.D., 2001

Qiao Lin  
Associate Professor of Mechanical Engineering  
B.S., Tsinghua University (Beijing), 1985; M.S., 1988; Ph.D., California Institute of Technology, 1993

Hoe I. Ling  
Professor of Civil Engineering  
B.S., Kyoto University, 1988; M.S., University of Tokyo, 1990; Ph.D., 1993

SEAS 2008–2009
Richard W. Longman
Professor of Mechanical Engineering and Civil Engineering
B.S., California (Riverside), 1965; M.S., California (San Diego), 1967; M.A., 1969; Ph.D., 1969

Helen H. Lu
Associate Professor of Biomedical Engineering
B.S., Pennsylvania, 1992; M.S., 1997; Ph.D., 1998

Tal Malkin
Assistant Professor of Computer Science
B.S., Bar-Ilan University (Israel), 1993; M.S., Weizmann Institute of Science (Israel), 1995; Ph.D., Massachusetts Institute of Technology, 2000

Jeremy J. Mao
Associate Professor of Orthodontics (Health Sciences) and Associate Professor of Biomedical Engineering
Ph.D., University of Alberta (Canada), 1992; M.S.D., 1996; D.D.S., University of Illinois–Chicago, 2002

Chris A. Marianetti
Assistant Professor of Materials Science (Henry Krumb School of Mines) and of Applied Physics and Applied Mathematics
B.S., Ohio State, 1997; M.S., 1998; Ph.D., Massachusetts Institute of Technology, 2004

Michael E. Mauel
Professor of Applied Physics
B.S., Massachusetts Institute of Technology, 1978; M.S., 1979; Sc.D., 1983

Nicholas F. Maxemchuk
Professor of Electrical Engineering
B.S., The City College of New York, 1968; M.S., Pennsylvania, 1970; Ph.D., 1975

Kathleen R. McKeown
Henry and Gertrude Rothschild Professor of Computer Science

V. Faye McNeill
Assistant Professor of Chemical Engineering
B.S., California Institute of Technology, 1999; M.S., Massachusetts Institute of Technology; Ph.D., 2005

Christian Meyer
Professor of Civil Engineering
Vordiplom, Technical University of Berlin, 1965; M.S., California (Berkeley), 1968; Ph.D., 1970

Vishal Misra
Associate Professor of Computer Science
B.S., Indian Institute of Technology, 1992; M.S., Massachusetts (Amherst), 1996; Ph.D., 2000

Vijay Modi
Professor of Mechanical Engineering
B.Tech., Indian Institute of Technology (Bombay), 1978; Ph.D., Cornell, 1984

Barclay Morrison III
Associate Professor of Biomedical Engineering
B.S.E., Johns Hopkins University, 1992; M.S.E., Pennsylvania, 1994; Ph.D., 1999

Van C. Mow
Stanley Dicker Professor of Biomedical Engineering and Professor of Orthopedic Engineering (Orthopedic Surgery, Health Sciences)
B.A.E., Rensselaer Polytechnic Institute, 1978; M.S., Massachusetts Institute of Technology, 1981; Ph.D., 1992

Arvind Narayanaswamy
Assistant Professor of Mechanical Engineering
B.Tech., Indian Institute of Technology, 1997; Ph.D., Massachusetts Institute of Technology, 2007

Gerald A. Navratil
Thomas Alva Edison Professor of Applied Physics
B.S., California Institute of Technology, 1973; M.S., Wisconsin, 1974; Ph.D., 1976

Shree Kumar Nayar
T. C. Chang Professor of Computer Science
B.S., Birla Institute of Technology (India), 1984; M.S., North Carolina State, 1986; Ph.D., Carnegie-Mellon, 1990

Gertrude F. Neumark
Howe Professor of Materials Science and Engineering and Professor of Applied Physics and Applied Mathematics
B.A., Barnard, 1948; M.A., Radcliffe, 1949; Ph.D., Columbia, 1951

Jason Nieh
Associate Professor of Computer Science
B.S., Massachusetts Institute of Technology, 1989; M.S., Stanford, 1990; Ph.D., 1999

Steven M. Nowick
Professor of Computer Science

Ismail C. Noyan
Professor of Materials Science (Henry Krumb School of Mines) and of Applied Physics and Applied Mathematics
B.S., Middle East Technical University (Turkey), 1978; Ph.D., Northwestern, 1984

Marina Olvera-Cravioto
Assistant Professor of Industrial Engineering and Operations Research
B.S., Instituto Tecnológico Autónomo de México, 2000; M.S. Stanford, 2004; Ph.D., 2006

Richard M. Osgood Jr.
Higgins Professor of Electrical Engineering and Professor of Applied Physics
B.S., U.S. Military Academy, 1965; M.S., Ohio State, 1968; Ph.D., Massachusetts Institute of Technology, 1973

Ben O’Shaughnessy
Professor of Chemical Engineering
B.Sc., Bristol (England), 1977; Ph.D., Cambridge (England), 1984

Ah-Hyung Alissa Park
Lenfest Earth Institute; Assistant Professor of Climate Change, Earth and Environmental Engineering
B.S., University of British Columbia, 1998; M.S., 2000; Ph.D., Ohio State, 2005

Thomas S. Pedersen
Associate Professor of Applied Physics
M.Sc., Technical University of Denmark, 1995; Ph.D., Massachusetts Institute of Technology, 2000

Itsik Pe’er
Assistant Professor of Computer Science
B.Sc., Tel Aviv University, 1990; M.S., 1995; Ph.D., 2002

Aron Pinczuk
Professor of Applied Physics and of Physics (Arts and Sciences)
Licenciado, Buenos Aires (Argentina), 1962; Ph.D., Pennsylvania, 1969

Lorenzo M. Polvani
Professor of Applied Mathematics and of Earth and Environmental Sciences (Arts and Sciences)
B.Sc., McGill, 1981; M.Sc., 1982; Ph.D., Massachusetts Institute of Technology, 1988

Ravi Ramamoorthy
Associate Professor of Computer Science
B.S., M.S., California Institute of Technology, 1998; Ph.D, Stanford, 2002

Kenneth A. Ross
Professor of Computer Science
B.Sc., Melbourne, 1986; Ph.D., Stanford, 1991
Dan Rubenstein
Associate Professor of Electrical Engineering
B.S., Massachusetts Institute of Technology, 1992; M.A., California (Los Angeles), 1994; Ph.D., Massachusetts (Amherst), 2000

Paul Sajda
Associate Professor of Biomedical Engineering
B.S., Massachusetts Institute of Technology, 1989; M.S., Pennsylvania, 1992; Ph.D., 1994

Peter Schlosser
Vinton Professor of Earth and Environmental Engineering (Henry Krumb School of Mines) and Professor of Earth and Environmental Sciences (Arts and Sciences)
B.S./M.S., Heidelberg, 1981; Ph.D., 1985

Christopher H. Scholz
Professor of Earth and Environmental Sciences (Arts and Sciences) and of Applied Physics and Applied Mathematics
B.S., Nevada, 1964; Ph.D., Massachusetts Institute of Technology, 1967

Henning G. Schulzrinne
Professor of Computer Science and of Electrical Engineering
B.S., Technical University of Darmstadt (Germany), 1984; M.S., Cincinnati, 1987; Ph.D., Massachusetts (Amherst), 1992

Amiya K. Sen
Professor of Electrical Engineering and of Applied Physics
Dipl., Indian Institute of Science, 1952; M.S., Massachusetts Institute of Technology, 1958; Ph.D., Columbia, 1963

Rocco A. Servedio
Associate Professor of Computer Science
A.B., Harvard, 1993; M.S., 1997; Ph.D., 2001

Simha Sethumadhavan
Assistant Professor of Computer Science
B.S.E., University of Madras, 2000; M.S., University of Texas, 2005; Ph.D., 2007

Jay Sethuraman
Associate Professor of Industrial Engineering and Operations Research
B.E., Birla Institute of Technology and Science (India), 1991; M.S., Indian Institute of Science, 1994; Ph.D., Massachusetts Institute of Technology, 1999

Nina C. Shapley
Assistant Professor of Chemical Engineering
A.B., Harvard, 1993; Ph.D., Massachusetts Institute of Technology, 2000

Kenneth L. Shepard
Professor of Electrical Engineering
B.S.E., Princeton, 1987; M.S.E.E., Stanford, 1988; Ph.D., 1992

Samuel K. Sia
Assistant Professor of Biomedical Engineering
B.Sc., University of Alberta (Edmonton, Canada), 1997; Ph.D., Harvard, 2002

Karl Sigman
Professor of Industrial Engineering and Operations Research
B.A., California (Santa Cruz), 1980; M.A., California (Berkeley), 1983; M.S., 1984; Ph.D., 1986

Nabil Simaan
Assistant Professor of Mechanical Engineering
B.S., M.S., Ph.D., Technion (Israel Institute of Technology), 2002

Andrew Smyth
Associate Professor of Civil Engineering
B.A./B.Sc., Brown, 1992; M.S., Rice, 1994; Ph.D., Southern California (Los Angeles), 1998

Adam H. Sobel
Associate Professor of Applied Physics and Applied Mathematics and of Environmental Sciences (Arts and Sciences)
B.A., Wesleyan, 1989; Ph.D., Massachusetts Institute of Technology, 1998

Ponisseril Somasundaran
LaVon Duddleson Krumb Professor of Mineral Engineering
B.Sc., Kerala (India), 1958; B.E., Indian Institute of Science, 1961; M.S., California (Berkeley), 1962; Ph.D., 1964

Marc W. Spiegelman
Associate Professor of Earth and Environmental Sciences (Arts and Sciences) and of Applied Physics and Applied Mathematics

Clifford Stein
Professor of Industrial Engineering and Operations Research
B.S.E., Princeton, 1987; M.S., Massachusetts Institute of Technology, 1989; Ph.D., 1992

Salvatore J. Stolfo
Professor of Computer Science
B.S., Brooklyn, 1974; M.S., New York University, 1976; Ph.D., 1979

Horst Stormer
Professor of Physics (Arts and Sciences) and of Applied Physics
B.S., Goethe-Universität (Germany), 1970; Diploma, 1974; Ph.D., Stuttgart (Germany), 1977

John E. Taylor
Assistant Professor of Civil Engineering
B.S., Tulane, 1991; M.S., 1996; M.S., Swiss Federal Institute of Technology, 1997; Ph.D., Stanford, 2006

Rene B. Testa
Professor of Civil Engineering

Joseph F. Traub
Edwin Howard Armstrong Professor of Computer Science
B.S., College of the City of New York, 1954; M.S., Columbia, 1955; Ph.D., 1959

Yannis P. Tsividis
Batchelor Memorial Professor of Electrical Engineering
B.E., Minnesota, 1972; M.S., California (Berkeley), 1973; Ph.D., 1976

Latha Venkataraman
Assistant Professor of Applied Physics
B.S., Massachusetts Institute of Technology, 1993; M.S., Harvard, 1997; Ph.D., 1999

Gordana Vunjak-Novakovic
Professor of Biomedical Engineering
B.S., University of Belgrade, 1972; S.M., 1975; Ph.D., 1980

Wen I. Wang
Thayer Lindsley Professor of Electrical Engineering and Professor of Applied Physics
B.S., National Taiwan, 1975; M.E.E., Cornell, 1979; Ph.D., 1981

Xiaodong Wang
Associate Professor of Electrical Engineering
B.S., Shangha Jiaotong University, 1992; M.S., Purdue, 1995; Ph.D., Princeton, 1998

Michael I. Weinstein
Professor of Applied Mathematics
B.S., Union College, 1977; M.S., Courant Institute–NYU, 1979; Ph.D., 1982
Alan C. West
Samuel Ruben–Peter G. Viele Professor of Electrochemistry and Chemical Engineering
B.S., Case Western Reserve, 1985; Ph.D., California (Berkeley), 1989

Ward Whitt
Wai T. Chang Professor of Industrial Engineering and Operations Research
A.B., Dartmouth, 1964; Ph.D., Cornell, 1969

Chris H. Wiggins
Associate Professor of Applied Mathematics

Chee Wei Wong
Assistant Professor of Mechanical Engineering
B.S., California (Berkeley), 1999; M.S., Massachusetts Institute of Technology, 2001; Ph.D., 2003

Henryk Wozniakowski
Professor of Computer Science
M.S., Warsaw, 1969; Ph.D., 1972

Cheng-Shie Wuu
Associate Professor of Clinical Radiation Oncology (in Public Health, Environmental Health Sciences, and Applied Physics)
B.S., National Tsinghua University (Taiwan), 1979; M.S., 1982; Ph.D., Kansas, 1985

Junfeng Yang
Assistant Professor of Computer Science
B.S., Tsinghua University (Beijing), 2000; M.S., Stanford, 2002; Ph.D., 2007

Mihalis Yannakakis
Percy K. and Vida L. Hudson Professor of Computer Science
Dipl., National Technical University of Athens (Greece), 1975; M.S., Ph.D., Princeton, 1979

David D. W. Yao
Professor of Industrial Engineering and Operations Research
M.A.Sc., Toronto, 1981; Ph.D., 1983

Y. Lawrence Yao
Professor of Mechanical Engineering
B.E., Shanghai Jiao Tong University, 1982; M.S., Wisconsin (Madison), 1984; Ph.D., 1988

Tuncel M. Yegulalp
Professor of Mining

Yechiam Yemini
Professor of Computer Science
B.Sc., Hebrew (Jerusalem), 1972; M.Sc., 1974; Ph.D., California (Los Angeles), 1978

Charles A. Zukowski
Professor of Electrical Engineering
B.S., Massachusetts Institute of Technology, 1982; M.S., 1982; Ph.D., 1985

Gil Zussman
Assistant Professor of Electrical Engineering
B.S., Technion (Israel Institute of Technology), 1995; M.Sc., 1999; Ph.D., 2004

FACULTY MEMBERS-AT-LARGE

Mark Cano
Chairman, Department of Earth and Environmental Sciences

R. Glenn Hubbard
Dean of the Graduate School of Business

John Morgan
Chairman, Department of Mathematics

Henry C. Pinkham
Dean, Graduate School of Arts and Sciences

Austin E. Quigley
Dean, Columbia College

Michael Sheetz
Chairman, Department of Biological Sciences

James Valentini
Chairman, Department of Chemistry

Erick J. Weinberg
Chairman, Department of Physics

EMERITI AND RETIRED OFFICERS (NOT IN RESIDENCE)

Nathaniel Arbiter
Professor Emeritus of Mineral Engineering

Theodore R. Bashkow
Professor Emeritus of Computer Science

Daniel N. Beshers
Professor Emeritus of Metallurgy

Paul W. Brandt-Rauf
Professor Emeritus of Environmental Health Sciences and Earth and Environmental Engineering

Huk Yuk Cheh
Samuel Ruben–Peter G. Viele Professor Emeritus of Electrochemistry

Rene Chevray
Professor Emeritus of Mechanical Engineering

C. K. Chu
Fu Foundation Professor Emeritus of Applied Mathematics

Lawrence B. Cohen
Professor Emeritus of Industrial Engineering

Herbert Deresiewicz
Professor Emeritus of Mechanical Engineering

Cyrus Derman
Professor Emeritus of Operations Research

Frank L. DiMaggio
Robert A. W. and Christine S. Carleton Professor Emeritus of Civil Engineering

Atle Gjelsvik
Professor Emeritus of Civil Engineering

Fletcher H. Griffis
Professor Emeritus of Civil Engineering

Robert A. Gross
Percy K. and Vida L.W. Hudson Professor Emeritus of Applied Physics and Dean Emeritus

Colin C. Harris
Professor Emeritus of Mineral Engineering

Cyril M. Harris
Charles Batchelor Professor Emeritus of Electrical Engineering and Professor Emeritus of Architecture

Herbert H. Kellogg
Stanley-Thompson Professor Emeritus of Chemical Metallurgy

John T. F. Kuo
Maurice Ewing and J. Lamar Worzel Professor Emeritus of Geophysics

W. Michael Lai
Professor Emeritus of Mechanical Engineering

Leon Lidofsky
Professor Emeritus of Applied Physics and Nuclear Engineering
Eugene S. Machlin  
Henry Marion Howe Professor Emeritus of Metallurgy

Thomas C. Marshall  
Professor Emeritus of Applied Physics

Henry E. Meadows Jr.  
Professor Emeritus of Electrical Engineering

Arthur S. Nowick  
Henry Marion Howe Professor Emeritus of Metallurgy

Glenn K. Rightmire  
Associate in Mechanical Engineering

Enders Robinson  
Maurice Ewing and J. Lamar Worzel Professor Emeritus of Applied Geophysics

Mischa Schwartz  
Charles Batchelor Professor Emeritus of Electrical Engineering

Jordan L. Spencer  
Professor Emeritus of Chemical Engineering

Thomas E. Stern  
Dicker Professor Emeritus of Electrical Engineering

Robert D. Stoll  
Professor Emeritus of Civil Engineering

Malvin Carl Teich  
Professor Emeritus of Engineering Science

Nickolas J. Themelis  
Stanley-Thompson Professor Emeritus of Chemical Metallurgy (Earth and Environmental Engineering, Henry Krumb School of Mines)

Stephen H. Unger  
Professor Emeritus of Computer Science and of Electrical Engineering

Rimas Vaicaitis  
Renwick Professor Emeritus of Civil Engineering

Howard W. Vreeland  
Professor Emeritus of Graphics

Omar Wing  
Professor Emeritus of Electrical Engineering

Edward S. Yang  
Professor Emeritus of Electrical Engineering

Margaret Kelly  
Associate Director, Communications

Jack McGourty  
Associate Dean for Undergraduate Studies

Anne Mongillo  
Associate Director, Alumni Relations

Lindsay N. Montanari  
Alumni Relations Coordinator

Leslie Murphy  
Director of Development

Gerald A. Navratil  
Interim Dean

Anna Marie O’Neill  
Associate Dean

Fredrik C. Palm  
Assistant Dean for Faculty Development and Diversity

Elaine Ragland  
Executive Assistant to the Dean

Tiffany M. Simon  
Assistant Dean for Graduate Student Services
This section contains a description of the curriculum of each department in the School, along with information regarding undergraduate and graduate degree requirements, elective courses, and suggestions about courses and programs in related fields. All courses are listed, whether or not they are being offered during the current year; if a course is not being given, that is indicated. Included as well are courses cross-listed with other departments and undergraduate divisions within the University.

**DESIGNATORS**

Each course is preceded by a four-letter designator, which indicates the department or departments presenting the course.

<table>
<thead>
<tr>
<th>Course Designator</th>
<th>Department/Subject</th>
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<tbody>
<tr>
<td>AHIS</td>
<td>Art History</td>
</tr>
<tr>
<td>AMCS</td>
<td>Applied Mathematics/Computer Science</td>
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<td>AMST</td>
<td>American Studies</td>
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<td>APAM</td>
<td>Applied Physics/Applied Mathematics</td>
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<td>APBM</td>
<td>Applied Physics/Biomedical Engineering</td>
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<td>APMA</td>
<td>Applied Mathematics</td>
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<td>APPH</td>
<td>Applied Physics</td>
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<td>ARCH</td>
<td>Architecture</td>
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<td>ASCE</td>
<td>Asian Civilizations–East Asian</td>
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<td>ASCM</td>
<td>Asian Civilizations–Middle East</td>
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<td>BIOC</td>
<td>Biology and Chemistry</td>
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<td>BIOL</td>
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<td>BIST</td>
<td>Biostatistics</td>
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<td>BMCH</td>
<td>Biomedical Engineering/Chemical Engineering</td>
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<td>BMEB</td>
<td>Biomedical Engineering/Electrical Engineering/Biology</td>
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<td>BMEE</td>
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<td>BUSI</td>
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<td>CBMF</td>
<td>Computer Science/Biomedical Engineering/Medical Informatics</td>
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<td>CHAP</td>
<td>Chemical Engineering/Applied Physics and Applied Math</td>
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<td>CHCB</td>
<td>Chemistry/Biology/Computer Science</td>
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<td>CHEE</td>
<td>Chemical Engineering/Earth and Environmental Engineering</td>
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<td>Course Code</td>
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<tr>
<td>MEBM</td>
<td>Mechanical Engineering/ Biomedical Engineering</td>
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<tr>
<td>MECE</td>
<td>Mechanical Engineering</td>
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<tr>
<td>MSAE</td>
<td>Materials Science and Engineering/ Solid-State Science and Engineering</td>
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<tr>
<td>MSIE</td>
<td>Management Science/Industrial Engineering and Operations Research</td>
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<td>Science</td>
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<td>Statistics/Industrial Engineering and Operations Research</td>
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<tr>
<td>VIAR</td>
<td>Visual Arts</td>
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</table>

**HOW COURSES ARE NUMBERED**

The course number that follows each designator consists of a capital letter followed by four digits. The **capital letter** indicates the University division or affiliate offering the course:

- B: Business
- C: Columbia College
- E: Engineering and Applied Science
- G: Graduate School of Arts and Sciences
- P: Mailman School of Public Health
- S: Summer Session
- U: International and Public Affairs
- V: Interschool course with Barnard
- W: Interfaculty course
- Z: American Language Program

The **first digit** indicates the level of the course, as follows:

- 0: Course that cannot be credited toward any degree
- 1: Undergraduate course
- 2: Undergraduate course, intermediate
- 3: Undergraduate course, advanced
- 4: Graduate course that is open to qualified undergraduates
- 5: Graduate course
- 6: Graduate course
- 8: Graduate course, advanced
- 9: Graduate research course or seminar

An **x** following the course number means that the course meets in the fall semester; a **y** indicates the spring semester.

**DIRECTORY OF CLASSES**

Room assignments and course changes for all courses are available online at [www.columbia.edu/cu/bulletin/uwb](http://www.columbia.edu/cu/bulletin/uwb).

The School reserves the right to withdraw or modify the courses of instruction or to change the instructors at any time.
The Department of Applied Physics and Applied Mathematics includes undergraduate and graduate studies in the fields of applied physics, applied mathematics, and materials science and engineering. The graduate program in applied physics includes plasma physics and controlled fusion; solid-state physics; optical and laser physics; medical physics; atmospheric, oceanic, and earth physics; and applied mathematics. The graduate programs in materials science and engineering are described on pages 165.

**Current Research Activities in Applied Physics and Applied Mathematics**

**Plasma physics and fusion energy.** In experimental plasma physics, research is being conducted on (1) equilibrium, stability, and transport in fusion plasmas: high-beta tokamaks, spherical tokamaks, and levitated dipoles; (2) magnetospheric physics: trapped particle instabilities and stochastic particle motion; (3) confinement of toroidal nonneutral plasmas; (4) plasma source operation and heating techniques; and (5) the development of new plasma measurement techniques. The results from our fusion science experiments are used as a basis for collaboration with large national and international experiments. For example, our recent demonstration of active feedback control of high temperature plasma...
instability is guiding research on NSTX at the Princeton Plasma Physics Laboratory, on the DIII-D tokamak at General Atomic, and for the design of the next generation burning plasma experiment, ITER. In theoretical plasma physics, research is conducted in the fluid theory of plasma equilibrium and stability, active control of MHD instabilities, the kinetic theory of transport, and the development of techniques based on the theory of general coordinates and dynamical systems. The work is applied to magnetic fusion, non-neutral and space plasmas.

Optical and laser physics. Active areas of research include inelastic light scattering in nanomaterials, the free-electron laser, accelerators, optical diagnostics of film processing, new laser systems, non-linear optics, ultrafast optoelectronics, photonic switching, optical physics of surfaces, laser-induced crystallization, and photon integrated circuits.

Solid-state physics. Research in solid-state physics covers nanoscience and nanoparticles, electronic transport and inelastic light scattering in low-dimensional correlated electron systems, fractional quantum Hall effect, heterostructure physics and applications, molecular beam epitaxy, grain boundaries and interfaces, nucleation in thin films, and surface physics. Research opportunities also exist within the interdisciplinary NSF Materials Research Science and Engineering Center, which focuses on complex films composed of nanocrystals, and the NSF Nanoscale Science and Engineering Center, which focuses on electron transport in molecular nanostructures.

Applied mathematics. Current research encompasses analytical and numerical analysis of deterministic and stochastic partial differential equations, large-scale scientific computation, fluid dynamics, dynamical systems and chaos, as well as applications to various fields of physics and biology. The applications to physics include condensed-matter physics, plasma physics, nonlinear optics, medical imaging, and the earth sciences, notably atmospheric, oceanic, and climate science, and solid earth geophysics (see below). The applications to biology include cellular biophysics, machine learning, and functional genomics, including collaborations with Columbia’s Center for Computational Biology and Bioinformatics (C2B2), the Center for Computational Learning Systems (CCLS), the NIH-funded Center for Multiscale Analysis of Genetic and Cellular Networks (MAGNet), and the NIH-funded NanoMedicine Center for Mechanical Biology. Extensive collaboration exist within the national climate research centers (the Geophysical Fluid Dynamics Laboratory and the National Center for Atmospheric Research) and with national laboratories of the U.S. Department of Energy, custodians of the nation’s most powerful supercomputers.

Atmospheric, oceanic, and earth physics. Current research focuses on the dynamics of the atmosphere and the ocean, climate modeling, cloud physics, radiation transfer, remote sensing, geo-physical/geological fluid dynamics, geochemistry. The department engages in ongoing research and instruction with the NASA Goddard Institute for Space Studies and the Lamont-Doherty Earth Observatory. Five faculty members share appointments with the Department of Earth and Environmental Sciences.

In addition to the faculty and graduate students, many other individuals, including a full-time research faculty, faculty and students from other departments, and an active flow of visiting scientists, participate in these projects.

Laboratory Facilities in Applied Physics and Applied Mathematics

The Plasma Physics Laboratory, founded in 1961, is one of the leading university laboratories for the study of plasma physics in the United States. There are four experimental facilities. The Columbia High-Beta Tokamak (HBT-EP) supports the national program to develop controlled fusion energy. It utilizes high voltage, pulsed power systems, and laser and magnetic diagnostics to study the properties of high-beta plasmas and the use of feedback stabilization to increase the achievable beta. A collaborative program with the Princeton Plasma Physics Laboratory and the DIII-D tokamak group at General Atomic is studying the properties of high-beta plasmas in order to maximize fusion power production in these large, neutral beam-heated tokamaks and spherical tori. The plasma physics group and MIT have jointly constructed the Levitated Dipole Experiment (LDX), a large plasma
Currently using supercomputing facilities at the National Center for Atmospheric Research; the San Diego Supercomputer Center; the National Energy Research Supercomputer Center in Berkeley, California; the National Leadership Class Facility at Oak Ridge, Tennessee; the IBM SUR cluster at Brookhaven National Laboratory in Upton, New York; and others.

Facilities, and research opportunities, also exist within the interdepartmental Materials Research Science and Engineering Center, which focuses on complex films composed of nanoparticles.

Current Research Activities and Laboratory Facilities in Materials Science and Engineering

See page 166.

UNDERGRADUATE PROGRAMS

The Department of Applied Physics and Applied Mathematics offers three undergraduate programs: applied physics, applied mathematics, and materials science and engineering. The materials science and engineering program is described on pages 166–167.

The applied physics and applied mathematics programs provide an excellent preparation for graduate study or for careers in which mathematical and technical sophistication are important. Using the large number of electives in these programs, students can tailor their programs to fit their personal and career interests. By focusing their technical electives, students can obtain a strong base of knowledge in a specialized area. In addition to formal minors, some areas of specialization that are available are described on pages 61–62. All technical electives are normally at the 3000 level or above.

UNDERGRADUATE PROGRAM IN APPLIED PHYSICS

The applied physics program stresses the basic physics that underlies most developments in engineering and the mathematical tools that are important to both physicists and engineers. Since the advances in most branches of technology lead to rapid changes in state-of-the-art techniques, the applied physics program provides the student with a broad base of fundamental science and mathematics while retaining the opportunity for specialization through technical electives.

The applied physics curriculum offers students the skills, experience, and preparation necessary for several career options, including opportunities to minor in economics and to take business-related courses. In recent years, applied physics graduates have entered graduate programs in many areas of applied physics or physics, enrolled in medical school, or been employed in various technical or financial areas immediately after receiving the B.S. degree.

Several areas of applied physics are represented by active research programs in the department for graduate instruction. These include fusion and space plasma physics, optical and laser physics, and condensed matter physics. Undergraduate students can receive course credit for research or an independent project with a faculty member. Opportunities also exist for undergraduate students in the applied physics program to participate in this research through part-time employment during the academic year and full-time employment during the summer, either at Columbia or as part of the NSF REU program nationwide. Practical research experience is a valuable supplement to the formal course of instruction. Applied physics students participate in an informal undergraduate seminar to study current and practical problems in applied physics, and obtain hands-on experience in at least two advanced laboratory courses.

Majors are introduced to two areas of application of applied physics (AP) by a course in each of two areas. Approved areas and courses are:

**DYNAMICAL SYSTEMS**

APMA E4101 or PHYS G4003

**OPTICAL OR LASER PHYSICS:**

APPH E4110 or E4112

**NUCLEAR SCIENCE:**

APPH E4010

**PLASMA PHYSICS:**

APPH E4301

**PHYSICS OF FLUIDS:**

APPH E4200

**CONDENSED MATTER PHYSICS:**

PHYS G4018

**BIOPHYSICAL MODELING:**

APMA E4400

In addition to these courses, courses listed in the Specialty Areas in Applied Physics can be used to satisfy this requirement with preapproval of the applied physics adviser.

All students must take 30 points of electives in the third and fourth years, of which 17 points must be technical courses approved by the adviser. The 17 points include 2 points of an advanced laboratory in addition to APPH E4018. Technical electives must be at the 3000 level or above unless prior
approval is obtained from the department. A number of approved technical electives are listed in the section on specialty areas following. The remaining points of electives are intended primarily as an opportunity to complete the four-year, 27-point nontechnical requirement, but any type of course work can satisfy them.

UNDERGRADUATE PROGRAM IN APPLIED MATHEMATICS
The applied mathematics program is flexible and intensive. A student must take the required courses listed below, or prove equivalent standing, and then may elect the other courses from mathematics, computer science, physics, Earth and environmental sciences, biophysics, economics, business and finance, or other application fields. Each student tailors his or her own program in close collaboration with an adviser. He or she must also register for the applied mathematics seminar during both the junior and senior years. During the junior year, the student attends the seminar lectures for 1 point; during the senior year, he or she attends the seminar lectures as well as tutorial problem sessions for 4 points.

While it is common for students in the program to go on to graduate school, many graduating seniors will find employment directly in industry, government, education, or other fields.

Of the 33 points of elective content in the third and fourth years, at least 21 points of technical courses approved by the adviser must be taken. The remaining points of electives are intended primarily as an opportunity to complete the four-year, 27-point nontechnical requirement, but any type of course work can satisfy them.

UNDERGRADUATE DOUBLE MAJOR IN APPLIED PHYSICS AND APPLIED MATHEMATICS
Students satisfy all requirements for both majors, except for the seminar requirements. They are required to take both senior seminars, APMA E4903 and APPH E4903 (taking one in the junior year and one in the senior year, due to timing conflicts), but not the junior seminars, APPH E4901 and APPH E4901. A single course may be used to fulfill a requirement in both majors. Students must maintain a GPA at or above 3.75, and must graduate with at least 143 points, 15 above the regular 128-point requirement. These extra 15 points should be technical electives appropriate for one or both majors.

To apply, a student first obtains the approval of both the general undergraduate AP adviser and the general undergraduate AM adviser, and then the approval of the Dean.

SPECIALTY AREAS IN APPLIED PHYSICS AND APPLIED MATHEMATICS
Both applied physics and applied mathematics students can focus their technical electives and develop a strong base of knowledge in a specialty area. There is no requirement to focus electives, so students may take as many or as few of the recommended courses in a specialty area as is appropriate to their schedules and interests. Some specialties are given below, but this is not an exclusive list and others can be worked out in coordination with the student’s adviser. The courses that are often taken, or in some cases need to be taken, in the junior year are denoted with a “J.”

Technical Electives
• Applications of Physics
  Courses that will give a student a broad background in applications of physics are:

  - MSAE E3103x: Elements of materials science (J)
  - ELEN E3000x: Introduction to circuits, systems, and electronics (J)
  - APPH E4010x: Introduction to nuclear science
  - APPH E4110x: Modern optics
  - APPH E4112y: Laser physics
  - APPH E4200x: Physics of fluids
  - APPH E4301y: Introduction to plasma physics
  - PHYS G4018y: Introduction to dynamical systems

• Earth and Atmospheric Sciences
  The Earth sciences provide a wide range of problems of interest to physicists and mathematicians ranging from the dynamics of the Earth’s climate to earthquake physics to dynamics of Earth’s deep interior. The Lamont-Doherty Earth Observatory, which is part of Columbia University, provides enormous resources for students interested in this area.

  A. ATMOSPHERE, OCEANS AND CLIMATE

  - APHP E4200x: Physics of fluids
  - APHP E4210y: Geophysical fluid dynamics
  - EESC W4008y: Introduction to atmospheric science
  - ESC W4295x: Introduction to physical oceanography
  - EES W4930y: Earth’s oceans and atmosphere

  B. SOLID EARTH GEOPHYSICS

  - APHP E4200x: Physics of fluids
  - EESC W4941y: Principles of geophysics
  - EESC W4001x: Advanced general geology
  - EESC W4113x: Introduction to mineralogy
  - EESC W4701y: Introduction to igneous petrology
  - EESC W4950x: Mathematical methods in the Earth sciences

  (See also courses listed under Scientific Computation and Computer Science, page 60)

• Basic Physics and Astrophysics
  Fundamental physics and astrophysics can be emphasized. Not only is astrophysics providing a deeper understanding of the universe, but it is also testing the fundamental principles of physics.

  - PHYS W3002y: From quarks to the cosmos: applications of modern physics
  - ASTR C3601x: General relativity, black holes, and cosmology (J)
  - ASTR C3602y: Physical cosmology and extragalactic astronomy (J)
  - APMA E4101x: Introduction to dynamical systems
  - ASTR G4001y: Astrophysics, I

• Business and Finance
  The knowledge of physics and mathematics that is gained in the applied physics and applied mathematics programs is a strong base for a career in business or finance.

  A. ECONOMICS

  - ECON W3211x,y: Intermediate microeconomics (J)
  - ECON W3213x,y: Intermediate macroeconomics (J)
on mathematics, such as physics. This view no longer coincides with reality. Researchers from biology as well as from the physical sciences, applied mathematics, and computer science are rapidly building a quantitative base of biological knowledge. Students can acquire a strong base of knowledge in quantitative biology, both biophysics and computational biology, while completing the applied physics or applied mathematics programs.

PROFESSIONAL-LEVEL COURSE:
APPH E1300y: Physics of the human body

RECOMMENDED:
Biol C2005x-C2006y: Introduction to molecular and cellular biology, I & II
APMA E4400y: Introduction to biophysical modeling

OTHER TECHNICAL ELECTIVES (A COURSE IN AT LEAST TWO AREAS RECOMMENDED):
A. BIOLOGICAL MATERIALS

CHEN E4650x: Biopolymers
BIOL W4070x: The biology and physics of single molecules

B. BIOMECHANICS

BMEN E3320y: Fluid biomechanics (J)
BMEN E4300y: Solid biomechanics (J)

C. GENOMICS AND BIOINFORMATICS

ECBM E3060x: Introduction to genomic information science and technology (J)
BIOL W3037y: Whole genome bioinformatics (J)
CBMF W4761y: Computational genomics

D. NEUROBIOLOGY

BIOL W3004x: Cellular and molecular neurobiology (J)
BIOL W3005y: Systems neurobiology (J)
ELEN G4011x: Computational neuroscience

The second term of biology will be considered a technical elective if a student has credits from at least two of the recommended courses in quantitative biology at the 3000 level or above.

• Scientific Computation and Computer Science
Advanced computation has become a core tool in science, engineering, and mathematics and provides challenges for both physicists and mathematicians. Courses that build on both practical and theoretical aspects of computing and computation include:

APMA E4300y: Introduction to numerical methods
APMA E4301: Numerical methods for partial differential equations
AMCS E4302: Parallel scientific computing
MATH V3020x: Number theory and cryptography (J)
COMS W3137y: Data structures and algorithms (or COMS W3139y: Honors data structures and algorithms) (J)
COMS W3157x:y: Advanced programming (J)
COMS W3203x:y: Discrete mathematics: introduction to combinatorics and graph theory (J)
COMS W4203y: Graph theory
COMS W4701x:y: Artificial intelligence
COMS W4771y: Machine learning

• Solid-State Physics
Much of modern technology is based on solid-state physics, the study of solids and liquids. Courses that will build a strong base for a career in this area are:

MSAE E3103x: Elements of material science (J)
ELEN E3106x: Solid-state devices and materials (J)
MSAE E4206x: Electronic and magnetic properties of solids
PHYS G4018y: Solid-state physics
MSAE E4207y: Lattice vibrations and crystal defects
PHYS W3083y: Electronics laboratory (J)

UNDERGRADUATE PROGRAM IN MATERIALS SCIENCE AND ENGINEERING
See page 166.

GRADUATE PROGRAMS
Financial aid is available for students pursuing a doctorate. Fellowships, scholarships, teaching assistantships, and graduate research assistantships are awarded on a competitive basis. The Aptitude Test of the Graduate Record Examination is required of candidates for admission to the department and for financial aid; the Advanced Tests are recommended.

M.S. Program in Applied Physics
The program of study leading to the degree of Master of Science, while emphasizing continued work in basic physics, permits many options in several
applied physics specialties. The program may be considered simply as additional education in areas beyond the bachelor’s level, or as preparatory to doctoral studies in the applied physics fields of plasma physics, laser physics, solid-state physics, and applied mathematics. Specific course requirements for the master’s degree are determined in consultation with the program adviser.

M.S. Program in Applied Physics / Concentration in Applied Mathematics

This 30-point program leads to a professional M.S. degree. Students must complete five core courses and five electives. The core courses provide a student with a foundation in the fundamentals of applied mathematics and contribute 15 points of graduate credit toward the degree. Students must complete five of the following seven courses:

- APMA E4001: Principles of applied mathematics
- APMA E4001: Introduction to nonlinear dynamical systems
- APMA E4150: Applied functional analysis
- APMA E4200: Partial differential equations
- APMA E4204: Functions of a complex variable
- APMA E4300: Introduction to numerical methods
- APMA E6301: Analytic methods for partial differential equations

A student must select five elective courses from those listed below (or any of those not used to satisfy the core requirements from the list above) for a total of 15 points of graduate credit. Additional courses not listed below can be applied toward the elective requirements, subject to the approval of the faculty adviser. Computer science elective courses include:

- CSOR W4231: Analysis of algorithms
- COMS W4236: Introduction to computational complexity
- COMS W4241: Numerical algorithms and complexity
- COMS W4252: Computational learning theory

Industrial engineering/operations research elective courses include:

- IEOR E4003: Industrial economics
- IEOR E4004: Introduction to operations research: deterministic models
- IEOR E4007: Optimization: models and methods
- IEOR E4106: Introduction to operations research: stochastic models
- SIEO W4150: Introduction to probability and statistics

IEOR E4403: Advanced engineering and corporate economics
IEOR E4407: Game theoretic models of operations
SIEO W4606: Elementary stochastic processes
IEOR E4700: Introduction to financial engineering

Other elective courses include:

- MECE E4100: Mechanics of fluids
- MSAE E4215: Mechanical behavior of structural materials
- EEME E6601: Introduction to control theory

M.S. Program in Medical Physics

This 35-point program in medical physics leads to the M.S. degree. It is administered by faculty from the School of Engineering and Applied Science in collaboration with faculty from the College of Physicians and Surgeons and the Mailman School of Public Health. It provides preparation toward certification by the American Board of Radiology. The program consists of a core curriculum of medical physics courses, anatomy, lab, seminar, and two practicums. A passing grade on a comprehensive examination is required for graduation. This examination, on subjects covered in the curriculum, is taken at the end of the program of study. Specific course requirements are APPT E4010, E4710/11, E4500, E4550, E4600, and APBM E4650, and, in the Mailman School of Public Health, EHSC P6310, P9319, P9330, and P9335. Some opportunities for specialization exist.

Certificate of Professional Achievement in Medical Physics

A graduate program of instruction leading to the Certificate of Professional Achievement and requiring satisfactory completion of at least four of the following courses:

- APPT E4500: Health physics
- APPT E4600: Dosimetry
- EHSC P6330: Radiation science
- EHSC P9319: Clinical nuclear medicine physics
- EHSC P9330: Diagnostic radiological physics
- EHSC P9335: Radiation therapy physics
- APBM E4650: Anatomy for physicists and engineers

This is a two-semester nondegree program. Students are admitted to the department as special certificate-track students.

Ph.D. and Eng.Sc.D. Programs

After completing the M.S. program in applied physics, doctoral students specialize in one applied physics field. Some programs have specific course requirements for the doctorate; elective courses are determined in consultation with the program adviser. Successful completion of an approved 30-point program of study is required in addition to successful completion of a written qualifying examination taken after two semesters of graduate study. An oral examination, taken within one year after the written qualifying examination, and a thesis proposal examination, taken within two years after the written qualifying examination, are required of all doctoral candidates.

M.S., Eng.Sc.D., and Ph.D. Programs in Materials Science and Engineering

See page 167.

Applied Mathematics

This academic program, for students registered in the Department of Applied Physics and Applied Mathematics, emphasizes applied mathematics research in nonlinear dynamics, fluid mechanics, and scientific computation with a current emphasis on geophysical, biophysical, and plasma physics applications.

Applied mathematics deals with the use of mathematical concepts and techniques in various fields of science and engineering. Historically, mathematics was first applied with great success in astronomy and mechanics. Then it developed into a main tool of physics, other physical sciences, and engineering. It is now important in the biological, geological, and social sciences. With the coming of age of the computer, applied mathematics has transcended its traditional style and now assumes an even greater importance and a new vitality.

Compared with the pure mathematician, the applied mathematician is more interested in problems coming from other fields. Compared with the engineer and the physical scientist, he or she is more concerned with the formulation of problems and the nature of solutions. Compared with the computer scientist, he or she is more concerned with the accuracy of approximations and the interpretation of results. Needless to say, even in this age of specialization, the
work of mathematicians, scientists, and engineers frequently overlaps. Applied mathematics, by its very nature, has occupied a central position in this interplay and has remained a field of fascination and excitement for active minds.

Materials Science and Engineering Program
See page 165.

Plasma Physics
This academic program is designed to emphasize preparation for professional careers in plasma research, controlled fusion, and space research. This includes basic training in relevant areas of applied physics, with emphasis on plasma physics and related areas leading to extensive experimental and theoretical research in the Columbia University Plasma Physics Laboratory. Specific course requirements for the plasma physics doctoral program are APPH E4018, E4200, E4300, E6101, E6102, and E9142 or E9143, or equivalents taken at another university.

Optical and Laser Physics
This academic program involves a basic training in relevant areas of applied physics with emphasis in quantum mechanics, quantum electronics, and related areas of specialization. Some active areas of research in which the student may concentrate are laser modification of surfaces, the free-electron laser, optical diagnostics of film processing, inelastic light scattering in nano-materials, nonlinear optics, ultrafast optoelectronics photonic switching, optical physics of surfaces, and photon integrated circuits. Specific course requirements for the optical and laser physics doctoral program are set with the academic adviser.

Solid-State Physics
This academic program encompasses the study of the electrical, optical, magnetic, thermal, high-pressure, and ultrafast dynamical properties of solids, with an aim to understanding them in terms of the atomic and electronic structure. The program emphasizes the formation, processing, and properties of thin films, low-dimensional structures—such as one- and two-dimensional electron gases, nanocrystals, and surfaces of electronic and optoelectronic interest. Facilities include a microelectronics laboratory, high-pressure diamond anvil cells, a molecular beam epitaxy machine, ultrahigh vacuum systems, lasers, equip-
COURSES IN APPLIED PHYSICS

APPH E1300y Physics of the human body
Lect. 3. 3 pts. Professor Herman.
Prerequisites: PHYS C1201 or C1401, and Calculus I; corequisites: PHYS C1202 or C1402, and Calculus II. This introductory course analyzes the human body from the basic principles of physics. Topics to be covered include the energy balance in the body, the mechanics of motion, fluid dynamics of the heart and circulation, vibrations in speaking and hearing, muscle mechanics, gas exchange and transport in the lungs, vision, structural properties and limits, electrical properties and the development and sensing of magnetic fields, and the basics of equilibrium and regulatory control. In each case, a simple model of the body organ, property, or function will be derived and then applied. The course is approved as a SEAS technical elective.

APAM E1601y Introduction to computational mathematics and physics
Introduction to computational methods in applied mathematics and physics. Students develop solutions in a small number of subject areas to acquire experience in the practical use of computers to solve mathematics and physics problems. Topics change from year to year. Examples include elementary interpolation of functions, solution of nonlinear algebraic equations, curve-fitting and hypothesis testing, wave propagation, fluid motion, gravitational and celestial mechanics, and chaotic dynamics. The basic requirement for this course is one year of college-level calculus and physics; programming experience is not required.

APPH E3300y Applied electromagnetism
Lect: 3.3 pts. Professor Venkataraman.
Prerequisites: APMA E3102. Vector analysis, electrostatic fields, Laplace’s equation, multipole expansions, electric fields in matter: dielectrics, magnetostatic fields, magnetic materials, and superconductors. Applications of electromagnetism to devices and research areas in applied physics.

APPH E3900x and y Undergraduate research in applied physics
0 to 4 pts. Members of the faculty.
This course may be repeated for credit, but no more than 6 points of this course may be counted toward the satisfaction of the B.S. degree requirements. Candidates for the B.S. degree may conduct an investigation in applied physics or carry out a special project under the supervision of the staff. Credit for the course is contingent upon the submission of an acceptable thesis or final report.

APAM E3105x Programming methods for scientists and engineers
Introduction to modern techniques of computer programming for the numerical solutions to familiarity with basic and advanced concepts of modern numerical programming and acquire practical experience solving representative problems in math and physics.

APPH E3300y Applied electromagnetism
Lect: 3. 3 pts. Professor Venkataraman.
Prerequisites: APMA E3102. Vector analysis, electrostatic fields, Laplace’s equation, multipole expansions, electric fields in matter: dielectrics, magnetostatic fields, magnetic materials, and superconductors. Applications of electromagnetism to devices and research areas in applied physics.

APPH E3900x and y Undergraduate research in applied physics
0 to 4 pts. Members of the faculty.
This course may be repeated for credit, but no more than 6 points of this course may be counted toward the satisfaction of the B.S. degree requirements. Candidates for the B.S. degree may conduct an investigation in applied physics or carry out a special project under the supervision of the staff. Credit for the course is contingent upon the submission of an acceptable thesis or final report.

APAM E3105x Programming methods for scientists and engineers
Introduction to modern techniques of computer programming for the numerical solutions to familiarity with basic and advanced concepts of modern numerical programming and acquire practical experience solving representative problems in math and physics.

APPH E3300y Applied electromagnetism
Lect: 3. 3 pts. Professor Venkataraman.
Prerequisites: APMA E3102. Vector analysis, electrostatic fields, Laplace’s equation, multipole expansions, electric fields in matter: dielectrics, magnetostatic fields, magnetic materials, and superconductors. Applications of electromagnetism to devices and research areas in applied physics.

APPH E3900x and y Undergraduate research in applied physics
0 to 4 pts. Members of the faculty.
This course may be repeated for credit, but no more than 6 points of this course may be counted toward the satisfaction of the B.S. degree requirements. Candidates for the B.S. degree may conduct an investigation in applied physics or carry out a special project under the supervision of the staff. Credit for the course is contingent upon the submission of an acceptable thesis or final report.
### APPLIED MATHEMATICS PROGRAM: FIRST AND SECOND YEARS

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<th>SEMESTER II</th>
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<td>(three tracks, choose one)</td>
<td>C1601 (3.5)</td>
<td>C1602 (3.5)</td>
<td>C2601 (3.5)</td>
<td>Lab C2699 (3)</td>
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<td>C2801 (4.5)</td>
<td>Lab W3081 (2)</td>
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<tr>
<td><strong>CHEMISTRY/BIOLOGY</strong></td>
<td>CHEM C1403 (3), or higher or BIOL W2001 (4) or BIOL C2005 (4), or higher</td>
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<td>(choose one course)</td>
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<tr>
<td><strong>ENGLISH COMPOSITION</strong></td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
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<tr>
<td>(three tracks, choose one)</td>
<td>Z1003 (0)</td>
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<td>Z2006 (0)</td>
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<td><strong>REQUIRED Nontechnical Electives</strong></td>
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<td></td>
<td>HUMA C1001, COCI C1101 or Major Cultures (3–4)</td>
<td>HUMA C1002, COCI C1102 or Major Cultures (3–4)</td>
<td>ECON W1105 (4) and W1155 recitation (0)</td>
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<td>HUMA W1121 or W1123 (3)</td>
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<td><strong>REQUIRED TECH ELECTIVES</strong></td>
<td>(3) Student’s choice, see list of first- and second-year technical electives (professional-level courses; see page 12)</td>
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<tr>
<td><strong>COMPUTER SCIENCE</strong></td>
<td>A computer language of the student’s choice at the 1000 level or higher</td>
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<tr>
<td><strong>PHYSICAL EDUCATION</strong></td>
<td>C1001 (1)</td>
<td>C1002 (1)</td>
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<tr>
<td><strong>GATEWAY LAB</strong></td>
<td>E1102 (4) either semester</td>
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1. Students with advanced standing may start the calculus sequence at a higher level.

2. Applied mathematics majors should satisfy their ODE requirement with the Mathematics Department (ordinarily MATH E1210). Students who take APMA E2101 prior to declaring their major in applied physics may use this course to satisfy their ODE requirement.

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**APPH E4010x** Introduction to nuclear science  
Lect: 3.3 pts. Professor Ostrow.  
Prerequisites: MATH V1202 and E1210 and PHYS C1403 or their equivalents. This introductory course is for individuals with an interest in medical physics and other branches of radiation science. Topics covered include basic concepts, nuclear models, semi-empirical mass formula, interaction of radiation with matter, nuclear detectors, nuclear structure and instability, radioactive decay processes and radiation, particle accelerators, and fission and fusion processes and technologies.

**APPH E4018y** Applied physics laboratory  
Lab: 4.2 pts. Professor Mauel.  
Prerequisite: ELEN E3401 or the equivalent. Typical experiments are in the areas of plasma physics, microwaves, laser applications, optical spectroscopy physics, and superconductivity.

**APPH E4090x** Nanotechnology  
Lect: 3.3 pts. Offered in alternate years.  
Prerequisites: APPH E3100 and MSAE E3103 or their equivalents with the instructor’s permission. The science and engineering of creating materials, functional structures, and devices on the nanometer scale. Carbon nanotubes, nanocrystals, quantum dots, size-dependent properties, self-assembly, nanostructured materials. Devices and applications, nanofabrication. Molecular engineering, bionanotechnology. Imaging and manipulating at the atomic scale. Nanotechnology in society and industry.

**APPH E4100x** Quantum physics of matter  
Lect: 3.3 pts. Professor Venkataraman.  
Prerequisite: APPH E3100. Corequisite: APMA E3102 or the equivalent. Basic theory of quantum mechanics, well and barrier problems, the harmonic oscillator, angular momentum identical particles, quantum statistics, perturbation theory and applications to the quantum physics of atoms, molecules, and solids.

**APPH E4110x** Modern optics  
Lect: 3.3 pts. Offered in alternate years.  
Instructor to be announced.  
Prerequisite: APPH E3300 or the equivalent. Ray optics, matrix formulation, wave effects, interference, Gaussian beams, Fourier optics, diffraction, image formation, electromagnetic theory of light, polarization and crystal optics, coherence, guided wave and fiber optics, optical elements, photons, selected topics in nonlinear optics.

**APPH E4112y** Laser physics  
Recommended but not required: APPH E3100 and E3300 or their equivalents. Optical resonators, interaction of radiation and atomic systems, theory of laser oscillation, specific laser systems, rate processes, modulation, detection, harmonic generation, and applications.
**APPLIED MATHEMATICS: THIRD AND FOURTH YEARS**

<table>
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<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
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<tr>
<td>APMA E3101 (3)&lt;sup&gt;1&lt;/sup&gt; Linear algebra (Applied math, I)</td>
<td>APMA E3102 (3)&lt;sup&gt;1&lt;/sup&gt; Partial differential equations (Applied math, II)</td>
<td>MATH W4061 (3) Modern analysis</td>
<td>APMA E3900 (3)&lt;sup&gt;3&lt;/sup&gt; Research</td>
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<tr>
<td>APMA E4901 (0) Seminar</td>
<td>Course from Group A or Group B&lt;sup&gt;2&lt;/sup&gt;</td>
<td>APMA E4300 (3) Introduction to numerical methods (Computational math, I)</td>
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<tr>
<td>Course from Group A or Group B&lt;sup&gt;2&lt;/sup&gt;</td>
<td>APMA E4204 (3)&lt;sup&gt;1&lt;/sup&gt; Complex variables</td>
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**REQUIRED COURSES**

**MAJOR-RELATED**

Includes courses designated: MATH, APMA, STAT, and COMS

**OTHER TECHNICAL**

3 points 3 points 3 points 3 or 6 points

Other approved science, engineering, economics, or finance courses

**NONTECH**

3 points 3 points 3 points 3 or 6 points

**TOTAL POINTS**

15 15 16 15

1 MATH V2010 may be substituted for APMA E3101; APMA E4200 or MATH V3028 may be substituted for APMA E3102; MATH W4007 may be substituted for APMA E4204.


3 With an adviser’s permission, an approved technical elective may be substituted.

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**CHAP E4120x Statistical mechanics**

*Lect: 3. 3 pts. Professor O’Shaughnessy.*

Prerequisite: CHEN E3210 or equivalent thermodynamics course, or the instructor’s permission. Fundamental principles and underlying assumptions of statistical mechanics. Boltzmann’s entropy hypothesis and its restatement in terms of Helmholtz and Gibbs free energies and for open systems. Correlation times and lengths. Exploration of phase space and observation timescale. Correlation functions, Fermi-Dirac and Bose-Einstein statistics. Fluctuation-response theory. Applications to ideal gases, interfaces, liquid crystals, microemulsions and other complex fluids, polymers, Coulomb gas, interactions between charged polymers and charged interfaces, ordering transitions.

**APPH E4200x Physics of fluids**

*Lect: 3. 3 pts. Professor Mauel.*

Prerequisites: APMA E3102 or the equivalent, PHYS C1401 or C1601 or the equivalent. An introduction to the physical behavior of fluids for science and engineering students. Derivation of basic equations of fluid dynamics: conservation of mass, momentum, and energy. Dimensional analysis. Vorticity. Laminar boundary layers. Potential flow. Effects of compressibility, stratification, and rotation. Waves on a free surface; shallow water equations. Turbulence.

**APPH E4210y Geophysical fluid dynamics**

*Lect: 3. 3 pts. Professor Polvani.*

Prerequisites: APMA E3101 and E3102 or the equivalents and APPH E4200 or the equivalent, or permission of the instructor. Fundamental concepts in the dynamics of rotating, stratified flows. Geostrophic and hydrostatic balances, potential vorticity, f and beta plane approximations, gravity and Rossby waves, geostrophic adjustment and quasigeostrophy, baroclinic and barotropic instabilities, Sverdrup balance, boundary currents, Ekman layers.

**APPH E4300x Applied electrodynamics**

*Lect: 3. 3 pts. Professor Boozer.*

Prerequisites: PHYS W3003 and APPH E3300 or their equivalents. Overview of properties and interactions of static electric and magnetic fields. Study of phenomena of time-dependent electric and magnetic fields, including induction, waves, and radiation as well as special relativity. Applications are emphasized.

**APPH E4301y Introduction to plasma physics**

*Lect: 3. 3 pts. Professor Maurer.*

Prerequisite: APPH E3300. Definition of a plasma. Plasmas in laboratories and nature, plasma production. Motion of charged particles in electric and magnetic fields, adiabatic invariants. Heuristic treatment of collisions, diffusion, trans-
port, and resistivity. Plasma as a conducting fluid. Electrostatic and magnetostatic equilibria of plasmas. Waves in cold plasmas. Demonstration of laboratory plasma behavior, measurement of plasma properties. Illustrative problems in fusion, space, and nonneutral or beam plasmas.

APPH E4500y Health physics
Lect: 3. 3 pts. E. A. Christman.
Prerequisite: APPH E4101. This course presents the fundamental principles of health physics: the physics of dose deposition, radiation dosimetry, elementary shielding and radiation protection devices, description and proper use (calibration and maintenance) of health physics instrumentation, and the regulatory and administrative requirements of health physics programs.

APPH E4550y Medical physics seminar
Lect: 1. 0 pts. J. C. Arbo.
Required for all graduate students in the medical physics program. Practicing professionals and faculty in the field present overviews of selected topics in medical physics.

APPH E4600x Fundamentals of radiological physics and radiation dosimetry
Lect: 2. 2 pts. J. A. Meli.
Co- or prerequisite: APPH E4101. Basic radiation physics: radioactive decay, radiation producing devices, characteristics of the different types of radiation (photons, charged and uncharged particles) and mechanisms of their interactions with materials. Essentials of the determination, by measurement and calculation, of absorbed doses from ionizing radiation sources used in medical physics (clinical) situations and for health physics purposes.

APPH E4650y Anatomy for physicists and engineers
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: BMEN E4002 or the instructor’s permission. A systemic approach to the study of the human body from a medical imaging point of view: skeletal, respiratory, cardiovascular, digestive, and urinary systems, breast and women’s issues, head and neck, and central nervous system. Lectures are reinforced by examples from clinical two- and three-dimensional and functional imaging (CT, MRI, PET, SPECT, U/S, etc.).

APPH E4710x-E4711y Radiation instrumentation and measurement laboratory, I and II
Lect: 1. Lab: 4. 3 pts. J. C. Arbo.
Co- or prerequisite: APPH E4010. Lab fee: $35 each term. E4710: theory and use of a, b, g, and x radiation detectors and associated electronics for counting, energy spectroscopy, and dosimetry; radiation safety; counting statistics and error propagation; mechanisms of radiation emission and interaction. E4711: additional detector types; applications and systems including coincidence, low-level, and liquid scintillation counting; neutron activation; diagnostic x-ray and fluoroscopy; planar gamma camera imaging; image analysis.

APPH E4901x Seminar: problems in applied physics
Lect: 1. 1 pt. Instructor to be announced.
Required for, and can be taken only by, all applied physics majors and minors in the junior year. Discussion of specific and self-contained problems in areas such as applied electrodynamics, physics of solids, and plasma physics. Topics change yearly.

APPH E4903x Seminar: problems in applied physics
Lect: 1. Tutorial: 1. 2 pts. Instructor to be announced.
Required for, and can be taken only by, all applied physics majors in the senior year. Discussion of specific and self-contained problems in areas such as applied electrodynamics, physics of solids, and plasma physics. Formal presentation of a term paper required. Topics change yearly.

APPH E4990x and y Special topics in applied physics
Lect: 3. 1–3 pts. Instructors to be announced.
Prerequisite for, and can be taken only by, all applied physics majors in the senior year. Discussion of specific and self-contained problems in areas such as applied electrodynamics, physics of solids, and plasma physics. Formal presentation of a term paper required. Topics change yearly.

APPH E6081x Solid state physics, I
Lect: 3. 3 pts. Professor Pinczuk.
Prerequisite: APPH E3100 or the equivalent. Knowledge of statistical physics on the level of MSAE E3111 or PHYS G4023 is strongly recommended. Crystal structure, reciprocal lattices, classification of solids, lattice dynamics, anharmonic effects in crystals, classical electron models of metals, electron band structure, and low-dimensional electron systems.

APPH E6082y Solid state physics, II
Lect: 3. 3 pts. Professor Aleiner.
Prerequisite: APPH E6081 or the instructor’s permission. Semiclassical and quantum mechanical electron dynamics and conduction, dielectric properties of insulators, semiconductors, defects, magnetism, superconductivity, low-dimensional structures, and soft matter.

APPH E6091x Plasma physics, I
Lect: 3. 3 points. Professor Pedersen.

APPH E6102y Plasma physics, II
Lect: 3. 3 pts. Professor Boozer.

APPH E6110x Laser interactions with matter
Prerequisites: APPH E4112 or the equivalent, and quantum mechanics. Principles and applications of laser-matter coupling, non-linear optics, three- and four-wave mixing, harmonic generation, laser processing of surfaces, laser probing of materials, spontaneous and stimulated light scattering, saturation spectroscopy, multiphoton excitation, laser isotope separation, transient optical effects.

APAM E6650x and y, and S6650 Research project
1 to 6 pts. Members of the faculty. This course may be repeated for credit. A special investigation of a problem in nuclear engineering, medical physics, applied mathematics, applied physics, and/or plasma physics consisting of independent work on the part of the student and embodied in a formal report.

APPH E9142x-E9143ySelected topics in applied physics.
These courses may be repeated for credit. Selected topics in applied physics.

APAM E9301x and y, and S9301 Doctoral research
0 to 15 pts. Members of the faculty. Prerequisite: the qualifying examination for the doctorate. Required of doctoral candidates.

APAM E9800x and y, and S9800 Doctoral research instruction
3, 6, 9, or 12 pts. Members of the faculty. A candidate for the Eng.Sc.D. degree must register for 12 points of doctoral research instruction. Registration for APAM E9800 may not be used to satisfy the minimum residence requirement for the degree.
APAM E9900x and y, and S9900

Doctoral dissertation
0 pts. Members of the faculty.
A candidate for the doctorate may be required to register for this course every term after the course work has been completed, and until the dissertation has been accepted.

COURSES IN APPLIED MATHEMATICS

APMA E2101y Introduction to applied mathematics
Lect: 3. 3 pts. Professor Keyes.
Prerequisite: Calculus III. A unified, single-semester introduction to differential equations and linear algebra with emphases on (1) elementary analytical and numerical technique and (2) discovering the analogs on the continuous and discrete sides of the mathematics of linear operators: superposition, diagonalization, fundamental solutions. Concepts are illustrated with applications using the language of engineering, the natural sciences, and the social sciences. Students execute scripts in Mathematica and Matlab (or the like) to illustrate and visualize course concepts (programming not required).

APMA E3101x Linear algebra
Lect: 3. 3 pts. Professor Spiegelman.

APMA E3102y Partial differential equations
Lect: 3. 3 pts. Professor Bal.
Prerequisite: MATH E1210 or the equivalent. Introduction to partial differential equations; integral theorems of vector calculus. Partial differential equations of engineering in rectangular, cylindrical, and spherical coordinates. Separation of the variables. Characteristic-value problems. Bessel functions, Legendre polynomials, other orthogonal functions; their use in boundary value problems. Illustrative examples from the fields of electromagnetic theory, vibrations, heat flow, and fluid mechanics.

APMA E3900x and y Undergraduate research in applied mathematics
0 to 4 pts. Members of the faculty.
This course may be repeated for credit, but no more than 6 points may be counted toward the satisfaction of the B.S. degree requirements. Candidates for the B.S. degree may conduct an investigation in applied mathematics or carry out a special project under the supervision of the staff. Credit for the course is contingent upon the submission of an acceptable thesis or final report.

APMA E4001y Principles of applied mathematics
Lect: 3. 3 pts. Professor Schmitt.

APMA E4101x Introduction to dynamical systems
Lect: 3. 3 pts. Professor Weinstein.
Prerequisites: APMA E2101 (or MATH V1210) and APMA E3101 or their equivalents, or the instructor’s permission. An introduction to the analytic and geometric theory of dynamical systems; basic existence, uniqueness, and parameter dependence of solutions to ordinary differential equations; constant coefficient and parametrically forced systems; fundamental solutions; resonance; limit points, limit cycles, and classification of flows in the plane (Poincare-Bendixson Theory); conservative and dissipative systems; linear and nonlinear stability analysis of equilibria and periodic solutions; stable and unstable manifolds; bifurcations, e.g. Andronov-Hopf; sensitive dependence and chaotic dynamics; selected applications.

APMA E4150x Applied functional analysis
Lect: 3. 3 pts. Professor Courdurier.
Prerequisites: Advanced calculus and a course in basic analysis, or the instructor’s permission. Introduction to modern tools in functional analysis that are used in the analysis of deterministic and stochastic partial differential equations and in the analysis of numerical methods: metric and normed spaces, Banach space of continuous functions, measurable spaces, the contraction mapping theorem, Banach and Hilbert spaces, bounded linear operators on Hilbert spaces and their spectral decomposition, and time permitting distributions and Fourier transforms.

APMA E4200x Partial differential equations
Lect: 3. 3 pts. Instructor to be announced.

APMA E4204x Functions of a complex variable
Lect: 3. 3 pts. Professor Polvani.
Prerequisite: MATH V1202 or the equivalent. Complex numbers, functions of a complex variable, differentiation and integration in the complex plane. Analytic functions, Cauchy integral theorem and formula, Taylor and Laurent series, poles and residues, branch points, evaluation of contour integrals. Conformal mapping, Schwarz-Christoffel transformation. Applications to physical problems.

APMA E4300y Introduction to numerical methods
Lect: 3. 3 pts. Instructor to be announced.
Prerequisites: MATH V1201, MATH E1210, and APMA E3101, or their equivalents. Some programming experience and Matlab will be extremely useful. Introduction to fundamental algorithms and analysis of numerical methods commonly used by scientists, mathematicians, and engineers. This course is designed to give a fundamental understanding of the building blocks of scientific computing that will be used in more advanced courses in scientific computing and numerical methods for PDEs. Topics include numerical solutions of algebraic systems, linear least-squares, eigenvalue problems, solution of nonlinear systems, optimization, interpolation, numerical integration and differentiation, initial value problems, and boundary value problems for systems of ODEs. All programming exercises will be in Matlab.

APMA E4301x Numerical methods for partial differential equations
Lect: 3. 3 pts. Professor Keyes.
Prerequisites: APMA E4300 and E3102 or E4200, or their equivalents. Numerical solution of partial differential equations (PDE) arising in various physical fields of application. Finite difference, finite element, and spectral methods. Elementary finite volume methods for conservation laws. Time stepping, method of lines, and simultaneous space-time discretization. Direct and iterative methods for boundary-value problems. Applied numerical analysis of PDE, including sources of numerical error and notions of convergence and stability, to an extent necessary for successful numerical modeling of physical phenomena. Applications will include the Poisson equation, heat equation, wave equation, and nonlinear equations of fluid, solid, and gas dynamics. Homework assignments will involve substantial programming.

AMCS E4302x Parallel scientific computing
Prerequisites: APMA E3101, E3102, and E4300, or their equivalents. Corequisites: APMA E4301 and programming ability in C/C++ or FORTRAN90. An introduction to the concepts, the hardware and software environments, and selected algorithms and applications of parallel scientific computing.
with an emphasis on tightly coupled computations that are capable of scaling to thousands of processors. Includes high-level descriptions of motivating applications and low-level details of implementation, in order to expose the algorithmic kernels and the shifting balances of computation and communication between them. Students run demonstration codes provided on a Linux cluster. Modest programming assignments using MPI and PETSc culminate in an independent project leading to an in-class report.

APMA E4400y Introduction to biophysical modeling
Lect: 3. 3 pts. Professor Wiggins.
Prerequisites: PHYS W1401 or the equivalent and APMA E2101 or MATH E1210 or the equivalent. Introduction to physical and mathematical models of cellular and molecular biology. Physics at the cellular scale (viscosity, heat, diffusion, statistical mechanics). RNA transcription and regulation of genetic expression. Genetic and biochemical networks. Bioinform-atics as applied to reverse engineering of naturally occurring networks and forward engineering of synthetic biological networks. Mathematical and physical aspects of functional genomics.

APMA E4901x Seminar: problems in applied mathematics
Lect: 1. 0 pt. Professor Wiggins.
This course is required for, and can be taken only by, all applied mathematics majors in the junior year. Prerequisites or corequisites: APMA E4200 and E4204, or their equivalents. Introductory seminars on problems and techniques in applied mathematics. Typical topics are nonlinear dynamics, scientific computation, economics, operations research, etc.

APMA E4903x Seminar: problems in applied mathematics
Lect: 1. Tutorial: 2. 3 or 4 pts. Professor Wiggins.
This course is required for, and can be taken only by, all applied mathematics majors in the senior year. Prerequisites or corequisites: APMA E4200 and E4204, or their equivalents. For 4 pts. credit, term paper required. Examples of problem areas are nonlinear dynamics, asymptotics, approximation theory, numerical methods, etc. Approximately three problem areas are studied per term.

APMA E490x and y Special topics in applied mathematics
Lect: 3. 1–3 pts. Instructors to be announced.
Prerequisites: Advanced calculus and junior year applied mathematics, or their equivalents. This course may be repeated for credit. Topics and instructors from the Applied Mathematics Committee and the staff change from year to year. For advanced undergraduate students and graduate students in engineering, physical sciences, biological sciences, and other fields.

APMA E6209x Approximation theory
Prerequisite: MATH W4061 or some knowledge of modern analysis. Theory and application of approximate methods of analysis from the viewpoint of functional analysis. Approximate numerical and analytical treatment of linear and nonlinear algebraic, differential, and integral equations. Topics include function spaces, operators in normed and metric spaces, fixed point theorems and their applications.

APMA E6301y Analytic methods for partial differential equations
Lect: 2. 3 pts. Professor Weinstein.
Prerequisite: Advanced calculus, basic concepts in analysis, APMA E3101 and E4200 or their equivalents, or permission of the instructor. Introduction to analytic theory of PDEs of fundamental and applied science; wave (hyperbolic), Laplace and Poisson equations (elliptic), heat (parabolic) and Schrödinger (dispersive) equations; fundamental solutions, Green’s functions, weak/distribution solutions, maximum principle, energy estimates, variational methods, method of characteristics; elementary functional analysis and applications to PDEs; introduction to nonlinear PDEs, shocks; selected applications.

APMA E6302x Numerical analysis of partial differential equations
Lect: 2. 3 pts. Offered in alternate years. Professor Bal.
Prerequisite: APMA E3102 or E4200. Numerical analysis of initial and boundary value problems for partial differential equations. Convergence and stability of the finite difference method, the spectral method, the finite element method, and applications to elliptic, parabolic, and hyperbolic equations.

APMA E6304y Integral transforms
Prerequisites: APMA E4204 and MATH E1210, or their equivalents. Laplace, Fourier, Hankel, and Mellin transforms. Selection of suitable transform for a given partial differential equation boundary value problem. Operational properties of transforms. Inversion theorems. Approximate evaluation of inversion integrals for small and large values of parameter. Application to the solution of integral equations.

APMA E6901x and y Special topics in applied mathematics
Lect: 3. 3 pts. Instructors to be announced.
Prerequisites: advanced calculus and junior year applied mathematics, or their equivalents. This course may be repeated for credit. Topics and instructors from the Applied Mathematics Committee and the staff change from year to year. For students in engineering, physical sciences, biological sciences, and other fields.

APMA E8308y Asymptotic methods in applied mathematics

APMA E9101x-E9102y and S9101-S9102 Research
1 to 4 pts. Members of the faculty.
Prerequisite: the permission of the supervising faculty member. This course may be repeated. Advanced study in a special area.

APMA E9810x or y Mathematical earth sciences seminar
Lect. 1. 0 pts. Professor Polvani.
Current research in problems at the interface between applied mathematics and earth and environmental sciences.

APMA E9815x or y Geophysical fluid dynamics seminar
Lect. 3. 1 to 3 pts. Instructors to be announced.
Problem in the dynamics of geophysical fluid flows. May be repeated for up to 10 points of credit.

COURSES IN MATERIALS SCIENCE AND ENGINEERING
See page 169.
Biomedical engineering is an evolving discipline in engineering that draws on collaboration among engineers, physicians, and scientists to provide interdisciplinary insight into medical and biological problems. The field has developed its own knowledge base and principles that are the foundation for the academic programs designed by the Department of Biomedical Engineering at Columbia.

The programs in biomedical engineering at Columbia (B.S., M.S., Ph.D., Eng.Sc.D.) prepare students to apply engineering and applied science to problems in biology, medicine, and the understanding of living systems and their behavior, and to develop biomedical systems and devices. Modern engineering encompasses sophisticated approaches to measurement, data acquisition and analysis, simulation, and systems identification. These approaches are useful in the study of individual cells, organs, entire organisms, and populations of organisms. The increasing value of mathematical models in the analysis of living systems is an important sign of the success of contemporary activity. The programs offered in the Department of Biomedical Engineering seek to emphasize the confluence of basic engineering science and applied engineering with the physical and biological sciences, particularly in the areas of biomechanics, cell and tissue engineering, and biomedical imaging.

Programs in biomedical engineering are taught by its own faculty, members of other SEAS departments, and faculty from other University divisions who have strong interests and involvement in biomedical engineering. Several of the faculty hold joint appointments in Biomedical Engineering and other University departments.

Courses offered by the Department of Biomedical Engineering are complemented by courses offered by other departments in The Fu Foundation School of Engineering and Applied Science, and by many departments in the Faculty of Medicine, the School of Dentistry and Oral Surgery, and the Mailman School of Public Health, as well as the science departments within the...
Graduate School of Arts and Sciences. The availability of these courses in a university that contains a large medical center and enjoys a basic commitment to interdisciplinary research is important to the quality and strength of the program.

Educational programs at all levels are based on engineering and biological fundamentals. From this basis, the program branches into concentrations along three tracks: biomechanics, cell and tissue engineering, and biomedical imaging. The intrinsic breadth included within these tracks, plus a substantial elective content, prepare bachelor’s and master’s students to commence professional activity in any area of biomedical engineering or to go on to graduate school for further studies in related fields. The program also provides excellent preparation for the health sciences and the study of medicine. Graduates of the doctoral program are prepared for research activities at the highest level.

Areas of particular interest to Columbia faculty include orthopaedic and musculoskeletal biomechanics (Professors Ateshian, Guo, Huang, Jacobs, and Mow), cardiovascular biomechanics (Professor Homma), cellular and tissue engineering and artificial organs (Professors Hung, Kam, Leonard, H. H. Lu, Morrison, Sia, and Vunjak-Novakovic), auditory biophysics (Professor Olson), and biomedical imaging (Professors Brown, Hielscher, Hillman, DeLaPaz, Konofagou, Laine, Z. F. Lu, Pile-Spellman, Sajda, and Smith).

Facilities
The Department of Biomedical Engineering has been materially assisted by University funding and awards from the Whitaker Foundation. Extensive new facilities have recently been added to the department, including new teaching and research laboratories that provide students with unusual access to contemporary research equipment specially selected for its relevance to biomedical engineering. An undergraduate wet laboratory devoted to biomechanics and cell and tissue engineering has been added, together with a biomedical imaging and data processing laboratory. Each laboratory incorporates equipment normally reserved for advanced research and provides exceptional access to current practices in biomedical engineering and related sciences. Adjacent to the new laboratories is a lounge that serves as a meeting point for biomedical engineering undergraduate and graduate students.

Research facilities of the Biomedical Engineering faculty include the Liu Ping Laboratory for Functional Tissue Research (Professor Mow), the Hatch MRI Research Center (Professor Brown), the Heffner Biomedical Imaging Laboratory (Professor Laine), the Laboratory for Intelligent Imaging and Neural Computing (Professor Sajda), the Biophotonics and Optical Radiology Laboratory (Professor Brown), the Bone Bioengineering Laboratory (Professor Guo), the Cell and Tissue Engineering Laboratory (Professor Hung), the Biomaterial and Interface Tissue Engineering Laboratory (Professor Lu), the Neurotrauma and Repair Laboratory (Professor Morrison), the Ultrasound and Elasticity Imaging Laboratory (Professor Konofagou), the Microscale Biocomplexity Laboratory (Professor Kam), the Molecular and Microscale Bioengineering Laboratory (Professor Sia), the Laboratory for Functional Optical Imaging (Professor Hillman), the Cell and Molecular Biomechanics Laboratory (Professor Jacobs), and the Biomechanics and Mechanotransduction Laboratory (Professor Huang). These laboratories are supplemented with core facilities, including a tissue culture facility, a histology facility, a confocal microscope, an atomic force microscope, a 2-photon microscope, an epifluorescence microscope, a freezer room, a machine shop, and a specimen prep room.

UNDERGRADUATE PROGRAM
The objectives of the undergraduate program in biomedical engineering are as follows:

1. professional employment in areas such as the medical device industry, engineering consulting, biomechanics, biomedical imaging, and biotechnology;
2. graduate studies in biomedical engineering or related fields;
3. attendance at medical or dental school.

The undergraduate curriculum is designed to provide broad knowledge of the physical and engineering sciences and their application to the solution of biological and medical problems. Students are strongly encouraged to take courses in the order specified in the course tables on pages 74–77; implications of deviations should be discussed with a departmental adviser before registration. The first two years provide a strong grounding in the physical and chemical sciences, engineering fundamentals, and mathematics. This background is used to provide a unique physical approach to the study of biological systems. The last two years of the undergraduate program provide substantial exposure to modern biology and include courses in engineering and science that extend the work of the first two years. The program also offers three tracks to guide students in the choice of technical courses, while sharing a common core curriculum. The tracks are different from one another, and there is great breadth within each. These qualities allow the faculty to prepare students for activity in all contemporary areas of biomedical engineering. Graduates of the program are equipped for employment in the large industrial sector devoted to health care, which includes pharmaceuticals, medical devices, artificial organs, prosthetics and sensory aids, diagnostics, medical instrumentation, and medical imaging. Graduates also accept employment in oversight organizations (FDA, NIH, OSHA, and others), medical centers, and research institutes. They are prepared for graduate study in biomedical engineering and several related areas of engineering and the health sciences. Students in all three tracks of the program can meet entrance requirements for graduate training in the various allied health professions. No more than three additional courses are required in any of the tracks to satisfy entrance requirements for most U.S. medical schools.

All biomedical engineering students are expected to register for nontechnical electives, both those specifically required by the School of Engineering and Applied Science and those needed to meet the 27-point total of nontechnical electives required for graduation.
First and Second Years
As outlined in this bulletin, in the first two years all engineering students are expected to complete a sequence of courses in mathematics, physics, chemistry, computer science, engineering, English composition, and physical education, as well as nontechnical electives including the humanities. For most of these sequences, the students may choose from two or more tracks. If there is a question regarding the acceptability of a course as a nontechnical elective, please consult the approved listing of courses on page 11 or contact your advising dean for clarification.

Please see the charts in this section for a specific description of course requirements.

In addition, a professional-level engineering course is required. Students may select from a variety of offerings within SEAS. For students interested in biomedical engineering, we recommend taking BMEN E1001: Engineering in medicine or APPH E1300y: Physics of the human body in fulfillment of this requirement. Note that E1201: Introduction to electrical engineering is required and cannot be double counted to satisfy the professional-level course requirement. For the computer science requirement, students must take COMS W1005.

All students must take APMA E2101: Introduction to applied mathematics (ordinary differential equations and linear algebra) in addition to ELEN E1201: Introduction to electrical engineering and ENME E3105: Mechanics in their second year. For the classes of 2010 and later, students must also take STAT W1211: Introduction to statistics.

Third and Fourth Years
The biomedical engineering programs at Columbia at all levels are based on engineering and biological fundamentals. This is emphasized in our core requirements across all tracks. In the junior year, all students begin their biomedical engineering study with the two-semester Introduction to molecular and cellular biology, I and II (BIOL C2005-C2006), which gives students a comprehensive overview of modern biology from molecular to organ system levels. Parallel to these biology studies, all students take the two-semester Quantitative physiology, I and II sequence (BMEN E4001-E4002) which is taught by biomedical engineering faculty and emphasizes quantitative applications of engineering principles in understanding biological systems and phenomena from molecular to organ system levels. In the fields of biomedical engineering, experimental techniques and principles are fundamental skills that good biomedical engineers must master. Beginning in junior year, all students take the three-semester sequence Biomedical engineering laboratory, I-III (BMEN E3810, BMEN E3820, BMEN E3830). In this three-semester series, students learn through hands-on experience the principles and methods of biomedical engineering experimentation, measurement techniques, quantitative theories of biomedical engineering, data analysis, and independent design of biomedical engineering experiments, the scope of which cover a broad range of topics from all three tracks—biomechanics, cell and tissue engineering, and biomedical imaging. In the senior year, students take the required course Ethics for biomedical engineers (BMEN E4010), a SEAS non-technical elective that covers a wide range of ethical issues expected to confront biomedical engineering graduates as they enter biotechnology industry, research, or medical careers. Also in the senior year, students are required to take a two-semester capstone design course, Biomedical engineering design (BMEN E3910 and BMEN E3920), in which students work within a team to tackle an open-ended design project in biomedical engineering. The underlying philosophy of these core requirements is to provide our biomedical engineering students with a broad knowledge and understanding of topics in the field of biomedical engineering. Parallel to these studies in core courses, students take track-specific required courses to obtain an in-depth understanding of their chosen concentration. The curriculum of all three academic tracks—biomechanics, cell and tissue engineering, and biomedical imaging—prepares students who wish to pursue careers in medicine by satisfying most requirements in the premedical programs with no more than three additional courses. Some of these additional courses may also be counted as nontechnical electives. Please see the course tables for schedules leading to a bachelor’s degree in biomedical engineering.

It is strongly advised that students take required courses during the specific term that they are designated in the course tables, as conflicts may arise if courses are taken out of sequence.

Students are required to take up to 9 points (6 points in the imaging track) of “technical electives,” allowing for exploration of related technical topics. A technical elective is defined as a 3000-level or above course in SEAS or courses taught by the Departments of Biology, Chemistry, and Biochemistry.

Technical Elective Requirements
Students are required to take at least 48 points of engineering content coursework toward their degree. The 48-point requirement is a criterion established by the Accreditation Board for Engineering and Technology (ABET). Taking into consideration the number of engineering content points conferred by the required courses of the BME curriculum, a portion of technical electives must be clearly engineering in nature (Engineering Content Technical Electives), specifically as defined below:

1. technical elective courses with sufficient engineering content that can count toward the 48 units of engineering courses required for ABET accreditation:
   a. all 3000-level or higher courses in the Department of Biomedical Engineering, except: BMEN E4010, E4103, E4104, E4105, E4106, E4107 and E4108
   b. all 3000-level or higher courses in the Department of Mechanical Engineering, except: MECE E4007: Creative engineering and entrepreneurship
   c. all 3000-level or higher courses in the Department of Chemical Engineering, except: CHEN E4020: Safeguarding intellectual and business property
   d. all 3000-level or higher courses in the Department of Electrical Engineering, except: EEHS E3900:
History of telecommunications: from the telegraph to the Internet
e. all 3000-level or higher courses in the Civil Engineering and Engineering Mechanics program, except: CIEN E4128, E4129, E4130, E4131, E4132, E4133, E4134, E4135, and E4136
f. all 3000-level or higher courses in the Earth and Environmental Engineering program

2. Courses from the following departments are not allowed to count toward the required 48 units of engineering courses:
a. Department of Applied Physics and Applied Mathematics
b. Department of Computer Science
c. Department of Industrial Engineering and Operations Research
d. Program of Materials Science and Engineering

The cell and tissue engineering track requires 4.5 of the required 9 points of technical electives to be from engineering courses; in the biomechanics track, 2.5 points of technical electives must be from engineering courses; in the imaging track, the requirements satisfy the 48 points of engineering content. Once 48 points of engineering-content technical electives are satisfied, students may choose any course above the 3000 level in SEAS as well as biology, chemistry, and biochemistry as technical electives.

The accompanying charts describe the eight-semester degree program schedule of courses leading to the bachelor’s degree in biomedical engineering.

GRADUATE PROGRAM
The graduate curriculum in biomedical engineering employs the same three tracks that compose the undergraduate curriculum: biomechanics, cell and tissue engineering, and biomedical imaging. Initial graduate study in biomedical engineering is designed to expand the student’s undergraduate preparation in the direction of the track chosen. In addition, sufficient knowledge is acquired in other areas to facilitate broad appreciation of problems and effective collaboration with specialists from other scientific, medical, and engineering disciplines. The Department of Biomedical Engineering offers a graduate program leading to the Master of Science degree (M.S.), the Doctor of Philosophy degree (Ph.D.), and the Doctor of Engineering Science degree (Eng.Sc.D.). Applicants who have a Master of Science degree or equivalent may apply directly to the doctoral degree program. All applicants are expected to have earned the bachelor’s degree in engineering or in a cognate scientific program. The Graduate Record Examination (General Test only) is required of all applicants. Students whose bachelor’s degree was not earned in a country where English is the dominant spoken language are required to take the TOEFL test. M.S. degree candidates must reach level 8 on the English Placement Test (EPT) offered by Columbia’s American Language Program (ALP). Doctoral degree candidates must attain level 10 on the English Placement Test (EPT). The ALP examination must be taken at orientation upon arrival. It is strongly recommended the students enroll in an appropriate ALP course if they have not achieved the required proficiency after the first examination. In addition, the individual tracks require applicants to have taken the following foundation courses:

- **Biomechanics:** One year of biology and/or physiology, solid mechanics, statics and dynamics, fluid mechanics, and biochemistry with laboratory, ordinary differential equations.
- **Cell and Tissue Engineering:** One year of biology and/or physiology, one year of organic chemistry or biochemistry with laboratory, fluid mechanics, rate processes, ordinary differential equations.
- **Biomedical Imaging:** One year of biology and/or physiology and/or biochemistry. Linear algebra, ordinary differential equations, fourier analysis, digital signal processing.

Applicants lacking some of these courses may be considered for admission with stipulated deficiencies that must be satisfied in addition to the requirements of the degree program. The Fu Foundation School of Engineering and Applied Science does not admit students holding the bachelor’s degree directly to doctoral studies; admission is offered either to the M.S. program or to the M.S. program/dottoral track. The Department of Biomedical Engineering also admits students into the 4-2 program, which provides the opportunity for students holding a bachelor’s degree from certain physical sciences to receive the M.S. degree after two years of study at Columbia.

CURRICULUM AND EXAM REQUIREMENTS

Master’s Degree
In consultation with an appointed faculty adviser, M.S. students should select a program of 30 points of credits of graduate courses (4000 level or above) appropriate to their career goals. This program must include the course in computational modeling of physiological systems (BMEN E6003); two semesters of BMEN E9700: Biomedical engineering seminar; at least four other biomedical engineering courses; and at least one graduate-level mathematics course. Students with deficiency in physiology course work are required to take the BMEN E4001-E4002 sequence before taking BMEN E6003. Candidates must achieve a minimum grade-point average of 2.5. For students interested in obtaining research experience, up to 6 credits of research (BMEN E9100) may be applied toward the M.S. degree.

Doctoral Degree
Students admitted to the doctoral degree program should select courses to prepare for the doctoral qualifying examination and register for research rotations during the first two semesters of graduate study. To facilitate future collaboration with clinicians and biomedical scientists, students are encouraged to consider courses at the Health Sciences campus or in the Department of Biological Sciences.

Doctoral students must complete a program of 30 points of credits beyond the M.S. degree. The course in computational modeling of physiological systems (BMEN E6003) is required for the doctoral program. At least two graduate mathematics courses must be taken, which may include the mathematics course required for the M.S. degree.
Students must register for BMEN E9700: Biomedical engineering seminar and for research rotations during the first two semesters of graduate study. Remaining courses should be selected in consultation with the student's faculty adviser to prepare for the doctoral qualifying examination and to develop expertise in a clearly identified area of biomedical engineering. Up to 12 credits of research (BMEN E9500) may be applied toward doctoral degree course requirements.

All graduate students admitted to the doctoral degree program must satisfy the equivalent of three semesters’ experience in teaching. This may include supervising and assisting undergraduate students in laboratory experiments, grading, and preparing lecture materials to support the teaching mission of the department.

**Doctoral Qualifying Examination**

Doctoral candidates are required to pass a qualifying examination. This examination is given once a year, in January. It should be taken after the student has completed 30 points of graduate study. The qualifying examination consists of oral and written examinations. The oral examination consists of the analysis of assigned scientific papers, and the written examination covers three areas: applied mathematics, quantitative biology and physiology, and track-specific material. Students must declare a track (biomedical imaging, biomechanics, or cell and tissue engineering) at the time of registration for the qualifying examination. A minimum cumulative grade-point average of 3.2 is required to register for this examination.

**Doctoral Committee and Thesis**

Students who pass the qualifying examination choose a faculty member to serve as their research adviser. Each student is expected to submit a research proposal and present it to a thesis committee that consists of three to five faculty members. The committee considers the scope of the proposed research, its suitability for doctoral research and the appropriateness of the research plan. The committee may approve the proposal without reservation or may recommend modifications. In general, the student is expected to submit his/her research proposal after five semesters of doctoral studies. In accord with regulations of The Fu Foundation School of Engineering and Applied Science, each student is expected to submit a thesis and defend it before a committee of five faculty, two of whom hold primary appointments in another department. Every doctoral candidate is expected to have had accepted at least one full-length paper for publication in a peer-reviewed journal prior to recommendation for award of the degree.

**COURSES IN BIOMEDICAL ENGINEERING**

See also Applied Physics, Mechanical Engineering, Cell Biology, Microbiology, Chemical Engineering, Computer Science, Electrical Engineering, Biomedical Informatics, and Physiology.

**BMEN E1001x Engineering in medicine**


**BMEN E2300x or y Biomechanics track**

0 pts.
Rising juniors are required to register for this course in the spring of their sophomore year if they choose the biomechanics track.

**BMEN E2400x or y Biomedical imaging track**

0 pts.
Rising juniors are required to register for this course in the spring of their sophomore year if they choose the biomedical imaging track.

**BMEN E2500x or y Cell and tissue engineering track**

0 pts.
Rising juniors are required to register for this course in the spring of their sophomore year if they choose the cell and tissue engineering track.

**ECBM E3060x Introduction to genomic information science and technology**

Lect: 3.3 pts. Professor Anastassiou.

Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function, and manipulation of the biomolecular sequences of nucleic acids and proteins. The role of enzymes and gene regulatory elements in natural biological functions as well as in biotechnology and genetic engineering. Recombination and other macromolecular processes viewed as mathematical operations with simulation and visualization using simple computer programming. This course shares lectures with ECBM E4060, but the work requirements differ somewhat.

**BMEN E3150y The cell as a machine**

Lect: 3.3 pts. Professor Sheetz.
Prerequisite: Calculus IA or IS; corequisite: one semester of cell biology or biochemistry, and one semester of general physics or equivalent. Cells as complex micron-sized machines, basic physical aspects of cell components (diffusion, mechanics, electrostatics, hydrophobicity), energy transduction (motors, transporters, chaperones, synthesis complexes), basic cell functions. Biophysical principles, feedback controls for robust cell function, adaptation to environmental perturbations.

**BMEN E3320y Fluid biomechanics**

Lect: 3.3 pts. Professor Elad.
Prerequisite: MATH E1210. The principles of continuum mechanics as applied to biological fluid flows and transport. Course covers continuum formulations of basic conservation laws, Navier-Stokes equations, mechanics of arterial and venous blood flow, blood rheology and non-Newtonian properties, flow and transport in the microcirculation, oxygen diffusion, capillary filtration.

**BMCH E3500y Biological transport and rate processes**

Lect: 3.3 pts. Professor Leonard.

**BMEN E3610y Biomedical engineering laboratory, I**

Lab: 4.3 pts. Professor Sia.

Statistical analysis of experimental measurements: normal distribution, test of significance, linear regression, correlation, error analysis and propagation. MATLAB programming, EKG signal acquisition and processing, microscopy, cell counting and scaffold encapsulation, mechanical testing of linear and nonlinear biomaterials.

**BMEN E3820x Biomedical engineering laboratory, II**

Lab: 4.3 pts. Professor Guo.

Statistical analysis of experimental measurements: analysis of variance, power analysis. Circuit implementation of nerve conduction, alginate
bead formation, mechanical testing and optical strain analysis, galvanotaxis, image segmentation and analysis of cells, computer aided design, library resources.

**BMEN E3830y Biomedical engineering laboratory, III**
Lab: 4. 3 pts. Professor Konofagou.
Experimental design. Cell adhesion, membrane transport, osmosis, ultrasound, design of cell encapsulation and drug delivery system, respiratory impedance. Selected clinical demonstrations: body compositions, magnetic resonance imaging, echocardiography, blood pressure.

**BMEN E3910x-E3920y Biomedical engineering design, I and II**
A two-semester design sequence to be taken in the senior year. Elements of the design process, with specific applications to biomedical engineering: concept formulation, systems synthesis, design analysis, optimization, biocompatibility, impact on patient health and comfort, health care costs, regulatory issues, and medical ethics. Selection and execution of a project involving the design of an actual engineering device or system. Introduction to entrepreneurship, biomedical start-ups, and venture capital. Semester I: statistical analysis of detection/classification systems (receiver operating characteristic analysis, logistic regression), development of design prototype, need, approach, benefits and competition analysis. Semester II: spiral develop process and testing, iteration and refinement of the initial design/prototype and business plan development. A laboratory fee of $100 is collected each semester.

**BMEN E3998x or y, or z Projects in biomedical engineering**
Independent projects involving experimental, theoretical, computational, or engineering design work. May be repeated, but no more than 3 points may be counted toward degree requirements as engineering technical electives.

**BMEN E4000x or y Special topics**
Lect: 3. 3 pts. Instructor to be announced.
Additional current topics in biomedical engineering taught by regular or visiting faculty. The same subject matter is not usually considered in different years.

**BMEN E4001x Quantitative physiology, I:**
cells and molecules
Lect: 3. 3 pts. Professor Kam.
Prerequisites or corequisites: CHEM C3443 or the equivalent and BIOL C2005. Physiological
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<tr>
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<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
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<tr>
<td>REQUIRED COURSES:</td>
<td>BIOL C2005 (4)</td>
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<td>BMEN E3910 (4)</td>
<td>BMEN 3920 (4)</td>
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<td>ALL TRACKS</td>
<td>Molec. &amp; cell biol.</td>
<td>Molec. &amp; cell. biol.</td>
<td>BME design I</td>
<td>BME design II</td>
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<td>BMEN E4001 (3)</td>
<td>BMEN E4002 (3)</td>
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<td>Quantitative physiol. I</td>
<td>Quantitative physiol. II</td>
<td>BME laboratory II</td>
<td>BMEN laboratory III</td>
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<td>STAT W1211 (3)</td>
<td>BMEN E3810 (3)</td>
<td>BMEN laboratory I</td>
<td>BMEN E4010 (2)^4</td>
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<td>Intro. to statistics</td>
<td>BME laboratory I</td>
<td></td>
<td>Ethics for BMEs</td>
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<td>NONTECH ELECTIONS</td>
<td>0–3 points</td>
<td>3 points</td>
<td>0–3 points</td>
<td>3 points</td>
</tr>
<tr>
<td>CELL &amp; TISSUE ENG.1</td>
<td>BMEN E2500 (0)</td>
<td>BMCH E3500 (3)</td>
<td>BMEN E4501 (3)</td>
<td>BMEN E4502 (3)</td>
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<td>BMEN E4210 (4)</td>
<td>Biol. transport. proc.</td>
<td>Tissue eng. I</td>
<td>Tissue eng. II</td>
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<td>Thermo. biolog. sys.</td>
<td>or BMEN E3320 (3)</td>
<td>Technical elective (6)</td>
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<td></td>
<td>MSAE E3103 (3)</td>
<td>Fluid biomech.</td>
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<td>Elements of mat. sci.</td>
<td>Technical elective (3)</td>
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<td>BIOMECH.2</td>
<td>BMEN E2300 (0)</td>
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<td>Mech. of fluids</td>
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<td>Thermodynamics</td>
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<td>Technical elective (6)</td>
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<td>BIOMED. IMAGING3</td>
<td>BMEN E2400 (0)</td>
<td>BMEN E4420 (3)</td>
<td>ELEN E4810 (3)</td>
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<td>ELEN E3801 (3.5)</td>
<td>Biosig. proc. &amp; modeling</td>
<td>Dig. sig. processing</td>
<td>Ultrasound imaging</td>
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<td>Signals &amp; systems</td>
<td>Technical elective (3)</td>
<td>BMEN E4894 (3)</td>
<td>or BMEN E4898 (3)</td>
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<td>Biomed. imaging</td>
<td>Biophotonics</td>
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<td>BMEN E4430 (3)</td>
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<td></td>
<td>Principles of MRI</td>
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<td>Technical elective (3)</td>
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<td>TOTAL POINTS</td>
<td>16–17</td>
<td>19</td>
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<td>15</td>
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</table>

1 In the cell and tissue engineering track, of the 9 points of technical electives, at least 4.5 must be from engineering courses.

2 In the biomechanics track, of the 9 points of technical electives, at least 2.5 points must be from engineering courses.

3 In the imaging track, core requirements satisfy the 48 points of engineering content.

4 BMEN E4010: Ethics for biomedical engineers is a SEAS nontechnical course.

**BMEN E402y Quantitative physiology, II: organ systems**

**Lect:** 3 pts, Professor Morrison.

Prerequisites or corequisites: CHEM C3443; BIOL C2005, C2006. Students are introduced to a quantitative, engineering approach to cellular biology and mammalian physiology. Beginning with biological issues related to the cell, the course progresses to considerations of the major physiological systems of the human body (nervous, circulatory, respiratory, renal).
<table>
<thead>
<tr>
<th>BIOMEDICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS</th>
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<tr>
<td>CLASS OF 2012 AND LATER</td>
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<thead>
<tr>
<th>SEMESTER I</th>
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<th>SEMESTER III</th>
<th>SEMESTER IV</th>
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<tr>
<td><strong>MATHEMATICS</strong></td>
<td>MATH V1101 (3)</td>
<td>MATH V1102 (3)</td>
<td>MATH V1201 (3)</td>
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<td><strong>PHYSICS</strong> (three tracks, choose one)</td>
<td>C1401 (3)</td>
<td>C1402 (3)</td>
<td>C1403 (3)</td>
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<td>C1601 (3.5)</td>
<td>C1602 (3.5)</td>
<td>C2601 (3.5)</td>
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<td></td>
<td>C2801 (4.5)</td>
<td>C2802 (4.5)</td>
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<tr>
<td><strong>CHEMISTRY</strong> (three tracks, choose one)</td>
<td>C1403 (3.5)</td>
<td>C1404 (3.5)</td>
<td>C3443 (3.5)</td>
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<td>C3045 (3.5)</td>
<td>C3046 (3.5)</td>
<td>C2507 (3)</td>
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<td><strong>ENGLISH COMPOSITION</strong> (three tracks, choose one)</td>
<td>C1010 (3)</td>
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<td><strong>COMPUTER SCIENCE</strong></td>
<td>COMS W1005 (3) Matlab (in semester I or III)</td>
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<td><strong>PHYSICAL EDUCATION</strong></td>
<td>C1001 (1)</td>
<td>C1002 (1)</td>
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<td><strong>GATEWAY LAB</strong></td>
<td>E1102 (4) either semester</td>
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<tr>
<td><strong>NONTECHNICAL REQUIREMENTS</strong></td>
<td>HUMA W1121 (3) or W1123 (3)</td>
<td>HUMA C1001, C01C C1101, or Major Cultures (3–4)</td>
<td>HUMA C1002, C01C C1102, or Major Cultures (3–4)</td>
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<tr>
<td><strong>TECHNICAL REQUIREMENTS</strong></td>
<td>Professional-level course (except ELEN E1201) (either semester)</td>
<td>ELEN E1201 Intro. to EE (3.5)</td>
<td>APMA E2101 ODE &amp; lin. alg. (3)</td>
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<td>STAT W1211 (3) Intro to statistics (either semester)</td>
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</table>

**BMEN E4010y Ethics for biomedical engineers**  
*Lect: 2. 2 pts. Professor Loike.*  
Prerequisite: senior status in biomedical engineering or the instructor’s permission. Covers a wide range of ethical issues expected to confront graduates as they enter the biotechnology industry, research, or medical careers. Topics vary and incorporate guest speakers from Physicians and Surgeons, Columbia Law School, Columbia College, and local industry.

**BMEN E4103 Anatomy of the thorax and abdomen**  
*Lect: 2. 2 pts. Professor April.*  
Prerequisite: graduate standing in biomedical engineering. This course is designed for the biomedical engineering graduate student interested in acquiring in-depth knowledge of anatomy relevant to his/her doctoral research. Lectures and

Biological sciences:  
Biophysicsofcomputation, the Hodgkin-Huxley neuron, modeling and analysis of ion channels, basic dendritic integration. Integrate-and-fire and other spiking neuron models, stimulus representation and the neural code, time encoding and stimulus recovery, information representation with time encoding machines, fast algorithms for stimulus recovery, elements of spike processing and neural computation. Modeling synapses and synaptic transmission, synaptic plasticity and learning algorithms. Projects in Matlab.

**ECBM E4060x Introduction to genonomic information science and technology**  
*Lect: 3. 3 pts. Professor Anastassiou.*  
Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function, and manipulation of the biomolecular sequence of nucleic acids and proteins. The role of enzymes and gene regulatory elements in natural biological functions as well as in biotechnology and genetic engineering. Recombination and other macromolecular processes viewed as mathematical operations with simulation and visualization using simple computer programming. This course shares lectures with ECBM E3060, but the work requirements differ somewhat.
### Required Courses: All Tracks

**Semester V**
- BIOL C2005 (4)
- BMEN E3810 (3)
- BMEN E4001 (3)

**Semester VI**
- BIOL C2006 (4)
- BMEN E3820 (3)
- BMEN E4002 (3)

**Semester VII**
- BMEN E3910 (4)
- BMEN E3830 (3)
- BMEN E4002 (3)

**Semester VIII**
- BMEN 3920 (4)
- BMEN E4010 (2)

### NonTech Electives

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<th>Semester</th>
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### Cell & Tissue Eng.

**Semester V**
- BMEN E2500 (0)
- BMEN E4210 (4)
- MSAE E3103 (3)

**Semester VI**
- BMCH E3500 (3)
- BMEN E4501 (3)

**Semester VII**
- BMEN E4502 (3)

**Semester VIII**
- Technical elective (3)

### Biomech.

**Semester V**
- BIOMED IMAGING (3.5)
- BMEN E2300 (0)
- MECE E3100 (3)

**Semester VI**
- BMEN E3320 (3)
- BMEN E4311 (3)

**Semester VII**
- MECE E3301 (3)

**Semester VIII**
- Technical elective (3)

### Biomed. Imaging

**Semester V**
- BIOMED IMAGING (3.5)
- ELEN E3801 (3.5)

**Semester VI**
- BMEN E4420 (3)
- ELEN E4810 (3)

**Semester VII**
- BMEN E4894 (3)

**Semester VIII**
- Biophotonics Technical elective (3)

### Total Points

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1. In the cell and tissue engineering track, of the 9 points of technical electives, at least 4.5 must be from engineering courses.
2. In the biomechanics track, of the 9 points of technical electives, at least 2.5 points must be from engineering courses.
3. In the imaging track, core requirements satisfy the 48 points of engineering content.
4. BMEN E4010: Ethics for biomedical engineers is a SEAS nontechnical course.

**BMEN E4105x Anatomy of the extremities**

**Lect: 2. 2 pts. Professor April.**

Prerequisite: graduate standing in biomedical engineering. This course is designed for the biomedical engineering graduate student interested in acquiring in-depth knowledge of anatomy relevant to his/her doctoral research. Lectures and tutorial sessions may be taken with or without the associated laboratory (BMEN E4106).

**BMEN E4106x Anatomy laboratory: extremities**

**Lab: 2. 2 pts. Professor April.**

Prerequisite: graduate standing in biomedical engineering. Corequisite: BMEN E4105.

**BMEN E4107x Anatomy of the head and neck**

**Lect: 2. 2 pts. Professor April.**

Prerequisite: graduate standing in biomedical engineering. This course is designed for the bio-
medical engineering graduate student interested in acquiring in-depth knowledge of anatomy relevant to his/her doctoral research. Lectures and tutorial sessions may be taken with or without the associated laboratory (BMEN E4108).

BMEN E4108x Anatomy laboratory: head and neck
Lab: 2. 2 pts. Professor April.
Prerequisite: standing in biomedical engineering. Corequisite: BMEN E4107.

BMEN E4210x Thermodynamics of biological systems
Lect: 4. 4 pts. Professor Sia.
Prerequisites: CHEM C1404 and MATH V1202.
Corequisite: BIOL C2005 or the equivalent.
Introduction to the thermodynamics of biological systems, with a focus on connecting microscopic molecular properties to macroscopic states. Both classical and statistical thermodynamics will be applied to biological systems; phase equilibria, chemical reactions, and colligative properties.

BMEN E4300y Solid biomechanics
Lect: 3. 3 pts. Professor Mow.
Prerequisites: ENME-MECE E3105 and ENME E3113. This course introduces applications of continuum mechanics to the understanding of various biological tissue properties. The structure, function, and mechanical properties of various tissues in biological systems, such as blood vessels, muscle, skin, brain tissue, bone, tendon, cartilage, ligaments, etc., will be examined. The focus will be on the establishment of basic governing mechanical principles and constitutive relations for each tissue. Experimental determination of various tissue properties will be introduced and demonstrated. The important medical and clinical implications of tissue mechanical behavior will be emphasized.

BMEN E4301x Structure, mechanics, and adaptation of bone
Introduction to structure, physiology, and biomechanics of bone. Structure, function, and physiology of skeletal bones; linear elastic properties of cortical and trabecular bone; anisotropy and constitutive models of bone tissue; failure and damage mechanics of bone; bone adaptation and fracture healing; experimental determination of bone properties; and morphological analysis of bone microstructure.

BMEN E4305y Cardiac mechanics
Prerequisites: BMEN E3310 and E3320 or equivalents. Cardiac anatomy, passive myocardial constitutive properties, electrical activation, ventricular pump function, ventricular-vascular coupling, invasive and noninvasive measures of regional and global function, models for predicting ventricular wall stress. Alterations in muscle properties and ventricular function resulting from myocardial infarction, heart failure, and left ventricular assist.

BMEN E4340y Biomechanics of cells
Lect: 3. 3 pts. Professor Huang.
Prerequisites: BMEN E3310 and E3320 or equivalents. Survey of experiments and theoretical analyses of the mechanical behavior of individual living nonmuscle cells. Emphasis on quantitative analytic description using continuum mechanics and molecular level theory from the standpoint of statistical mechanics and mechanical models. Mechanics of erythrocytes, leukocytes, endothelial cells, and fibroblasts; models of aggregation, adhesion, locomotion, amoeba motility, cell division and morphogenesis; molecular level models of actin, myosin, microtubules, and intermediate filaments and relation to mechanical properties of cells and cytoskeleton. Alternative models of cytoskeletal mechanics, foam theory, tensegrity. Analysis of experimental techniques including micropipette studies, optical and magnetic cytometry, and nano-indentation.

BMEN E4400x Wavelet applications in biomedical image and signal processing
Lect: 3. 3 pts. Professor Laine.
Prerequisite: the instructor’s permission. An introduction to methods of wavelet analysis and processing techniques for the quantification of biomedical images and signals. Topics include frames and complete representations, multi-resolution algorithms for denoising and image restoration, multiscale texture segmentation and classification methods for computer-aided diagnosis.

BMEN E4410y Principles of ultrasound in medicine
Lect: 3. 3 pts. Professor Konofagou.
Prerequisite: Calculus, Fourier analysis. Physics of diagnostic ultrasound and principles of ultrasound imaging instrumentation. Propagation of plane waves in lossless media; ultrasound propagation through biological tissues; single-element and array transducer design; pulse-echo and Doppler ultrasound instrumentation, performance evaluation of ultrasound imaging systems using tissue-mimicking phantoms, ultrasound tissue characterization; ultrasound nonlinearity and bubble activity; harmonic imaging; acoustic output of ultrasound systems; biological effects of ultrasound.

BMEN E4420y Biomedical signal processing and signal modeling
Lect: 3. 3 pts. Professor Hielcher.
Prerequisites: APMA E3101 and ELEN E3202, or the instructor’s permission. Fundamental concepts of signal processing in linear systems and stochastic processes. Estimation, detection, and filtering methods applied to biomedical signals. Harmonic analysis, auto-regressive model, Wiener and matched filters, linear discriminants, and independent components. Methods are developed to answer concrete questions on specific data sets in modalities such as ECG, EEG, MEG, Ultrasound. Lectures accompanied by data analysis assignments using MATLAB.

BMEN E4430x Principles of magnetic resonance imaging
Lect: 3. 3 pts. Professor Brown.
Prerequisite: APMA E1201, PHYS C1403, or the instructor’s permission. Fundamental principles of Magnetic Resonance Imaging (MRI), including the underlying spin physics and mathematics of image formation with an emphasis on the application of MRI to neuroimaging, both anatomical and functional. The course will examine both theory and experimental design techniques.

BMEN E4440y Physiological control systems
Lect: 3. 3 pts. Professor Chbat.
Prerequisites: APMA E2101 and instructor’s permission or senior standing. Dynamic system modeling and simulation of cardiovascular, respiratory, and thermoregulatory systems. Open and closed physiological loops. Internal and external controllers: baroreflex, chemoreflex, and ventilator. Fundamentals of time and frequency domain analyses and stability. Emulation of normal and pathophysiological conditions. Clinical relevance and decision support. Matlab and SIMULINK programming environments will be utilized.

BMEN E4450y Dental and craniofacial tissue engineering
Lect: 3. 3 pts. Professor Mao.
Prerequisites: MSAE E3103, BMEN E4210, and BMEN E4501 or equivalent. Principles of dental and craniofacial bioengineering, periodontal tissue engineering; beyond guided tissue regeneration, craniofacial regeneration by stem cells and engineered scaffolds, biomaterials. Engineering approaches in tissue regeneration, bone biology and development; instructive cues for tissue engineers.

BMEN E4501x Tissue engineering, I: biomaterials and scaffold design
Lect: 3. 3 pts. Professor H. H. Lu.
Prerequisites: BIOL C2005-C2006, BMEN E4001-E4002. An introduction to the strategies and fundamental bioengineering design criteria in the development of biomaterials and tissue engineered grafts. Material structural-functional relationships, biocompatibility in terms of material and host responses. Through discussions, readings, and a group design project, students acquire an understanding of cell-material interactions and identify the parameters critical in the design and selection of biomaterials for biomedical applications.

BMEN E4502y Tissue engineering, II: biological tissue substitutes
Lect: 3. 3 pts. Professor Hung.
Prerequisites: BIOL C2005-C2006 and BMEN E4001-E4002. An introduction to the strategies and fundamental bioengineering design criteria
behind the development of cell-based tissue substitutes. Topics include biocompatibility, biological grafts, gene therapy-transfer, and bioreactors.

**BMEN E4540y Bioelectrochemistry**
Lect: 3 pts. Professor Pilla.
Prerequisite: elementary physical and organic chemistry. Application of electrochemical kinetics to interfacial processes occurring in biomedical systems. Basics of electrochemistry, electrochemical instrumentation, and relevant cell and electrophysiology reviewed. Applications to interpretation of excitable and nonexcitable membrane phenomena, with emphasis on heterogeneous mechanistic steps. Examples of therapeutic devices created as a result of bioelectrochemical studies.

**BMEN E4560y Dynamics of biological membranes**
Prerequisite: Undergraduate cell biology or BMEN E4001. The structure and dynamics of biological (cellular) membranes are discussed, with an emphasis on biophysical properties. Topics will include membrane composition, fluidity, lipid asymmetry, lipid-protein interactions, membrane turnover, membrane fusion, transport, lipid phase behavior. In the second half of the semester, students will lead discussions of recent journal articles.

**BMEN E4570x Science and engineering of body fluids**
Lect: 3 pts. Professor Matsuoka.
Prerequisites: General chemistry, organic chemistry, and basic calculus. Body fluids as a dilute solution of polyelectrolyte molecules in water. Study of physical behavior as affected by the presence of ions in surrounding environments. The physics of covalent, ionic, and hydrogen bonds are reviewed, in relation to the structure/properties of the body fluid. Selected physiological processes are examined in physical-chemical terms for polymers.

**BMEN E4601y Cellular electricity**
Bioelectricity of the cell membrane. Basis of cell resting voltage, voltage changes that lead to the action potential and electrical oscillations used in sensing systems. Laboratory includes building electronic circuits to measure capacitance of artificial membranes and ion pumping in frog skin.

**MEBM E4702x Advanced musculoskeletal biomechanics**
Lect: 2.5. Lab: 0.5. 3 pts. Not given in 2008–2009. Advanced analysis and modeling of the musculoskeletal system. Topics include advanced concepts of 3-D segmental kinematics, musculoskeletal dynamics, experimental measurements of joint kinematics and anatomy, modeling of muscles and locomotion, multibody joint modeling, introduction to musculoskeletal simulations.

**BMEN E4737x Computer control of medical instrumentation**
Prerequisite: basic knowledge of the C programming language. Acquisition and presentation of data for medical interpretation. Operating principles of medical devices: technology of medical sensors, algorithms for signal analysis, computer interfacing and programming, interface design. Laboratory assignments cover basic measurement technology, interfacing techniques, use of Labview software instrument interrogation and control, automated ECG analysis, ultrasonic measurements, image processing applied to x-ray images and CAT scans.

**BMEN E4738y Transduction and acquisition of biomedical data**
Lect: 2. Lab: 1. 3 pts. Not given in 2008–2009. Data transduction and acquisition systems used in biomedicine. Assembly of bio-transducers and the analog/digital circuitry for acquiring electrocardiogram, electromyogram, and blood pressure signals. Each small group will develop and construct a working data acquisition board, which will be interfaced with a signal generator to elucidate the dynamics of timing constraints during retrieval of bio-data.

**BMEN E4750y Sound and hearing**
Lect: 3 pts. Professor Leslie.
Prerequisites: general physics sequence and two semesters of calculus. Introductory acoustics, basics of waves and discrete mechanical systems. The mechanics of hearing—how sound is transmitted through the external and middle ear to the inner ear, and the mechanical processing of sound within the inner ear.

**CBMF W4761y Computational genomics**
Lect: 3. 3 pts. Professor Leslie.
Prerequisites: Working knowledge of at least one programming language, and some background in probability and statistics. Computational techniques for analyzing and understanding genomic data, including DNA, RNA, protein, and gene expression data. Basic concepts in molecular biology relevant to these analyses. Emphasis on techniques from artificial intelligence and machine learning. String-matching algorithms, dynamic programming, hidden Markov models, expectation-maximization, neural networks, clustering algorithms, support vector machines. Students with life sciences backgrounds who satisfy the prerequisites are encouraged to enroll.

**BMEN E4810y Artificial organs**

**BMEN E4894x Biomedical imaging**
Lect: 3. 3 pts. Professor Hielscher.
This course covers image formation, methods of analysis, and representation of digital images. Measures of qualitative performance in the context of clinical imaging. Algorithms fundamental to the construction of medical images via methods of computed tomography, magnetic resonance, and ultrasound. Algorithms and methods for the enhancement and quantification of specific features of clinical importance in each of these modalities.

**BMEN E4898y Biophotonics**
Prerequisite: BMEN E4894, PHYS C1403, or the instructor’s permission. This course provides a broad-based introduction into the field of biophotonics. Fundamental concepts of optical, thermal, and chemical aspects of the light-tissue interactions are presented. The application of these concepts for medical therapy and diagnostics is discussed. The course includes theoretical modeling of light-tissue interactions as well as optical medical instrument design and methods of clinical data interpretation.

**BMEN E6003x: Computational modeling of physiological systems**
Lect: 3. 3 pts. Professor Morrison.
Prerequisites: BMEN E4001–E4002 and APMA E4200 or the equivalent. Advanced modeling and quantitative analysis of selected molecular, cellular, or organ systems. Four systems are analyzed, with emphasis on biologic systems. Systems may include muscle contraction, respiratory physiology, nerve transmission, pharmacokinetics, circulatory control, auditory signal processing, cell signaling, molecular transport, excitable membranes, and statistical data analysis.

**EEBM E6020y Methods of computational neuroscience**
Lecture: 3. 4.5 pts. Instructor to be announced.
Prerequisite: BMEB W4011 or the instructor’s permission. Formal methods in computational neuroscience, including methods of signal processing, communications theory, information theory, systems and control, system identification and machine learning. Molecular models of transduction pathways. Robust adaptation and integral feedback. Stimulus representation and groups. Stochastic and dynamical systems models of spike generation. Neural diversity and ensemble encoding. Time encoding machines and neural codes. Stimulus recovery with time decoding mechanisms. MIMO models of neural computation. Synchronous plasticity and learning algorithms. Major project(s) in Matlab.

**BMEE E6030y Neural modeling and neuroengineering**
Prerequisites: APMA E3101, ELEN 3202, and ELEN-BMEN E4011, or the equivalent, or the instructor’s permission. Engineering perspective on the study of multiple levels of brain organization, from single neurons to cortical modules and systems. Mathematical models of spiking neu-
rons, neural dynamics, neural coding, and biologically based computational learning. Architectures and learning principles underlying both artificial and biological neural networks. Computational models of cortical processing, with an emphasis on the visual system. Applications of principles in neuroengineering; neural prostheses, neuromorphic systems, and biomimetics. Course will include a computer simulation laboratory.

BMEN E6301y Modeling of biological tissues with finite elements
Lect: 3. 3 pts. Professor Guo.
Prerequisite: MECE E6422 or ENME E6315, or the equivalent. Structure-function relations and linear/ nonlinear constitutive models of biological tissues; anisotropic elasticity, viscoelasticity, porous media theories, mechano-electrochemical models, infinitesimal and large deformations. Emphasis on the application and implementation of constitutive models for biological tissues into existing finite-element software packages. Model generation from biomedical images by extraction of tissue geometry, inhomogeneity, and anisotropy. Element-by-element finite element solver for large-scale image-based models of trabecular bone. Implementation of tissue remodeling simulations in finite element models.

MEBM E6310x–E6311y Mixture theories for biological tissues, I and II
Prerequisites: MECE E6422 and APMA E4200 or the equivalent. Development of governing equations for mixtures with solid matrix, interstitial fluid, and ion constituents. Formulation of constitutive models for biological tissues. Linear and nonlinear models of fibrillar and viscoelastic porous matrices. Solutions to special problems, such as confined and unconfined compression, permeation, indentation and contact, and swelling experiments.

BMEN E6400y Analysis and quantification of medical images
Novel methods of mathematical analysis applied to problems in medical imaging. Design requirements for screening protocols, treatment therapies, and surgical planning. Sensitivity and specificity in screening mammography and chest radiographs, computer-aided diagnosis systems, surgical planning in orthopaedics, analysis of cardiac performance, functional magnetic resonance imaging, positron emission tomography, and echocardiography data.

BMEN E9100x or y, or s Master’s research
1 to 6 pts. Professors Anastassiou, Ateshian, Brown, Das, Guo, Hilscher, Hillman, Homma, Huang, Hung, Jacobs, Kam, Konofagou, Laine, Leonard, H. H. Lu, Mao, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic. Candidates for the M.S. degree and candidates for the M.S. degree leading to the doctoral degree may conduct an investigation of some problem in biomedical engineering culminating in a thesis describing the results of their work. No more than 6 points in this course may be counted for graduate credit, and this credit is contingent upon the submission of an acceptable term report.

BMEN E9500x or y, or s Doctoral research

BMEN E9700x or y, or s Biomedical engineering seminar
Sem: 1. 0 pts. Professor Sia.
All matriculated graduate students are required to attend the seminar as long as they are in residence. No degree credit is granted. The seminar is a principal medium of communication among those with biomedical engineering interests within the University. Guest speakers from other institutions, Columbia faculty, and students within the Department who are advanced in their studies frequently offer sessions.

BMEN E9800x or y, or s Doctoral research instruction
3, 6, 9, or 12 pts. Professors Anastassiou, Ateshian, Brown, Das, Guo, Hilscher, Hillman, Homma, Huang, Hung, Jacobs, Kam, Konofagou, Laine, Leonard, H. H. Lu, Mao, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic. A candidate for the doctorate in biomedical engineering is required to register for this course in every term after the student’s course work has been completed and until the dissertation has been accepted.

BMEN E9900x or y, or s Doctoral dissertation
Chemical engineering is a highly interdisciplinary field concerned with materials and processes at the heart of a broad range of technologies. Practicing chemical engineers are the experts in charge of the development and production of diverse products in traditional chemical industries as well as many emerging new technologies. The chemical engineer guides the passage of the product from the laboratory to the marketplace, from ideas and prototypes to functioning articles and processes, from theory to reality. This requires a remarkable depth and breadth of understanding of physical and chemical aspects of materials and their production.

The expertise of chemical engineers is essential to production, marketing, and application in such areas as pharmaceuticals, high-performance materials in the aerospace and automotive industries, biotechnologies, semiconductors in the electronics industry, paints and plastics, petroleum refining, synthetic fibers, artificial organs, biocompatible implants and prosthetics and numerous others. Increasingly, chemical engineers are involved in new technologies employing highly novel materials whose unusual response at the molecular level endows them with unique properties. Examples include environmental technologies, emerging biotechnologies of major medical importance employing DNA- or protein-based chemical sensors, controlled-release drugs, new agricultural products, and many others.

Driven by this diversity of applications, chemical engineering is perhaps the broadest of all engineering disciplines: chemistry, physics, mathematics, biology, and computing are all deeply involved. The research of the faculty of Columbia’s Chemical Engineering Department is correspondingly broad. Some of the areas under active investigation are the fundamental physics, chemistry, and engineering of polymers and other soft materials; the electrochemistry of fuel cells and other interfacial engineering phenomena; the bioengineering of artificial organs and immune cell activation; the engineering and biochemistry of sequencing the human genome; the chemistry and physics of surface-polymer interactions; the biophysics of cellular processes in living organisms; the physics of thin polymer films; the chemistry of smart polymer materials with environment-sensitive surfaces; biosensors with tissue engineering applications; the physics and chemistry of DNA-DNA hybridization and melting; the chemistry and physics of DNA microarrays with applications in gene expression and drug discovery; the physics and chemistry of nanoparticle-polymer composites with novel electronic and photonic properties. Many experimental techniques are employed, from neutron scattering to fluorescence microscopy, and the theoretical work involves both analytical mathematical physics and numerical computational analysis.

Students enrolling in the Ph.D. program will have the opportunity to conduct research in these and other areas. Students with degrees in chemical engi-
neering and other engineering disciplines, in chemistry, in physics, in biochemistry, and in other related disciplines are all natural participants in the Ph.D. program and are encouraged to apply. The Department of Chemical Engineering at Columbia is committed to a leadership role in research and education in frontier areas of research and technology where progress derives from the conjunction of many different traditional research disciplines. Increasingly, new technologies and fundamental research questions demand this type of interdisciplinary approach.

The undergraduate program provides a chemical engineering degree that is a passport to many careers in directly related industries as diverse as biochemical engineering, environmental management, and pharmaceuticals. The degree is also used by many students as a springboard from which to launch careers in medicine, law, management, banking and finance, politics, and so on. For those interested in the fundamentals, a career of research and teaching is a natural continuation of their undergraduate studies. Whichever path the student may choose after graduation, the program offers a deep understanding of the physical and chemical nature of things and provides an insight into an exploding variety of new technologies that are rapidly reshaping the society we live in.

Current Research Activities

Science and Engineering of Polymers and Soft Materials. Theoretical and experimental studies of novel or important macromolecules and their applications, especially surface-active species: ultrasonic sensor, scanning probe microscopy and reflectivity studies of adsorption and self-assembly of highly branched “dendrimers” at the solid-liquid interface, with the aim of creating novel surface coatings; fluorescence tracer studies of molecular level mobility in ultrathin polymer films with the aim of improving resolution in lithography; reflectivity studies and computer simulation of flexible polymer adsorption and the response of adsorbed polymer layers to imposed flows with the aim of improving polymer processing operations; optical microscopy studies and numerical simulation of microporous polymer membrane formation with the aim of improving ultrafiltration membrane technology; synthesis and structural characterization of bioactive polymer surfaces in order to realize new in-vivo devices; contact angle, x-ray photoelectron spectroscopy, and reflectivity analysis, and lattice model simulation, of responsive polymer surfaces based on unique polymeric “surfactants” in order to develop “smart” surface-active materials; preparation and IR/fluorescence characterization of DNA-decorated surfaces for “recognition” of DNA in solution in order to further medical diagnostic technologies; preparation and characterization via TEM, AFM, and reflectivity of nano-particle– block copolymer composites; computer simulation and theory of unique “living” polymerization processes important to synthetic polymer production and biological systems; theory and simulation of irreversible polymer adsorption.

Genomics Engineering. Research and development of novel biochemical reagents, systems, and processes using chemical science, engineering principles, and experimental biological approaches to study problems in genomics are actively pursued in the Department of Chemical Engineering in collaboration with the Columbia Genome Center: high-throughput DNA sequencing; novel gene chip development and fundamental understanding of the processes involved; applying the cutting-edge genomic technologies to study fundamental biology and for disease gene discovery.


Bioinductive and Biomimetic Materials. The thrust of this research is to develop new strategies for the molecular design of polymeric and soft materials for biological and biomedical applications. Ongoing research pertains to the development of bioactive hydrogel coatings for applications in glucose sensors. The objective of the coatings is to control the tissue-sensor interactions by incorporating cell-signaling motifs into the hydrogel in such a manner that the hydrogel induces the formation of new vascular tissue within the surface coating. In this fashion, the biosensor can continue to operate in vivo, even if there is an immune response leading to fibrous encapsulation. Complementary research programs are aimed at developing methods for patterning biological surfaces in order to prepare new bio-compatible surfaces as well as to fabricate antigen/antibody and protein arrays for diagnostic applications.

Interfacial Engineering and Electrochemistry. Research efforts within the department are focused on mass transfer and reaction mechanisms in electrochemical systems, and the effects that such variables have on process design and materials properties. Applications of the research program include fuel cells, electrodeposition, and corrosion. Both electrochemical and microscopy methods are used extensively for characterization. A significant numerical simulation component of the research programs also exists.

 Facilities for Teaching and Research

The Department of Chemical Engineering is continually striving to provide access to state-of-the-art research instrumentation and computational facilities for its undergraduate and graduate students, postdoctoral associates, and faculty. Departmental equipment is considered to be in most cases shared, which means that equipment access is usually open to all qualified individuals with a need to use particular instrumentation.
The most extensive collection of instrumentation in the department is associated with the polymer and soft matter research faculty. Faculty banded together to create a unique shared-facilities laboratory, completed at the end of 2001. The shared facilities include a fully equipped polymer synthesis lab with four fumes hoods, a 10’x16’ soft wall clean room, metal evaporator system, a Milligen 9050 peptide synthesizer, and polymer thin film preparation and substrate cleaning stations. Also installed are new, computer-controlled thermal analysis, rheometric, and light-scattering setups. Specialized instrumentation for surface analysis includes an optical/laser system dedicated to characterization of polymer surface dynamics by Fluorescence Recovery after Photobleaching and a PHI 5500 X-ray photoelectron spectrophotometer with monochromator that is capable of angle-dependent depth profiling and XPS imaging. The system can also perform SIMS and ion scattering experiments. A digital image analysis system for the characterization of sessile and pendant drop shapes is also available for the purpose of polymer surface and interfacial tension measurements as well as contact angle analysis. An X-ray reflectometer that can perform X-ray standing wave–induced fluorescence measurements is also housed in the new shared equipment laboratory, along with instrumentation for characterizing the friction and wear properties of polymeric surfaces. The laboratory also houses an infrared spectrometer ( Nicolet Magna 560, MCT detector) with a variable angle grazing incidence, temperature-controlled attenuated-total-reflectance, transmission, and liquid cell accessories. These facilities are suitable for mid-IR, spectroscopic investigations of bulk materials as well as thin films. The laboratory also has a UV-Vis spectrometer (a Cary 50), an SLM Amino 8000 spectrofluorimeter, and a high-purity water system (Millipore Biocel) used for preparation of biological buffers and solutions. Facilities are available for cell tissue culture and for experiments involving bio-compatibilization of materials or cellular engineering. In addition, gel electrophoresis apparatus is available for the molecular weight characterization of nucleic acids. A total-internal-reflection-fluorescence (TIRF) instrument with an automated, temperature-controlled flow cell has been built for dedicated investigations of surface processes involving fluorescently tagged biological and synthetic molecules. The instrument can operate at different excitation wavelengths (typically HeNe laser, 633 nm, using Cy5 labeled nucleic acids). Fluorescence is collected by a highly sensitive photomultiplier tube and logged to a personal computer. Because fluorescence is only excited in the evanescent wave region near an interface, signals from surface-bound fluorescent species can be determined with minimal background interference from fluorophores in bulk solution.

**Chemistry Department.** Access to NMR and mass spectrometry facilities is possible through interactions with faculty members who also hold appointments in the Chemistry Department. The NMR facility consists of a 500 MHz, a 400 MHz, and two 300 MHz instruments that are operated by students and postdocs after training. The mass spectrometry facility is run by students for routine samples and by a professional mass spectrometrist for more difficult samples. The Chemistry Department also provides access to the services of a glass blower and machine shop and to photochemical and spectroscopic facilities. These facilities consist of (1) two nanosecond laser flash photolysis instruments equipped with UV-VIS, infrared, EPR, and NMR detection; (2) three EPR spectrometers; (3) two fluorescence spectrometers; (4) a single photon counter for analysis of the lifetimes and polarization of fluorescence and phosphorescence; and (5) a high-performance liquid chromatographic instrument for analysis of polymer molecular weight and dispersity.

**Columbia Genome Center.** Because of its affiliation with the Columbia Genome Center (CGC), the Department of Chemical Engineering also has access to over 3,000 sq. ft. of space equipped with a high-throughput DNA sequencer (Amersham Pharmacia Biotech MegaBace1000), a nucleic acid synthesizer (PE Biosystems 8909 Expedite Nucleic Acid/Peptide Synthesis System), an UV/VIS spectrophotometer (Perkin-Elmer Lambda 40), a fluorescence spectrophotometer (Jobin Yvon, Inc. Fluorolog-3), Waters HPLC, and a sequencing gel electrophoresis apparatus (Life Technologies Model S2), as well as the facilities required for state-of-the-art synthetic chemistry. The division of DNA sequencing and chemical biology at the Columbia Genome Center consists of 6,000 sq. ft. of laboratory space and equipment necessary for carrying out the state-of-the-art DNA analysis. The laboratory has one Amersham Pharmacia Biotech MegaBace1000 sequencer, three ABI 377 sequencers with complete 96 land upgrades, a Qiagen 9600 Biorobot, a Hydra 96 microdispenser robot, and standard molecular biology equipment.

**NSF-Columbia MRSEC Shared Facilities.** Through their participation in an NSF-MRSEC grant, faculty also have access to shared facilities located in the Schapiro Center for Engineering and Physical Science Research at Columbia University. The shared facilities include a Scintag X2 X-ray diffractometer aligned for low-angle reflectivity work, and a Beaglehole Instruments Picometer modulated ellipsometer. As needed, these capabilities are available for characterization of the surface coverage and composition of modified surfaces and thin organic films. Access to atomic force microscopy, scanning and transmission electron microscopy, and scanning tunneling microscopy is possible through collaborations within the NSF-MRSEC program and with colleagues in the Chemistry and Materials Science Departments. The NSF-Columbia MRSEC facility is located within five minutes’ walking distance from the Chemical Engineering Department.

**UNDERGRADUATE PROGRAM**

**Chemical Engineering**

The undergraduate program in chemical engineering at Columbia, recently revised, has five formal educational objectives:

A. Prepare students for careers in industries that require technical expertise in chemical engineering.

B. Prepare students to assume leadership positions in industries that require technical expertise in chemical engineering.
C. Enable students to pursue graduate-level studies in chemical engineering and related technical or scientific fields (e.g., biomedical or environmental engineering, materials science).

D. Provide a strong foundation for students to pursue alternative career paths, especially careers in business, management, finance, law, medicine, or education.

E. Establish in students a commitment to life-long learning and service within their chosen profession and society.

The expertise of chemical engineers is essential to production, marketing, and application in such areas as pharmaceuticals, high performance materials as in the automotive and aerospace industries, semiconductors in the electronics industry, paints and plastics, consumer products such as food and cosmetics, petroleum refining, industrial chemicals, synthetic fibers, and just about every bioengineering and bio-technology area from artificial organs to biosensors. Increasingly, chemical engineers are involved in exciting new technologies employing highly novel materials, whose unusual response at the molecular level endows them with unique properties. Examples include controlled release drugs, materials with designed interaction with in vivo environments, "nanomaterials" for electronic and optical applications, agricultural products, and a host of others. This requires a depth and breadth of understanding of physical and chemical aspects of materials and their production that is without parallel.

The chemical engineering degree also serves as a passport to exciting careers in directly related industries as diverse as biochemical engineering, environmental management, and pharmaceuticals. Because the deep and broad-ranging nature of the degree has earned it a high reputation across society, the chemical engineering degree is also a natural platform from which to launch careers in medicine, law, management, banking and finance, politics, and so on. Many students choose it for this purpose, to have a firm and respected basis for a range of possible future careers. For those interested in the fundamentals, a career of research and teaching is a natural continuation of undergraduate studies.

The first and sophomore years of study introduce general principles of science and engineering and include a broad range of subjects in the humanities and social sciences. Although the program for all engineering students in these first two years is to some extent similar, there are important differences. The Professional Engineering Elective, usually taken in Semester II, is designed to provide an overview of an engineering discipline. Those wishing to learn about chemical engineering are encouraged to take CHEN E1040: Molecular engineering and product design, taught by the Chemical Engineering Department. Students who major in chemical engineering are not currently required to take computer science or programming, and should in their sophomore year take CHEN E3100: Material and energy balances (see table on page 86).

In the junior-senior sequence one specializes in the chemical engineering major. The table on page 87 spells out the core course requirements, which are split between courses emphasizing engineering science and those emphasizing practical and/or professional aspects of the discipline. Throughout, skills required of practicing engineers are developed (e.g. writing and presentation skills, competency with computers).

The table on page 87 shows that a significant fraction of the junior-senior program is reserved for electives, both technical and nontechnical. Nontechnical electives are courses that are not quantitative, such as those taught in the humanities and social sciences. These provide an opportunity to pursue interests in areas other than engineering. A crucial part of the junior-senior program is the 12-point technical elective requirement. Technical electives are science and/or technology based and feature quantitative analysis. Generally, technical electives must be 3000 level or above but there are a few exceptions: PHYS C1403, PHYS C2601, BIOL C2005, BIOL C2006, and BIOL W2501. The technical electives are subject to the following constraints:

- One technical elective must be within chemical engineering (i.e. with the designator BMCH, CHEN, CHEE, or CHAP).
- The technical electives must include 6 points of "advanced natural science" course work, including chemistry, physics, biology, and certain engineering courses. Qualifying engineering courses are determined by Chemical Engineering Department advisers.

The junior-senior technical electives provide the opportunity to explore new interesting areas beyond the core requirements of the degree. Often, students satisfy the technical electives by taking courses from another SEAS department in order to obtain a minor from that department. Alternately, you may wish to take courses in several new areas, or perhaps to explore familiar subjects in greater depth, or you may wish to gain experience in actual laboratory research. Three points of CHEN E3900: Undergraduate research project may be counted toward the technical elective content.

The program details discussed above, and the accompanying tables, apply to undergraduates who are enrolled at Columbia as freshmen and declare the chemical engineering major in the sophomore year. However, the chemical engineering program is designed to be readily accessible to participants in any of Columbia’s Combined Plans and to transfer students. In such cases, the guidance of one of the departmental advisers in planning your program is required (contact information for the departmental UG advisers is listed on the department’s Web site).

Columbia’s program in chemical engineering leading to the B.S. degree is fully accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

Requirements for a Minor in Chemical Engineering
See page 187.

Requirements for a Minor in Biomedical Engineering
Students majoring in chemical engineering who wish to include in their records
a minor in biomedical engineering may do so by taking BMEN E4001 or E4002; BIOL C2005; BMEN E4501 and E4502; and any one of several chemical engineering courses approved by the BME Department. See also page 187.

GRADUATE PROGRAM
The graduate program in chemical engineering, with its large proportion of elective courses and independent research, offers experience in any of the fields of departmental activity mentioned in previous sections. For both chemical engineers and those with undergraduate educations in other related fields such as physics, chemistry, and biochemistry, the Ph.D. program provides the opportunity to become expert in research fields central to modern technology and science.

M.S. Degree
The requirements are (1) the core courses: Chemical process analysis (CHEN E4010), Transport phenomena, III (CHEN E4110), and Statistical mechanics (CHAP E4120); and (2) 21 points of 4000- or 6000-level courses, approved by the graduate coordinator or research adviser, of which up to 6 may be Master's research (CHEN 9400). Students with undergraduate preparation in physics, chemistry, biochemistry, pharmacy, and related fields may take advantage of a special two-year program leading directly to the master's degree in chemical engineering. This program enables such students to avoid having to take all undergraduate courses in the bachelor's degree program.

Doctoral Degrees
The Ph.D. and D.E.S. degrees have essentially the same requirements. All students in a doctoral program must (1) earn satisfactory grades in the three core courses (CHEN E4010, CHEN E4110, CHAP E4120); (2) pass a qualifying exam; (3) defend a proposal of research within twelve months of passing the qualifying exam; (4) defend their thesis; and (5) satisfy course requirements beyond the three core courses. For detailed requirements, please consult the departmental office or graduate coordinator. Students with degrees in related fields such as physics, chemistry, biochemistry, and others are encouraged to apply to this highly interdisciplinary program.

Areas of Concentration
After satisfying the core requirement of Chemical process analysis (CHEN E4010), Transport phenomena, III (CHEN E4110), and Statistical mechanics (CHAP E4120), chemical engineering graduate students are free to choose their remaining required courses as they desire, subject to their research adviser's approval. However, a number of areas of graduate concentration are suggested below, with associated recommended courses. Each concentration provides students with the opportunity to gain in-depth knowledge about a particular research field of central importance to the department. Graduate students outside the department are very welcome to participate in these concentration areas, many of which are highly interdisciplinary. The department strongly encourages interdepartmental dialogue at all levels.

Science and Engineering of Polymers and Soft Materials. Soft materials include diverse organic media with supramolecular structure having scales in the range 1–100 nm. Their small-scale structure imparts unique, useful macroscopic properties. Examples include polymers, liquid crystals, colloids, and emulsions. Their "softness" refers to the fact that they typically flow or distort easily in response to moderate shear and other external forces. They exhibit a great many unique and useful macroscopic properties stemming from their supramolecular structure, from the simple orientational order of a nematic liquid crystal to the full periodic "crystalline" order of block copolymer mesophases. Soft materials provide ideal testing grounds for such fundamental concepts as the interplay between order and dynamics or topological defects. They are of primary importance to the paint, food, petroleum, and other industries as well as a variety of advanced materials and devices. In addition, most biological materials are soft, so that understanding of soft materials is very important to improving our understanding of cellular function and therefore human pathologies. At Columbia Chemical Engineering, we focus on several unique aspects of soft matter, such as their special surface and interfacial properties. This concentration is similar in thrust to that of the "Biophysics and Soft Matter" concentration, except here there is greater emphasis on synthetic rather than biological soft matter, with particular emphasis on interfacial properties and materials with important related applications. Synthetic polymers are by far the most important material in this class.

CHEN E4620: Introduction to polymers
CHEN E4640: Polymer surfaces and interfaces
CHEN E6620: Physical chemistry of macromolecules
CHEN E6610: Polymers: synthesis of macromolecules
CHEN E6910: Theoretical methods in polymer physics
CHEN E4252: Introduction to surface and colloid chemistry
CHEN E6100: Dynamics of complex media
CHEN E6920: Physics of soft matter
CHEN E4750: The genome and the cell

Biophysics and Soft Matter Physics. Soft matter denotes polymers, gels, self-assembled surfactant structures, colloidal suspensions, and many other complex fluids. These are strongly fluctuating, floppy, fluidlike materials that can nonetheless exhibit diverse phases with remarkable long-range order. In the last few decades, statistical physics has achieved a sound understanding of the scaling and universality characterizing large length scale properties of much synthetic soft condensed matter. More recently, ideas and techniques from soft condensed matter physics have been applied to biological soft matter such as DNA, RNA, proteins, cell membrane surfactant assemblies, actin and tubulin structures, and many others. The aim is to shed light on (1) fundamental cellular processes such as gene expression or the function of cellular motors and (2) physical mechanisms central to the exploding field of biotechnology involving systems such as DNA microarrays and methods such as genetic engineering. The practitioners in this highly interdisciplinary field include physicists, chemical engineers, biologists, biochemists, and chemists.
### CHEMICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS

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<tr>
<th></th>
<th>SEMESTER I</th>
<th>SEMESTER II</th>
<th>SEMESTER III</th>
<th>SEMESTER IV</th>
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<tr>
<td><strong>MATH</strong></td>
<td>MATH V1101 (3)</td>
<td>MATH V1102 (3)</td>
<td>MATH V1201 (3)</td>
<td>MATH V1202 (3)</td>
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<tr>
<td><strong>PHYSICS</strong></td>
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<td>and one of the following:</td>
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<td>(three tracks, choose one)</td>
<td>C1401 (3)</td>
<td>C1402 (3)</td>
<td>Lab C1493 (3)</td>
<td>MATH E1210 (3)</td>
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<tr>
<td></td>
<td>C1601 (3.5)</td>
<td>C1602 (3.5)</td>
<td>Lab W3081 (2)</td>
<td>Ord. diff. equations or</td>
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<td></td>
<td>C2801 (4.5)</td>
<td>C2802 (4.5)</td>
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<td>APMA E2101 (3)</td>
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<td><strong>CHEMISTRY</strong></td>
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<td>Intro. to appl. math.</td>
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<td>C1404 (3.5)</td>
<td>C3443 (3.5)</td>
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<td>C1604 (3.5)</td>
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<td>C3045 (3.5)</td>
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<td>Lab C2507 (3)</td>
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<td><strong>ENGLISH COMPOSITION</strong></td>
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<td><strong>NONTECH</strong></td>
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<td>One core humanities elective (3–4 points)²</td>
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<tr>
<td><strong>TECH</strong></td>
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<td>Three core humanities electives (11 points)²</td>
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<td><strong>CHEM. ENG. REQUIREMENT</strong></td>
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<td><strong>COMPUTER SCIENCE</strong></td>
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<td><strong>PHYSICAL EDUCATION</strong></td>
<td>C1001 (1)</td>
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<td><strong>GATEWAY LAB</strong></td>
<td>E1102 (4) either semester</td>
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<td><strong>TOTAL POINTS</strong></td>
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1. Students are encouraged to take CHEN 1040: Molecular engineering and product design.
2. Four core humanities electives should be taken as follows: In Semester III, HUMA C1001, C1101 (4), or any initial course in one of the Major Cultures sequences offered by the College (3–4); in Semester IV, HUMA C1002, C1102 (4), or the second course in the Major Cultures sequence elected in Semester III (3–4); also in Semester IV, ECON W1105 (4) with W1105 recitation (0) and either HUMA C1121 or C1123 (3).
3. Should be taken in Semester III, but may be moved upon advisor’s approval to Semester V if CHEM C3543: Organic chemistry lab is taken in Semester III.
4. Taking the first track in each row and E1102 in Semester II.

The “Biophysics and Soft Matter” concentration is closely related to the “Science and Engineering of Polymers and Soft Materials” concentration, but here greater emphasis is placed on biological materials and cellular biophysics. Both theory and experiment are catered to. Students will be introduced to statistical mechanics and its application to soft matter research and to cellular biophysics. In parallel, the student will learn about genomics and cellular biology to develop an understanding of what the central and fascinating biological issues are.  

**CHAP E4120**: Statistical mechanics  
**CHEN E6920**: Physics of soft matter

**CHEN E6100y**: Dynamics of complex fluids  
**CHEN E4650**: Biopolymers  
**BIOC G6300**: Biochemistry/molecular biology—eukaryotes, I  
**BIOC G6301**: Biochemistry/molecular biology—eukaryotes, II  
**CHEN E4750**: The genome and the cell  
**CMBS G4350**: Cellular molecular biophysics
Genomic Engineering. Genomic engineering may be defined as the development and application of novel technologies for identifying and evaluating the significance of both selected and all nucleotide sequences in the genomes of organisms. An interdisciplinary course concentration in genomic engineering is available to graduate students, and to selected undergraduate students. The National Science Foundation is sponsoring the development of this concentration, which is believed to be the first of its kind.

The concentration consists of five courses that address the principal areas of genomic technology: sequencing and other means of acquiring genomic information; bioinformatics as a means of assembling and providing structured access to genomic information; and methods of elucidating how genomic information interacts with the developmental state and environment of cells in order to determine their behavior. Prof. E. F. Leonard directs the program and teaches CHEN E4750. The other instructors are Prof. D. Anastassiou (ECBM E4060), Jingyue Ju (CHEN E4700, CHEN E4730), and C. Leslie (CBMF W4761). The departments of Chemical, Biomedical, and Electrical Engineering and of Computer Science credit these courses toward requirements for their doctorates. Students may take individual courses so long as they satisfy prerequisite requirements or have the instructor’s permission. All lecture courses in the program are available through the Columbia Video Network, which offers a certificate for those students completing a prescribed set of the courses.

The course Introduction to genomic information science and technology (ECBM E4060) provides the essential concepts of the information system paradigm of molecular biology and genetics. Principles of genomic technology (CHEN E4700) provides students with a solid basis for understanding both the principles that underlie genomic technologies and how these principles are applied. The Genomics sequencing laboratory (CHEN E4760) provides hands-on experience in high-throughput DNA sequencing, as conducted in a bioscience research laboratory. The genome and the cell (CHEN E4750) conveys a broad but precise, organized, and quantitative overview of the cell and its genome: how the genome, in partnership with extragenomic stimuli, influences the behavior of the cell and how mecha-
nisms within the cell enable genomic regulation. Computational genomics (CBMF W4761) introduces students to basic and advanced computational techniques for analyzing genomic data.

Interested parties can obtain further information, including a list of cognate courses that are available and recommended, from Professor Leonard (leonard@columbia.edu).

Interfacial Engineering and Electrochemistry. Electrochemical processes are key to many alternative energy systems (batteries and fuel cells), to electrical and magnetic-device manufacturing (interconnects and magnetic-storage media), and to advanced materials processing. Electrochemical processes are also involved in corrosion and in some waste-treatment systems. Key employers of engineers and scientists with knowledge of electrochemical/interfacial engineering include companies from the computer, automotive, and chemical industries. Knowledge of basic electrochemical principles, environmental sciences, and/or materials science can be useful to a career in this area.

CHEN E4201: Engineering applications of electrochemistry
CHEN E4252: Introduction to surface and colloid science
CHEN E6050: Advanced electrochemistry
CHEN E4205: Electrochemical energy systems
CHEN E3900: Undergraduate research project

Bioinductive and Biomimetic Materials. This is a rapidly emerging area of research, and the department’s course concentration is under development. At present, students interested in this area are recommended to attend Polymer surfaces and interfaces (CHEN E4640); Physical chemistry of macromolecules (CHEN E6620); and Polymers: synthesis of macromolecules (CHEN E6610). Other courses in the “Science and Engineering of Polymers and Soft Materials” concentration are also relevant. When complete, the concentration will include courses directly addressing biomaterials and immunological response.

**COURSES IN CHEMICAL ENGINEERING**

See also Center for Biomedical Engineering. Note: Check the department Web site for the most current course offerings/descriptions.

CHEN E1040y Molecular engineering and product design
Lect: 3. 3 pts. Professor West.
An introductory course intended to expose students to chemical engineering. Examines the ways in which chemical and biological sciences are interpreted through analytical, design, and engineering frameworks to generate products that enhance human endeavor. Students are introduced to the culture of chemical engineering and the wide variety of chemical engineering practices, through lectures by department faculty and practicing chemical engineers, trips to industrial facilities, reverse engineering of chemical products, and a chemical design competition.

CHEN E3100x Material and energy balances
Lect: 4. 4 pts. Professor Castaldi.
Prerequisite: CHEM C1403. Introduction to thermodynamics. Fundamentals are emphasized: the laws of thermodynamics are derived and their meaning explained and elucidated by applications to engineering problems. Pure systems are treated, followed by an introduction to mixtures and phase equilibrium.

CHEN E3110x Transport phenomena, I
Lect: 4. 4 pts. Professor Durning.
Prerequisites: Classical mechanics, vector calculus, ordinary differential equations. Focuses on the momentum and energy transport in pure (one-component) Newtonian fluids, i.e. elementary fluid mechanics, elementary conduction-dominated heat transfer, and forced convection heat transfer in fluids. This is an introductory-level course. It includes a review of the mathematical methods needed (vector calculus and ordinary differential equations). Applications to problems important in modern chemical engineering are used to illustrate concepts.

CHEN E3120y Transport phenomena, II
Lect: 4. 4 pts. Professor Durning.
Prerequisite: CHEN E3110, of which this course is a continuation. Focuses on the mass transport in isothermal mixtures of Newtonian fluids, i.e., elementary diffusion-dominated mass transfer, and forced convection mass transfer in fluid mixtures. Includes instruction in new mathematical methods needed (introductory partial differential equations). Applications to problems important in modern chemical engineering are used to illustrate concepts.

CHEN E3210y Chemical engineering thermodynamics
Lect: 3. 4 pts. Professor Koberstein.
Prerequisites: CHEN E3010 and E3100. This course deals with fundamental and applied thermodynamic principles that form the basis of chemical engineering practice. Topics include phase equilibria, methods to treat ideal and non-ideal mixtures, and estimation of properties using computer-based methods.

BMCH E3500y Transport in biological systems
Lect: 3. 3 pts. Professor Leonard.

CHEN E3810y Chemical engineering laboratory
Lab: 3. 3 pts. Professors Banta, Spencer, and West.
Prerequisite: Completion of core chemical engineering curricula through the fall semester of senior year (includes CHEN E3110, E3120, E4230, E3100, E3210, E4140, E4500), or the instructor’s permission. The course emphasizes active, experiment-based resolution of open-ended problems involving use, design, and optimization of equipment, products, or materials. Under faculty guidance students formulate, carry out, validate, and refine experimental procedures, and present results in oral and written form. The course develops analytical, communications, and cooperative problem-solving skills in the context of problems that span from traditional, large-scale separations and processing operations to molecular-level design of materials or products. Sample projects include scale up of apparatus, process control, chemical separations, microfluidics, surface engineering, molecular sensing, and alternative energy sources. Safety awareness is integrated throughout the course.

CHEN E3900x and y Undergraduate research project
0 to 6 pts. The staff.
Candidates for the B.S. degree may conduct an investigation of some problem in chemical engineering or applied chemistry or carry out a special project under the supervision of the staff. Credit for the course is contingent upon the submission of an acceptable thesis or final report. No more than 6 points in this course may be counted toward the satisfaction of the B.S. degree requirements.
CHEN E4010x Chemical process analysis
Lect: 3. 3 pts. Professor Leonard.
Open to undergraduates only with the instructor’s permission. Application of selected mathematical methods to solution of chemical engineering problems.

CHEN E4020x Protection of industrial and intellectual property
Lect: 3. 3 pts. Professor Pearlman.
To expose engineers, scientists, and technology managers to areas of the law they are most likely to be in contact with during their careers. Principles are illustrated with various case studies, together with active student participation.

CHEE E4050y Principles of industrial electrochemistry
Lect: 3. 3 pts. Professor Duby.
Prerequisite: CHEN E3120. A presentation of the basic principle underlying electrochemical processes. Thermodynamics, electrode kinetics, and ionic mass transport. Examples of industrial and environmental applications illustrated by means of laboratory experiments: electroplating, refining, and winning in aqueous solutions and in molten salts; electrolytic treatment of wastes; primary, secondary, and fuel cells.

CHEN E4110x Transport phenomena, III
Lect: 3. 3 pts. Professor Shapley.
Prerequisite: CHEN E3120. Tensor analysis; kinematics of continua; balance laws for one-component media; constitutive laws for free energy and stress in one-component media; exact and asymptotic solutions to dynamic problems in fluids and solids; balance laws for mixtures; constitutive laws for free energy, stress and diffusion fluxes in mixtures; solutions to dynamic problems in mixtures.

CHAP E4120x Statistical mechanics
Lect: 3. 3 pts. Professor O’Shaughnessy.
Prerequisite: CHEN E3100 or equivalent thermodynamics course, or the instructor’s permission. Fundamental principles and underlying assumptions of statistical mechanics. Boltzmann’s entropy hypothesis and its restatement in terms of Helmholtz and Gibbs free energies and for open systems. Correlation times and lengths. Exploration of phase space and observation timescale. Correlation functions. Fermi-Dirac and Bose-Einstein statistics. Fluctuation-response theory. Applications to ideal gases, interfaces, liquid crystals, microemulsions and other complex fluids, polymers, Coulomb gas, interactions between charged polymers and charged interfaces, ordering transitions.

CHEN E4140x Chemical and biochemical separations
Lect: 3. 3 pts. Professor Banta.
Prerequisites: CHEN E3100, E3120, and E3210, or the instructor’s permission. Design and analysis of unit operations employed in chemical and biochemical separations. Emphasis is placed on learning the fundamental aspects of distillation, gas adsorption, and crystallization through a combination of lectures, open-ended problem solving, self-learning exercises, and computer process simulation.

CHEN E4201x Engineering applications of electrochemistry
Lect: 3. 3pts. Professor West.
Prerequisites: Physical chemistry and a course in transport phenomena. Engineering analysis of electrochemical systems, including electrode kinetics, transport phenomena, mathematical modeling, and thermodynamics. Common experimental methods are discussed. Examples from common applications in energy conversion and metallization are presented.

CHEN E4230y Reaction kinetics and reactor design
Lect: 3. 3 pts. Professor Leonard.
Prerequisite: CHEN E3100. Reaction kinetics, applications to the design of batch and continuous reactors. Multiple reactions, non-isothermal reactors. Analysis, modeling of reactor behavior. Required recitation.

CHEE E4252x Introduction to surface and colloid chemistry
Lect: 3. 3 pts. Professor Somasundaran.
Prerequisite: elementary physical chemistry. Thermodynamics of surfaces, properties of surfactant solutions and surface films, electrostatic and electrokinetic phenomena at interfaces, adsorption; interfacial mass transfer and modern experimental techniques.

CHEN E4300x Chemical engineering control
Lab: 2. 2 pts. Professor West.
Prerequisites: Ordinary differential equations (including Laplace transforms), CHEN E3100, and CHEN E4230. An introduction to process control applied to chemical engineering through lecture and laboratory. Concepts include the dynamic behavior of chemical engineering systems, feedback control, controller tuning, and process stability.

CHEN E4320x Molecular phenomena in chemical engineering
Lect: 3. 4 pts. Professor O’Shaughnessy.
This new course located strategically at the end of the curriculum is intended to provide students with a molecular basis for the engineering concepts covered in the curriculum. It is meant to both validate the basic science and math foundations developed earlier and to stimulate the student toward applying modern molecular concepts of chemical engineering that will define their future.

CHEN E4410x Environmental control technology
Lect: 3. 3 pts. Professor Zudkevitch.

CHEN E4500x Process and product design, I
Lect: 3. 4 pts. Professor Kumar.
Prerequisites: CHEN E4140 and E3100. An introduction to the process engineering function. The design of chemical process, process equipment, and plants and the economic and ecological evaluation of the chemical engineering project. Use of statistics to define product quality is illustrated with case studies.

CHEN E4510y Process and product design, II
Lect: 4. 4 pts. Professors Kumar and Hill.
Prerequisite: CHEN E4500. Students carry out a semester-long process or product design course with significant industrial involvement. The project culminates with a formal written design report and a public presentation.

CHEE E4530y Corrosion of metals
Lect: 3. 3 pts. Professor Duby.
Prerequisite: CHEN E3100. The theory of electrochemical corrosion, corrosion tendency, rates, and passivity. Application to various environments. Cathodic protection and coatings. Corrosion testing.

CHEN E4620y Introduction to polymers and soft materials
Lect: 3. 3 pts. Professor Durning.
Prerequisites: An elementary course in physical chemistry or thermodynamics. Organic chemistry, statistics, calculus and mechanics are helpful, but not essential. An introduction to the chemistry and physics of soft materials systems (polymers, colloids, organized surfactant systems, and others), emphasizing the connection between microscopic structure and macroscopic physical properties. To develop an understanding of each system, illustrative experimental studies are discussed along with basic theoretical treatments. High molecular weight organic polymers are discussed first (basic notions, synthesis, properties of single polymer molecules, polymer solution and blend thermodynamics, rubber and gels). Colloidal systems are treated next (dominant forces in colloidal systems, flocculation, preparation and manipulation of colloidal systems) followed by a discussion of self-organizing surfactant systems (architecture of surfactants, micelles and surfactant membranes, phase behavior).

CHEN E4640x or y Polymer surfaces and interfaces
Prerequisites: CHEN E4620 or the instructor’s permission. A fundamental treatment of the thermodynamics and properties relating to polymer
surfaces and interfaces. Topics include the character- 
arization of interfaces, theoretical modeling of interfacial thermodynamics and structure, and practical means for surface modification.

Prerequisite: BMEN E4001 or the equivalent. 
Engineering of biochemical and microbiological reaction systems. Kinetics, reactor analysis, and design of batch and continuous fermentation and enzyme processes. Recovery and separations in biochemical engineering systems.

CHEN 4680x Soft materials laboratory Lect/lab: 3. 3 pts. Professors Koberstein and Shapley.
Prerequisites: Two years of undergraduate science courses and the instructors’ permission. Covers modern characterization methods for soft materials (polymers, complex fluids, biomaterials). Techniques include differential scanning calorimetry, dynamic light scattering, gel permeation chromatography, rheology, and spectroscopic methods. Team taught by several faculty and open to graduate and advanced undergraduate students (limit 15).

CHEN E4700x Principles of genomic technologies Lect: 3. 3 pts. Professor Ju.

CHEN E4740x: Biological transport and rate phenomena, II Lect: 3. 3 pts. Professor Leonard
Prerequisites: Any two of the following: CHEN E3110; BIOL C2005; CHEN E3210 or BMCH E3500. Advanced course intended as preparation for research. Analysis of transport and rate phenomena in biological systems and in the design of biomimetic transport-reaction systems for technological and therapeutic applications. Modeling of homogeneous and heterogeneous biochemical reactions. The bases of biological transport: roles of convection, ordinary diffusion, forced diffusion. Systems where reaction and transport interact strongly. Applications to natural and artificial tissue beds, tumor modelling, controlled release, natural and artificial organ function.

Syllabus: Analysis of transport and rate phenomena in biological systems and in the design of biomimetic transport-reaction systems for technological and therapeutic applications.


Molecular transformation systems involving both transport and reaction. Rate-limiting step. Nonequilibrium steady states; the resting cell. Mitochondrial kinetics. Simple models of cellular operons.

Prerequisite: BIOL C2005 and MATH E1210, or equivalents. The utility of genomic information lies in its capacity to predict the behavior of living cells in physiological, developmental, and pathological situations. The effect of variations in genome structure between individuals within a species, including those deemed healthy or diseased, and among species, can be inferred statistically by comparison of sequences with behaviors, and mechanistically, by studying the action of molecules whose structure is encoded within the genome. This course examines known mechanisms that elucidate the combined effect of environmental stimulation and genetic makeup on the behavior of cells in homeostasis, disease states, and during development, and includes assessments of the probable effect of these behaviors on the whole organism. Quantitative models of gene translation and intracellular signal transduction will be used to illustrate switching of intracellular processes, transient and permanent gene activation, and cell commitment, development, and death.

CHEN E4760y Genomics sequencing laboratory Lect: 1. Lab: 2. 3 pts. Professor Ju.
Prerequisites: undergraduate-level biology, organic chemistry, and the instructor’s permission. The chemical, biological, and engineering principles involved in the genomics sequencing process will be illustrated throughout the course for engineering students to develop the hands-on skills in conducting genomics research.

CHEN E4800x Protein engineering Lect: 3. 3 pts. Professor Banta.
Prerequisite: CHEN E4230 (may be taken concurrently) or the instructor’s permission. Fundamental tools and techniques currently used to engineer protein molecules. Methods used to analyze the impact of these alterations on different protein functions, with specific emphasis on enzymatic catalysis. Case studies reinforce concepts covered and demonstrate the wide impact of protein engineering research. Application of basic concepts in the chemical engineering curriculum (reaction kinetics, mathematical modeling, thermodynamics) to specific approaches utilized in protein engineering.

Prerequisite: The instructor’s permission. An advanced overview of the fundamentals of electrochemistry, with examples taken from modern applications. An emphasis is placed on mass transfer and scaling phenomena. Principles are reinforced through the development of mathematical models of electrochemical systems. Course projects will require computer simulations. The course is intended for advanced graduate students, conducting research involving electrochemical technologies.

CHEE E6220y Equilibria and kinetics in hydrometallurgical systems 
Lect: 3. 3 pts. Professor Duby.
Prerequisite: CHEE E4050 or EAEE E4003. Detailed examination of chemical equilibria in hydrometallurgical systems. Kinetics and mechanisms of homogeneous and heterogeneous reaction in aqueous solutions.

CHEE E6252y Applied surface and colloid chemistry
Lect: 2. Lab: 3. 3 pts. Professor Somasundaran.
Prerequisite: CHEN E4252. Applications of surface chemistry principles to wetting, flocculation, flotation, separation techniques, catalysis, mass transfer, emulsions, foams, aerosols, membranes, biological surfactant systems, microbial surfaces, enhanced oil recovery, and pollution problems. Appropriate individual experiments and projects.

CHEN E6300y Experimental fluid mechanics: Complex fluids and biological applications 
Lect: 3. Lab: 2. 3 pts. Professor Shapley.
Prerequisite: CHEN E4110 or equivalent, or the instructor’s permission. The goal of this course is to introduce graduate students to several experimental techniques used to study complex fluids (materials with internal microstructure that influences macroscopic flow properties) such as polymer solutions and melts, suspensions, and emulsions. The course will focus in depth on rheology and noninvasive imaging methods such as magnetic
resonance imaging, laser Doppler velocimetry, and video imaging. Part of each class will be devoted to understanding the techniques, and then the techniques will be implemented in the lab on model flows. Biological systems involving complex fluids and application of measurement techniques to such systems will also be discussed.

**CHEN E6620y Physical chemistry of macromolecules**
Lect: 3. 3 pts. Professor Koberstein.
Modern studies of static and dynamic behavior in macromolecular systems. Topics include single-chain behavior adsorption, solution thermodynamics, the glass transition, diffusion, and viscoelastic behavior. The molecular understanding of experimentally observed phenomena is stressed.

**CHEN E6630x Special topics in soft condensed matter**
Tutorial lectures on selected topics in soft condensed matter.

**CHEN E6910y Theoretical methods in polymer physics**
Prerequisite: CHEN E4120 or equivalent statistical mechanics course, or the instructor’s permission. Modern methods for understanding polymeric liquids and critical phenomena are introduced and applied in detail. Scaling and universality. Relationship of high polymer physics to critical phenomena. Landau theory, self-consistent field method. Scaling approach. Renormalization group theory. Epsilon expansion for polymer and other critical exponents. Applications to polymer statics and dynamics, and to other complex fluids.

**CHEN E6920y Physics of soft matter**
Prerequisite: the instructor’s permission. Physics of polymers, biopolymers (especially DNA), membranes, gels, and other types of soft matter. Statistical mechanics, scaling theory, self-consistent field theory; experimental surveys. Dilute, semidilute, and concentrated polymer solutions. Mesophases and self-assembly in soft matter.

Polymers at interfaces, polymer-membrane interactions. Fluctuating double helix models of DNA. DNA melting, pattern recognition in DNA. Polyelectrolytes, charged biopolymers, DNA charge-induced condensation.

**CHEN E6100y Topics in biology**
Lect: 3. 3 pts. Professor O’Shaughnessy.
This research seminar introduces topics at the forefront of biological research in a format and language accessible to quantitative scientists and engineers lacking biological training. Conceptual and technical frameworks from both biological and physical science disciplines are utilized. The objective is to reveal to graduate students where potential lies to apply techniques from their own disciplines to address pertinent biological questions in their research. Classes entail reading, criticism, and group discussion of research papers and textbook materials providing overviews to various biological areas including evolution, immune system, development and cell specialization, the cytoskeleton and cell motility, DNA transcription in gene circuits, protein networks, recombinant DNA technology, aging, and gene therapy.

**CHEN E9000x and y Chemical engineering colloquium**
Col: 1. 0 pts. The staff.
All graduate students are required to attend the department colloquium as long as they are in residence. No degree credit is granted.

**CHEN E9400x and y Master’s research problems**
1 to 6 pts. The staff.
Prerequisite: recommendation of the professor concerned and approval of the master’s research department. For postdoctoral students and other qualified special students who wish to pursue research under the guidance of members of the department. Not open to undergraduates or to candidates for the degrees of Ch.E., M.S., Ph.D., or Eng.Sc.D.

**CHEN E9800x and y, and s Doctoral research instruction**
3, 6, 9, or 12 pts. The staff.
A candidate for the Eng.Sc.D. degree in chemical engineering must register for 12 points of doctoral research instruction. Registration in CHEN E9800 may not be used to satisfy the minimum residence requirement for the degree.

**CHEN E9900x and y, and s Doctoral dissertation**
0 pts. The staff.
Open only to certified doctoral candidates. A candidate for the doctorate in chemical engineering may be required to register for this course in every term after the student’s course work has been completed, and until the dissertation has been accepted.
The Department of Civil Engineering and Engineering Mechanics focuses on two broad areas of instruction and research. The first, the classical field of civil engineering, deals with the planning, design, construction, and maintenance of the built environment. This includes buildings, foundations, bridges, transportation facilities, nuclear and conventional power plants, hydraulic structures, and other facilities essential to society. The second is the science of mechanics and its applications to various engineering disciplines. Frequently referred to as applied mechanics, it includes the study of the mechanical and other properties of materials, stress analysis of stationary and movable structures, the dynamics and vibrations of complex structures, aero- and hydrodynamics, and the mechanics of biological systems.

MISSION
The Department aims to provide students with a technical foundation anchored in theory together with the breadth needed to follow diverse career paths, whether in the profession via advanced study or apprenticeship, or as a base for other pursuits.

Current Research Activities
Current research activities in the Department of Civil Engineering and Engineering Mechanics are centered in the areas outlined below. A number of these activities impact directly on problems of societal importance, such as rehabilitation of the infrastructure, mitigation of natural or man-made disasters, and environmental concerns.


- **Multihazard risk assessment and mitigation**: integrated risk studies of the civil infrastructure form a multihazard perspective including earthquake, wind, flooding, fire, blast, and terrorism. The engineering, social, financial, and decision-making perspectives of the problem are examined in an integrated manner.
- **Probabilistic mechanics**: random processes and fields to model uncertain loads and material/soil properties, nonlinear random vibrations, reliability and safety of structural systems, computational stochastic mechanics, stochastic finite element and boundary element techniques, Monte Carlo simulation techniques, random micromechanics.
• **Structural control and health monitoring:** topics of research in this highly cross-disciplinary field include the development of “smart” systems for the mitigation and reduction of structural vibrations, assessment of the health of structural systems based on their vibration response signatures, and the modeling of nonlinear systems based on measured dynamic behavior.

**Fluid mechanics:** solid-laden turbulent flows, porous surface turbulence, flow through porous media, numerical simulation of flow and transport processes, flow and transport in fractured rock.

**Environmental engineering/water resources:** modeling of flow and pollutant transport in surface and subsurface waters, unsaturated zone hydrology, geoenvironmental containment systems, analysis of watershed flows including reservoir simulation.

**Structures:** dynamics, stability, and design of structures, structural failure and damage detection, fluid and soil structure interaction, ocean structures subjected to wind-induced waves, inelastic dynamic response of reinforced concrete structures, earthquake-resistant design of structures.

**Geotechnical engineering:** soil behavior, constitutive modeling, reinforced soil structures, geotechnical earthquake engineering, liquefaction and numerical analysis of geotechnical systems.

**Structural materials:** cement-based materials, micro- and macro-models of fiber-reinforced cement composites, utilization of industrial by-products and waste materials, beneficiation of dredged material.

**Earthquake engineering:** response of structures to seismic loading, seismic risk analysis, active and passive control of structures subject to earthquake excitation, seismic analysis of long-span cable-supported bridges.

**Flight structures:** aeroelasticity, aeroacoustics, active vibration and noise control, smart structures, noise transmission into aircraft, and vibro-acoustics of space structures.

**Construction engineering and management:** contracting strategies; alternative project delivery systems, such as design-build, design-build-operate, and design-build-finance-operate; minimizing project delays and disputes; advanced technologies to enhance productivity and efficiency; strategic decisions in global engineering and construction markets.

**Infrastructure delivery and management:** decision support systems for infrastructure asset management; assessing and managing infrastructure assets and systems; capital budgeting processes and decisions; innovative financing methods; procurement strategies and processes; data management practices and systems; indicators of infrastructure performance and service.

**Laboratories**

The offices and laboratories of the department are in the S. W. Mudd Building and the Engineering Terrace.

**Computing**

The department manages a substantial computing facility of its own in addition to being networked to all the systems operated by the University. The department facility enables its users to perform symbolic and numeric computation, three-dimensional graphics, and expert systems development. Connections to wide-area networks allow the facility’s users to communicate with centers throughout the world. All faculty and student offices and department laboratories are hardwired to the computing facility, which is also accessible remotely to users. Numerous personal computers and graphics terminals exist throughout the department, and a PC lab is available to students in the department in addition to the larger school-wide facility.

**Facilities**

The Robert A. W. Carleton Strength of Materials Laboratory is a very large facility equipped for research into all types of engineering materials and structural elements. The Heffner Laboratory for Hydrologic Research is a newly established facility for both undergraduate instruction and research in all aspects of fluid mechanics and its applications. The Eugene Mindlin Laboratory for Structural Deterioration Research is a teaching and research facility dedicated to all facets of the assessment of structures and the processes of deterioration of structural performance. The concrete laboratory is
equipped to perform a wide spectrum of experimental research in cement-based materials. The Donald M. Burmister Soil Mechanics Laboratory is used in both undergraduate and graduate instruction for static and dynamic testing of soils and foundations. The geotechnical centrifuge located in the Carleton Laboratory is used for geotechnical and geoenvironmental research.

**The Institute of Flight Structures**

The Institute of Flight Structures was established within the department through a grant by the Daniel and Florence Guggenheim Foundation. It provides a base for graduate training in aerospace and aeronautical related applications of structural analysis and design.

**Center for Infrastructure Studies**

The Center was established in the department to provide a professional environment for faculty and students from a variety of disciplines to join with industry and government to develop and apply the technological tools and knowledge bases needed to deal with the massive problems of the city, state, and regional infrastructure. The Center is active in major infrastructure projects through a consortium of universities and agencies.

**UNDERGRADUATE PROGRAMS**

The Department of Civil Engineering and Engineering Mechanics offers undergraduate programs in civil engineering and engineering mechanics. Both are intended to prepare students with firm technical bases while nurturing decision-making and leadership potential.

The civil engineering program is designed to enable the student, upon completion of the B.S. degree program, to enter the profession—for example, in industry, on a construction project, in a consulting engineering office, through a government agency—or to begin graduate study, or both. The program is fully accredited by the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET) and provides a broad traditional civil engineering background that focuses on basic theory and design. Technical electives can be selected to obtain a strong technical base in a particular field.

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### CIVIL ENGINEERING PROGRAM: FIRST AND SECOND YEARS

<table>
<thead>
<tr>
<th></th>
<th>SEMESTER I</th>
<th>SEMESTER II</th>
<th>SEMESTER III</th>
<th>SEMESTER IV</th>
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</thead>
<tbody>
<tr>
<td><strong>MATHEMATICS</strong></td>
<td>MATH V1101 (3)</td>
<td>MATH V1102 (3)</td>
<td>MATH V1201 (3)</td>
<td>APMA E2101 (3)</td>
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<td></td>
<td></td>
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<td></td>
<td>Intro. to applied math.</td>
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</tbody>
</table>
| **PHYSICS**  
(three tracks, choose one) | C1401 (3) | C1402 (3) | Lab C1493 (3) | or chem. lab |
|                    | C1601 (3.5) | C1602 (3.5) | Lab W3081 (2) |             |
|                    | C2801 (4.5) | C2802 (4.5) |             |             |
| **CHEMISTRY**       | one-semester lecture (3–4): C1403 or C1404 or C3045 or C1604 | |             |             |
|                     | Chem lab C1500 (3) either semester or physics lab | | | |
| **MECHANICS**       | ENME-MECE E3105 (4) either semester | | | |
| **CIVIL ENGINEERING** | CIEN E1201 (3) or equivalent | | CIEN E3004 (3) | Urban infra. systems |
|                      | HUMA C1001, C0CI C1101, HUMA W1121 or W1123 (3) | | HUMA C1002, C0CI C1102, or Major Cultures (3–4) |
|                      | (three tracks, choose one) | | | |
| **ENGLISH COMPOSITION** | C1010 (3) | C1010 (3) | C1010 (3) | |
| (three tracks, choose one) | Z1003 (0) | Z1003 (0) | Z1003 (0) | |
| **REQUIRED NONTECHNICAL ELECTIVES** | | | | |
| **COMPUTER SCIENCE** | Computer Language: W1005 (3) or W1003 (3) or W1004 (3) (any semester) | | | |
| **PHYSICAL EDUCATION** | C1001 (1) | C1002 (1) | | |
| **GATEWAY LAB**      | E1102 (4) either semester | | | |

1 EAEE is recommended for students concentrating in environmental engineering and water resources.
## CIVIL ENGINEERING: THIRD AND FOURTH YEARS

<table>
<thead>
<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CORE REQUIRED COURSES</strong></td>
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<td></td>
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<tr>
<td>ENME E3113 (3) Mech. of solids</td>
<td>CIEN E3125 (3) Structural design</td>
<td>CIEN E4111 (3) Uncertainty &amp; risk in infrastructure systems</td>
<td>CIEN E3128 (4) Design projects</td>
</tr>
<tr>
<td>ENME E3161 (4) Fluid mech.</td>
<td>CIEN E3126 (1) Computer-aided struct. design</td>
<td>CIEN E3129 (3) Proj. mgmt. for construction</td>
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<tr>
<td></td>
<td>CIEN E3141 (4) Soil mech.</td>
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<tr>
<td><strong>GEOTECH ENG. (GE) OR STRUCT. ENG. (SE)</strong></td>
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<tr>
<td>ENME E3106 (3) Dynamics &amp; vibrations</td>
<td>ENME E3114 (4) Exper. mech. of materials</td>
<td>CIEN E4332 (3) Finite element anal.</td>
<td>CIEN E3128 (4) Design projects</td>
</tr>
<tr>
<td>CIEN E3121 (3) Struct. anal.</td>
<td></td>
<td>CIEN E3127 (3) Struct. design projects (SE) or CIEN E4241 (3) Geotech. eng. fund. (GE)</td>
<td></td>
</tr>
<tr>
<td>CIEE E3250 (3) Hydrosystems eng.</td>
<td>CIEN E3127 (3) or CIEN E4241 (3)</td>
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<tr>
<td><strong>TECH ELECTIVES</strong></td>
<td>3 points</td>
<td>3 points</td>
<td>12 points</td>
</tr>
<tr>
<td><strong>CIVIL ENG. &amp; CONSTR. MNGMT.</strong></td>
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<tr>
<td>CIEE E3255 (3) Environ. control / pollution</td>
<td>CIEN E4333 (3) Capital facility planning &amp; financing</td>
<td>CIEN E4131 (3) Princ. of constr. tech.</td>
<td>CIEN E3128 (4) Design projects</td>
</tr>
<tr>
<td>CIEE E3250 (3) Hydrosystems eng.</td>
<td>CIEN E3127 (3) or CIEN E4241 (3)</td>
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<tr>
<td>CIEN E3303 (1) Independent studies</td>
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<tr>
<td><strong>TECH ELECTIVES</strong></td>
<td>6 points</td>
<td>3 points</td>
<td>9 points</td>
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<tr>
<td><strong>WATER RES./ENVIRON. ENG.</strong></td>
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<tr>
<td>CIEE E3255 (3) Environ. control / pollution</td>
<td>CIEN E4163 (3) Environ. eng. wastewater</td>
<td>CIEN E4250 (3) Waste containm. design &amp; practice or CIEN E4257 (3) contam. transport in subsurface sys.</td>
<td></td>
</tr>
<tr>
<td>CIEE E3250 (3) Hydrosystems eng.</td>
<td>CIEE E4260 (4) Urban ecology studio</td>
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<tr>
<td>CIEN E3303 (1) Independent studies</td>
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<tr>
<td><strong>TECH ELECTIVES</strong></td>
<td>6 points</td>
<td>3 points</td>
<td>9 points</td>
</tr>
<tr>
<td><strong>NONTECH ELECTIVES</strong></td>
<td>3 points</td>
<td>3 points</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL POINTS</strong></td>
<td>16</td>
<td>17</td>
<td>15 (water res./environ. eng. 16)</td>
</tr>
</tbody>
</table>
of civil engineering or other engineering disciplines.

The engineering mechanics program provides a strong analytical background in mechanics for students planning to continue on to graduate school and to pursue research. Admission to the engineering mechanics program requires a grade point average of B or better and maintenance of performance while in the program.

Program Objectives

In developing and continually updating our program to achieve the stated mission of the Department, we seek to achieve the following objectives:

1. To provide a firm foundation in the basic math, science, and engineering sciences that underlie all technological development so our graduates will be well equipped to adapt to changing technology in the profession.

2. To provide the broad and fundamental technical base needed by graduates who will enter the profession through the increasingly common path of a specialized M.S., but also provide suitable preparation to those who choose to enter the professional workforce with a B.S. to develop specialized expertise by way of apprenticeship.

3. To provide the breadth and choices in our programs that can accommodate and foster not only students with differing technical objectives, but also those who will use their technical background to follow other career paths.

4. To provide a basis for effective writing and communication as well as a background to foster awareness of societal issues.

Engineering Mechanics

The prerequisites for this program are the courses listed in the First Year–Sophomore Program, or their equivalents, with the provision that **ENME E3105: Mechanics** be taken in the sophomore year and that the student have obtained a grade of B or better.

Civil Engineering

The prerequisites for this program are the courses listed in the First Year–Sophomore Program or their equivalents. The civil engineering program

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### Engineering Mechanics Program: First and Second Years

<table>
<thead>
<tr>
<th></th>
<th>Semester I</th>
<th>Semester II</th>
<th>Semester III</th>
<th>Semester IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mathematics</strong></td>
<td>Math V1101 (3)</td>
<td>Math V1102 (3)</td>
<td>Math V1201 (3)</td>
<td>Math V1202 (3) and ODE (3)</td>
</tr>
<tr>
<td><strong>Physics</strong></td>
<td>C1401 (3)</td>
<td>C1402 (3)</td>
<td>Lab C1493 (3) or chem. lab</td>
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<tr>
<td></td>
<td>C1601 (3.5)</td>
<td>C1602 (3.5)</td>
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<tr>
<td></td>
<td>C2801 (4.5)</td>
<td>C2802 (4.5)</td>
<td>Lab C3081 (2)</td>
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</tr>
<tr>
<td><strong>Chemistry</strong></td>
<td>one-semester lecture (3–4): C1403 or C1404 or C3045 or C1604 Chem lab C1500 (3) either semester or physics lab</td>
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<tr>
<td><strong>Mechanics</strong></td>
<td></td>
<td>ENME-MECE E3105 (4) any semester</td>
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<tr>
<td><strong>English Composition</strong></td>
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<tr>
<td></td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
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<td>Z1003 (3)</td>
<td>Z1003 (3)</td>
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<td></td>
<td>Z1006 (3)</td>
<td></td>
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<tr>
<td><strong>Required Non-technical Electives</strong></td>
<td>HUMA C1001, C0CI C1101, or Major Cultures (3–4)</td>
<td>HUMA C1002, C0CI C1102 or Major Cultures (3–4)</td>
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<tr>
<td></td>
<td>HUMA W1121 or W1123 (3)</td>
<td></td>
<td>ECON W1105 (4) and W1155 recitation (0)</td>
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<tr>
<td><strong>Required Tech Electives</strong></td>
<td>(3) Student’s choice, see list of first- and second-year technical electives (professional-level courses; see page 12)</td>
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<tr>
<td><strong>Computer Science</strong></td>
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<tr>
<td></td>
<td>Computer Language: W1005 (3), W1003 (3) or W1004 (3) (any semester)</td>
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<tr>
<td><strong>Physical Education</strong></td>
<td>C1001 (1)</td>
<td>C1002 (1)</td>
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<tr>
<td><strong>Gateway Lab</strong></td>
<td>E1102 (4) either semester</td>
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</tbody>
</table>
offers four areas of concentration: civil engineering and construction management, geotechnical engineering, structural engineering, and water resources/environmental engineering. An optional minor can be selected in architecture, education, economics, and any of the engineering departments in the School. In the junior and senior years, 18 credits of technical electives are allocated.

The department offers a first-year design course, CIEN E1201: Design of buildings, bridges, and spacecraft, which all students are required to take in the spring semester of the first year or later. An equivalent course could be substituted for E1201.

**Minor in Architecture**

Civil engineering program students may want to consider a minor in architecture (see page 187).

**GRADUATE PROGRAMS**

The Department of Civil Engineering and Engineering Mechanics offers graduate programs leading to the degree of Master of Science (M.S.), the professional degrees Civil Engineer and Mechanics Engineer and the degrees of Doctor of Engineering Science (Eng.Sc.D.) and Doctor of Philosophy (Ph.D.). These programs are flexible and may involve concentrations in structures, construction engineering, reliability and random processes, soil mechanics, fluid mechanics, hydrogeology, continuum mechanics, finite element methods, computational mechanics, experimental mechanics, acoustics, vibrations and dynamics, earthquake engineering, or any combination thereof, such as fluid-structure interaction. The Graduate Record Examination (GRE) is required for admission to the department.

**Civil Engineering**

By selecting technical electives, students may focus on one of several areas of concentration or prepare for future endeavors such as architecture. Some typical concentrations are:

- **Structural engineering:** applications to steel and concrete buildings, bridges, and other structures
- **Geotechnical engineering:** soil mechanics, engineering geology, and foundation engineering
- **Construction engineering and management:** capital facility planning and financing, strategic management, managing engineering and construction processes, construction industry law, construction techniques, managing civil infrastructure systems, civil engineering and construction entrepreneurship

- **Environmental engineering and water resources:** transport of waterborne substances, hydrology, sediment transport, hydrogeology, and geoenvironmental design of containment systems

**Engineering Mechanics**

Programs in engineering mechanics offer comprehensive training in the principles of applied mathematics and continuum mechanics and in the application of these principles to the solution of engineering problems. The emphasis is on basic principles, enabling students to choose from among a wide range of technical areas. Students may work on problems in such disciplines as systems analysis, acoustics, and stress analysis, and in fields as diverse as transportation, environmental, structural, nuclear, and aerospace engineering. Program areas include:

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### ENGINEERING MECHANICS: THIRD AND FOURTH YEARS

<table>
<thead>
<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
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</thead>
<tbody>
<tr>
<td><strong>REQUIRED COURSES</strong></td>
<td></td>
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</tr>
<tr>
<td>ENME E3161 (4) Fluid mechanics</td>
<td>CIEN E3121 (3) Structural analysis</td>
<td>ENME E4113 (3) Advanced solids</td>
<td></td>
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<tr>
<td>APMA E3101 (3) Applied math. I</td>
<td>APMA E3102 (3)</td>
<td>ENME E4215 (3) Theory of vibrations</td>
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<tr>
<td>ENME E3106 (3) Dynamics &amp; vibrations</td>
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<tr>
<td><strong>ELECTIVES</strong></td>
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<tr>
<td></td>
<td>3 points</td>
<td>6 points</td>
<td>9 points</td>
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<tr>
<td><strong>NONTECH</strong></td>
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<td></td>
<td></td>
<td>3 points</td>
<td>3 points</td>
</tr>
<tr>
<td><strong>TOTAL POINTS</strong></td>
<td>16</td>
<td>16</td>
<td>18</td>
</tr>
</tbody>
</table>
• Continuum mechanics: solid and fluid mechanics, theories of elastic and inelastic behavior, and damage mechanics
• Vibrations: nonlinear and random vibrations; dynamics of continuous media, of structures and rigid bodies, and of combined systems, such as fluid-structure interaction; active, passive, and hybrid control systems for structures under seismic loading; dynamic soil-structure interaction effects on the seismic response of structures
• Random processes and reliability: problems in design against failure under earthquake, wind, and wave loadings; noise, and turbulent flows; analysis of structures with random properties
• Fluid mechanics: turbulent flows, two-phase flows, fluid-structure interaction, fluid-soil interaction, flow in porous media, computational methods for flow and transport processes, and flow and transport in fractured rock under mechanical loading
• Computational mechanics: finite element and boundary element techniques, symbolic computation, and bioengineering applications

A flight structures program is designed to meet the needs of industry in the fields of high-speed and space flight. The emphasis is on mechanics, mathematics, fluid dynamics, flight structures, noise transmission, and control. The program is a part of the Guggenheim Institute of Flight Structures in the department. Specific information regarding degree requirements is available in the department office.

COURSES IN CIVIL ENGINEERING

See also Engineering Mechanics.

CIEN 1201y The art of structural design
Lect: 3. 3 pts. Professor Deodatis.
Introduction to the basic scientific and engineering principles used for the design of buildings, bridges, and other parts of the built infrastructure. Application of these principles to the analysis and design of a number of actual large-scale structures. Experimental verification of these principles through laboratory experiments. Coverage of the history of major structural design innovations and of the engineers who introduced them. Critical examination of the unique aesthetic/artistic perspectives inherent in structural design. Consideration of management, socioeconomic, and ethical issues involved in the design and construction of large-scale structures. Introduction to some recent developments in sustainable engineering, including green building design and adaptable structural systems.

Every student in the course will be exposed with equal emphasis to issues related to geotechnical engineering, water resources/environmental engineering, structural engineering, and construction engineering and management.

CIEN E3129x Project management for construction
Lect: 3. 3 pts. Professor Taylor.
Prerequisite: senior standing in civil engineering or permission of the instructor. Introduction to project management for design and construction processes. Elements of planning, estimating, scheduling, bidding, and contractual relationships. Computer scheduling and cost control. Critical path method: Design and construction activities. Field supervision.

CIEN E3141y Soil mechanics
Lect: 3. Lab: 3. 4 pts. Professor Ling.
Prerequisite: ENME E3113. Index properties and classification; compaction; permeability and seepage; effective stress and stress distribution; consolidation; shear strength of soil; consolidation; slope stability.

CIEE E3250y Hydrosystems engineering
Lect: 3. 3 pts. Professor Gong.
Prerequisite(s): CHEN E3110 or ENME E3161 or equivalent, SIEO W3600 or equivalent, or the instructor’s permission. A quantitative introduction to hydrologic and hydraulic systems, with a focus on integrated modeling and analysis of the water cycle and associated mass transport for water resources and environmental engineering. Coverage of unit hydrologic processes such as precipitation, evaporation, infiltration, runoff generation, open channel and pipe flow, subsurface flow and well hydraulics in the context of example watersheds and specific integrative problems such as risk-based design for flood control, provision of water, and assessment of environmental impact or potential for non-point source pollution. Spatial hydrologic analysis using GIS and watershed models. Note: This course is to be joint listed with CIEN, and replaces the previous CIEN 3250.

CIEE E3255y Environmental control and pollution reduction systems
Lect: 3. 3 pts. Professor Castaldi.
Prerequisite: ENME E3161 or MECE E3100. Review of engineered systems for prevention and control of pollution. Fundamentals of material and energy balances and reaction kinetics. Analysis of engineered systems to address environmental problems, including solid and hazardous waste, and air, water, soil, and noise pollution. Life cycle assessments and emerging technologies.

CIEN E3303x and y Independent studies in civil engineering for juniors
1–3 pts. By conference. The faculty.
A project on civil engineering subjects approved by the chairman of the department. Lab fee: $200.
CIEN E3304x and y Independent studies in civil engineering for seniors
1–3 pts. By conference. The faculty.
A project on civil engineering subjects approved by the chairman of the department. Lab fee: $200.

CIEN E4010y Transportation engineering
Lect: 3. 3 pts. Professor Peterson.
Comprehensive multidisciplinary course in engineering and planning design principles applied to understanding major transportation systems, from people to planes. Fundamentals of pedestrian, road, rail, aviation and marine planning, designing, financing, legislat ing, and analyzing. Engineering principles of human control, vehicles, feedback control and signal systems, lane systems, energy, goods movement, networks, and parking. Novel system design presentation.

CIEN E4021x Elastic and plastic analysis of structures
Lect: 3. 3 pts. Professor Meyer.
Prerequisite: CIEN E3121 or the equivalent. Overview of classical indeterminate structural analysis methods (force and displacement methods), approximate methods of analysis, plastic analysis methods, collapse analysis, shakedown theorem, structural optimization.

CIEN E4022y Bridge design and management
Lect: 3. 3 pts. Professor Yanev.

CIEN E4100y Earthquake and wind engineering
Prerequisite: ENME E3106 or the equivalent. Basic concepts of seismology. Earthquake characteristics, magnitude, response spectrum, dynamic response of structures to ground motion. Base isolation and earthquake-resistant design. Wind loads and aeroelastic instabilities. Extreme winds. Wind effects on structures and gust factors.

CIEN E4111x Uncertainty and risk in infrastructure systems
Lect: 3. 3 pts. Professor Smyth.
Prerequisites: Working knowledge of calculus. Introduction to basic probability; hazard function; reliability function; stochastic models of natural and technological hazards; extreme value distributions; Monte Carlo simulation techniques; fundamentals of integrated risk assessment and risk management; topics in risk-based insurance; case studies involving civil infrastructure systems, environmental systems, mechanical and aerospace systems, construction management.

CIEN E4129x and y Managing engineering and construction processes
Lect: 3. 3 pts. Professor Nagaraja.
Prerequisite: Senior standing in civil engineering or the instructor’s permission. Introduction to the principles, methods, and tools necessary to manage design and construction processes. Elements of planning, estimating, scheduling, bidding, and contractual relationships. Valuation of project cash flows. Critical path method. Survey of construction procedures. Cost control and effectiveness. Field supervision.

CIEN E4130x Design of construction systems
Lect: 3. 3 pts. Professor Tirolo.
Prerequisite: CIEN E3125 or the equivalent, or the instructor’s permission. Introduction to the design of systems that support construction activities and operations. Determination of design loads during construction. Design of excavation support systems, earth retaining systems, temporary supports and underpinning, concrete formwork and shoring systems. Cranes and erection systems. Tunneling systems. Instrumentation and monitoring. Students prepare and present term projects.

CIEN E4131x and y Principles of construction techniques
Lect: 3. 3 pts. Professors Hart and Papachristos.
Prerequisite: CIEN E4129 or the equivalent. Current methods of construction, cost-effective designs, maintenance, safe work environment. Design functions, constructability, site and environmental issues.

CIEN E4132y Prevention and resolution of construction disputes
Lect: 3. 3 pts. Professor Nikain.
Prerequisite: CIEN E4129 or the equivalent. Contractual relationships in the engineering and construction industry and the actions that result in disputes. Emphasis on procedures required to prevent disputes and resolve them quickly and cost-effectively. Case studies requiring oral and written presentations.

CIEN E4133x Capital facility planning and financing
Lect: 3. 3 pts. Professor Chang.
Prerequisite: CIEN E4129 or the equivalent. Planning and financing of capital facilities with a strong emphasis upon civil infrastructure systems. Project feasibility and evaluation. Design of project delivery systems to encourage best value, innovation, and private sector participation. Fundamentals of engineering economy and project finance. Elements of life-cycle cost estimation and decision analysis. Environmental, institutional, social, and political factors. Case studies from transportation, water supply, and wastewater treatment.

CIEN E4134y Construction industry law
Lect: 3. 3 pts. Professors Rubin and Quintas.
Prerequisite: Graduate standing or the instructor’s permission. Practical focus upon legal concepts applicable to the construction industry. Provides sufficient understanding to manage legal aspects, instead of being managed by them. Topics include contractual relationships, contract performance, contract flexibility and change orders, liability and negligence, dispute avoidance/resolution, surety bonds, insurance, and site safety.

CIEN E4135y Strategic management in design and construction
Lect. 3. 3 pts. Professor Taylor.
Corequisite: CIEN E4129 or the equivalent. Core concepts of strategic planning, management, and analysis within the construction industry. Industry analysis, strategic planning models, and industry trends. Strategies for information technology, emerging markets, and globalization. Case studies to demonstrate key concepts in real-world environments.

CIEN E4136y Entrepreneurship in civil engineering and construction
Lect: 3. 3 pts. Professor Taylor.
Prerequisite: CIEN E4129, CIEN E4134, or the equivalent. Capstone practicum where teams develop strategies and business plans for a new enterprise in the engineering and construction industry. Identification of attractive market segments and locations; development of an entry strategy; acquisition of financing, bonding, and insurance; organizational design; plans for recruiting and retaining personnel; personnel compensation/incentives. Invited industry speakers.

CIEN E4163x Environmental engineering: wastewater
Lect: 3. 3 pts. Professor Becker.
Prerequisites: Introductory chemistry (with laboratory) and fluid mechanics. Fundamentals of water pollution and wastewater characteristics. Chemistry, microbiology, and reaction kinetics. Design of primary, secondary, and advanced treatment systems. Small community and residential systems.

CIEN E4210x Forensic structural engineering
Lect: 3. 3 pts. Professor Ratay.
Prerequisite: CIEN E3125 or the equivalent. Review of significant failures, civil/structural engineering design and construction practices, ethical standards and the legal positions as necessary background to forensic engineering. Discussion of standard-of-care. Study of the process of engineering evaluation of structural defects and failures in construction and in service. Examination of the roles, activities, conduct, and ethics of the forensic consultant and expert witness. Students are assigned projects of actual cases of nonperformance or failure of steel, concrete, masonry, geotechnical and temporary structures, in order to perform, discuss, and report their own investigations under the guidance of the instructor.

CIEN E4212x Structural assessment and failure
Lect: 3. 3 pts. Professor Testa.
Prerequisites: ENME E3113 and CIEN E3121.
Laboratory and field test methods in assessment of structures for rehabilitation and to determine causes of failure; ASTM and other applicable standards; case histories of failures and rehabilitation in wood, steel, masonry, and concrete structures.

CIEN E4213x Elastic and inelastic buckling of structures
Lect: 3. 3 pts. Professor Laufs.

CIEN E4226y Advanced design of steel structures
Lect: 3. 3 pts. Professor Harris.
Prerequisite: CIEN E3125 or the equivalent. Review of loads and structural design approaches. Material considerations in structural steel design. Behavior and design of rolled steel, welded, cold-formed light-gauge, and composite concrete/steel members. Design of multi-story buildings and space structures.

CIEN E4232y Advanced design of concrete structures
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: CIEN E3125 or the equivalent. Design of concrete slabs, deep beams, walls, and other plane structures; introduction to design of prestressed concrete structures.

CIEN E4233x Design of large-scale bridges
Lect: 3. 3 pts. Professor Zoli.
Prerequisites: CIEN E3121 or the equivalent and CIEN E3127 or the equivalent. Design of large-scale and complex bridges, with emphasis on cable-supported structures. Static and dynamic loads, component design of towers, superstructures, and cables; conceptual design of major bridge types, including arches, cable-stayed bridges, and suspension bridges.

CIEN E4234y Design of large-scale building structures
Lect: 3. 3 pts. Professors Tomasetti, Brazil, Panariello, and Gottlieb.
Prerequisites: CIEN E3121 and CIEN E3127. Modern challenges in the design of large-scale building structures will be studied. Tall buildings, large convention centers, and major sports stadiums present major opportunities for creative solutions and leadership on the part of engineers. This course is designed to expose the students to this environment by having them undertake the complete design of a large structure from initial design concepts through all the major design decisions. The students work as members of a design team to overcome the challenges inherent in major projects. Topics include overview of major projects, project criteria, and interface with architecture, design of foundations and structural systems, design challenges in the post 9/11 environment and roles, responsibilities, and legal issues.

CIEN E4241x Geotechnical engineering fundamentals
Lect: 3. 3 pts. Professor Mohammad.
Prerequisite: CIEN E3141 or the instructor’s permission. Bearing capacity and settlement of shallow and deep foundations; earth pressure theories; retaining walls and reinforced soil retaining walls; sheet pile walls; braced excavation; slope stability.

CIEN E4242x Geotechnical earthquake engineering
Lect: 3. 3 pts. Professor Ling.
Prerequisite: CIEN E3141 or the equivalent. Seismicity, earthquake intensity, propagation of seismic waves, design of earthquake motion, seismic site response analysis, in situ and laboratory evaluation of dynamic soil properties, seismic performance of underground structures, seismic performance of port and harbor facilities, evaluation and mitigation of soil liquefaction and its consequences. Seismic earth pressures, slope stability, safety of dams and embankments, seismic code provisions and practice. To alternate with E4244.

CIEN E4243x Foundation engineering
Lect: 3. 3 pts. Professor Burke.
Prerequisite: CIEN E3141 or the equivalent. Conventional types of foundations and foundation problems: subsurface exploration and testing. Performance of shallow and deep foundations and evaluation by field measurements. Case histories to illustrate typical design and construction problems. To alternate with CIEN E4246.

CIEN E4244y Geosynthetics and waste containment
Lect: 3. 3 pts. Professor Brant.
Prerequisite: CIEN E4241 or the equivalent. Properties of geosynthetics. Geosynthetic design for soil reinforcement. Geosynthetic applications in solid waste containment system. To alternate with CIEN E4242.

CIEN E4246x Earth retaining structures
Lect: 3. 3 pts. Professor Leifer.
Prerequisite: CIEN E3141. Retaining structures, bulkheads, cellular cofferdams, and braced excavations. Construction dewatering and underpinning. Instrumentation to monitor actual performances. Ground improvement techniques, including earth reinforcement, geotextiles, and grouting. To alternate with CIEN E4243.

CIEN E4250y Waste containment design and practice
Prerequisites: CIEN E3141 or the equivalent; ENME E3161 or the equivalent. Strategies for the containment of buried wastes. Municipal and hazardous waste landfill design; bioreactor landfills; vertical barriers, evapo-transpiration barriers and capillary barriers; hydraulic containment; in situ stabilization and solidification techniques; site investigation; monitoring and stewardship of buried wastes; options for land reuse/redevelopment.

CIEN E4252x Environmental engineering
Lect: 3. 3 pts. Professor Gong.
Prerequisites: CHEM C1403, or the equivalent; ENME E3161 or the equivalent. Engineering aspects of problems involving human interaction with the natural environment. Review of fundamental principles that underlie the discipline of environmental engineering, i.e., constituent transport and transformation processes in environmental media such as water, air, and ecosystems. Engineering applications for addressing environmental problems such as water quality and treatment, air pollutant emissions, and hazardous waste remediation. Presented in the context of current issues facing practicing engineers and government agencies, including legal and regulatory framework, environmental impact assessments, and natural resource management.

CIEN E4253y Finite elements in geotechnical engineering
Prerequisites: CIEN E3141 and CIEN E4332. State-of-the-art computer solutions in geotechnical engineering; 3-D consolidation, seepage flows, and soil-structure interaction; element and mesh instabilities. To be offered in alternate years with CIEN E4254.

CIEN E4255y Flow in porous media
Prerequisite: CIEN E3250 or the equivalent. Principles of groundwater flow, steady and transient flow through porous media; pumping tests, well hydraulics, potential theory; parameter identification and calibration of groundwater flow models; stochastic description of heterogeneous porous media; physically based numerical models for solution of groundwater problems; geostatistical simulation applications to groundwater problems; unsaturated flow problems.

CIEN E4257y Contaminant transport in subsurface systems
Lect: 3. 3 pts. Professor Mutch.
Prerequisite: CIEN E3250 or the equivalent. Single and multiple phase transport in porous media; contaminant transport in variably saturated heterogeneous geologic media; physically based numerical models of such processes.

CIEE E4260x Urban ecology studio
Lect: 3. Lab: 3. 4 pts. Professors Culligan and Lall.
Prerequisite: Senior standing or the instructor’s permission. Joint studio run with the Graduate School of Architecture, Planning and Preservation
(GSAPP) that explores solutions to problems of urban density. Engineering and GSAPP students will engage in a joint project that addresses habitability and sustainability issues in an urban environment and also provides community service. Emphasis will be on the integration of science, engineering, and design within a social context. Interdisciplinary approaches and communication will be stressed. The studio can be used as a replacement for the capstone design project in CEEM water resources/environmental engineering concentration, or the undergraduate design project in Earth and Environmental Engineering.

CIEN E4332x Finite element analysis, I
Lect: 3. 3 pts. Professor Betti.

CIEN E6131x Managing risk in global civil infrastructure systems
Lect: 3. 3 pts. Professor Chiara.
Prerequisites: IOR E4003 or CIEN E4133, or the equivalent. Examination of the fundamentals of infrastructure planning and management with a focus on the application of rational methods to support decision-making about infrastructure systems. Institutional environment and issues; decision-making under certainty and uncertainty; capital planning and financing; evaluation of system condition and performance; group decision processes. Elements of decision and finance theory.

CIEN E6132y Advanced systems and technologies in civil engineering and construction
Prerequisite: CIEN E4129 or the equivalent. Systems and technologies that support programming, design, and construction of capital projects, and methods for analyzing their effectiveness in improving value and performance. Decision support systems for capital programming and decision-making. Information technologies for visualization and project management, including Web-based applications. Emerging construction technologies such as automation and robotics.

CIEN E6246y Advanced soil mechanics
Prerequisite: CIEN E3141. Stress-dilatancy of sand; failure criteria; critical state soil mechanics; limit analysis; finite element method and case histories of consolidation analysis.

CIEN E6246x Experimental soil mechanics
Lect: 2.5. 3 pts. Professor Ling.
Prerequisite: CIEN E3141. Advanced soil testing, including triaxial and plane strain compression tests; small-strain measurement. Model testing; application (of test results) to design.

CIEN E6333y Finite element analysis, II

CIEN E9101x and y, and s Civil engineering research
1 to 4 pts. By conference. The faculty. Advanced study in a specialized field under the supervision of a member of the department staff. Before registering, the student must submit an outline of the proposed work for approval of the supervisor and the department chair.

CIEN E9120x and y, and s Independent studies in flight sciences
3 pts. By conference. Professor Vaičaitis. Prerequisite: the instructor’s permission. This course is geared toward students interested in flight sciences and flight structures. Topics related to aerodynamics, propulsion, noise, structural dynamics, aeroelastics, and structures may be selected for supervised study. A term paper will be required.

CIEN E9130x and y, and s Independent studies in construction
3 pts. By conference. Professor Wilson. Prerequisite: department chair’s and instructor’s permission. Independent study of engineering and construction industry problems. Topics related to capital planning and financing, project management, contracting strategies and risk allocation, dispute mitigation and resolution, and infrastructure assessment and management may be selected for supervised study. A term paper is required.

CIEN E9165x and y, and s Independent studies in environmental engineering
4 pts. By conference. The faculty. Prerequisite: CIEN E4252 or the equivalent. Emphasizes a one-on-one study approach to specific environmental engineering problems. Students develop papers or work on design problems pertaining to the treatment of solid and liquid waste, contaminant migration, and monitoring and sampling programs for remediation design.

CIEN E9201x and y, and s Civil engineering reports
1 to 4 pts. By conference. The faculty. A project on some civil engineering subject approved by the chairman.

CIEN E9800x and y, and s Doctoral research instruction
3, 6, 9, or 12 pts. The staff. A candidate for the Eng.Sc.D. degree in civil engineering must register for 12 points of doctoral research instruction. Registration in CIEN E9800 may not be used to satisfy the minimum residence requirement for the degree.

CIEN E9900x and y, and s Doctoral dissertation
The staff. A candidate for the doctorate may be required to register for this course every term after the student’s course work has been completed and until the dissertation has been accepted.

COURSES IN ENGINEERING MECHANICS
See also Civil Engineering.

ENME-MECE E3105x or y Mechanics
Lect: 4. 4 pts. Instructor to be announced. Prerequisites: PHYS C1402 and MATH V1101-V1102 and V1201. Elements of statics; dynamics of a particle and systems of particles; dynamics of rigid bodies.

ENME E3106x Dynamics and vibrations
Lect: 2. 3 pts. Professor Smyth. Prerequisite: MATH E1210. Corequisite: ENME E3105. Kinematics of rigid bodies; momentum and energy methods; vibrations of discrete and continuous systems; eigen-value problems; natural frequencies and modes. Basics of computer simulation of dynamic problems using MATLAB or Mathematica.

ENME E3113x Mechanics of solids

ENME E3114y Experimental mechanics of materials

ENME E3161x Fluid mechanics
Lect: 3. Lab: 3. 4 pts. Professor Culligan. Prerequisites: ENME E3105 and ordinary differ-
ENME E4113x Advanced mechanics of solids
Lect: 3.3 pts. Professor Chen.
Stress and deformation formulation in two- and three-dimensional solids; viscoelastic and plastic material in one and two dimensions.

ENME E4114y Mechanics of fracture and fatigue
Lect: 3.3 pts. Professor Testa.
Prerequisite: Undergraduate mechanics of solids course. Elastic stresses at a crack; energy and stress intensity criteria for crack growth; effect of plastic zone at the crack; fracture testing applications. Fatigue characterization by stress-life and strain-life; damage index; crack propagation; fail safe and safe life analysis.

ENME E4202y Advanced mechanics
Lect: 3.3 pts. Professor Smyth.

ENME E4214y Theory of plates and shells
Lect: 3.3 pts. Professor Dasgupta.
Prerequisite: ENME 3113. Static flexural response of thin, elastic, rectangular, and circular plates. Exact (series) and approximate (Ritz) solutions. Circular cylindrical shells. Axisymmetric and non-axisymmetric membrane theory. Shells of arbitrary shape.

ENME E4215x Theory of vibrations
Lect: 3.3 pts. Professor Betti.

ENME E6220x Random processes in mechanics
Lect: 2.5.3 pts. Professor Deodatis.
Prerequisite: ENME E4215 or the equivalent. Random variables, stationary and ergodic random processes, correlation functions, and power spectra. Input-output relations of linear systems: analysis of response of discrete and continuous structures to random loadings. Crossing rates, peak distributions, and response analysis of nonlinear structures to random loading. Simulation of stationary random processes.

ENME E6315x Theory of elasticity
Lect: 2.5.3 pts. Instructor to be announced.

ENME E8320y Viscoelasticity and plasticity
Prerequisite: ENME E6315 or the equivalent, or the instructor’s permission. Constitutive equations of viscoelastic and plastic bodies. Formulation and methods of solution of the boundary value, problems of viscoelasticity and plasticity.

ENME E8323y Nonlinear vibrations
Prerequisite: ENME E4215 or the equivalent. Free and forced motion of simple oscillators with nonlinear damping and stiffness. Exact, perturbation, iteration, and graphical methods of solution. Stability of motion. Chaotic vibrations.

COURSES IN GRAPHICS

GRAP E1115x or y Engineering graphics
Lect: 1. Lab: 3.3 pts. Mr. Sanchez.
Open to all students. Visualization and simulation in virtual environments; computer graphics methods for presentation of data. 3-D modeling; animation; rendering; image editing; technical drawing. Lab fee: $200.

GRAP E2005y Computer-aided engineering graphics
Prerequisite: CALC Is. Basic concepts needed to prepare and understand engineering drawings and computer-aided representations: preparation of sketches and drawings, preparation and transmission of graphic information. Lectures and demonstrations, hands-on computer-aided graphics laboratory work. Term project.

GRAP E3115x or y Advanced computer modeling and animation
Lect: 1. Lab: 3.3 pts. Mr. Sanchez.
Prerequisite: GRAP E1115 or the instructor’s permission. Explores applications of 3-D modeling, animation, and rendering techniques in the arts, architecture, engineering, entertainment, and science. Visualization through conceptual modeling and animation techniques for product design and realistic presentations. Lab fee: $200.

GRAP E4005y Computer graphics in engineering
Lect: 3.3 pts. Professor Dasgupta.
Prerequisites: Any programming language and linear algebra. Numerical and symbolic (algebraic) problem solving with Mathematica. Formulation for graphics application in civil, mechanical, and bioengineering. Example of two- and three-dimensional curve and surface objects in C++ and Mathematica; special projects of interest to electrical and computer science.
The computer engineering programs are run jointly by the Electrical Engineering and Computer Science Departments through a joint Computer Engineering Committee. Student records are kept in the Electrical Engineering Department.

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The computer engineering programs are run jointly by the Electrical Engineering and Computer Science Departments through a joint faculty committee. Students in the programs have two “home” departments. The Electrical Engineering Department maintains student records and coordinates advising appointments.

UNDERGRADUATE PROGRAM

This undergraduate program incorporates most of the core curricula in both electrical engineering and computer science so that students will be well prepared to work in the area of computer engineering, which substantially overlaps both fields. Both hardware and software aspects of computer science are included, and, in electrical engineering, students receive a solid grounding in circuit theory and in electronic circuits. The program includes several electrical engineering laboratory courses as well as the Computer Science Department’s advanced programming course.

Students will be prepared to work on all aspects of the design of digital hardware, as well as on the associated software that is now often an integral part of computer architecture. They will also be well equipped to work in the growing field of telecommunications. Students will have the prerequisites to delve more deeply into either hardware or software areas, and enter graduate programs in computer science, electrical engineering, or computer engineering. For example, they could take more advanced courses in VLSI, communications theory, computer architecture, electronic circuit theory, software engineering, or digital design.

Minors in electrical engineering and computer science are not open to computer engineering majors, due to excessive overlap.

Technical Electives

The Computer Engineering Program includes 15 points of technical electives. Any 3000-level or higher courses listed in the Computer Science or Electrical Engineering sections of this bulletin can be used for this requirement with the following exceptions: ELEN E3000, EEHS 3900/4900, EEJR E4901, COMS W3101, COMS W4400, COMS W4405, courses used for other computer engineering requirements (including COMS W3203 and either CSEE W4840 or EECS E4340), and courses that have significant overlap with other required or elective courses (e.g., COMS W3137 and COMS W3139). Up to one course may be chosen from outside the departments with adviser approval. Courses at the 3000 level or higher in other areas of engineering, math, and science can be considered for approval, as long as they do not significantly overlap with other required or elective courses. Economics courses cannot be used as technical electives.

Starting Early

Students are strongly encouraged to begin taking core computer engineering courses as sophomores. They start with ELEN E1201: Introduction to electrical engineering in the second semester of their first year and may continue with other core courses one semester after that. For sample “early-starting” programs, see the charts on the following two pages. It must be emphasized that these charts, as well as the “late-starting” charts that follow, present examples only; actual schedules may be customized in consultation with academic advisers.

GRADUATE PROGRAM

The Computer Engineering Program offers a course of study leading to the degree of Master of Science (M.S.). The basic courses in the M.S. program come from the Electrical Engineering and Computer Science Departments. Students completing the program are prepared to work (or study further) in such fields as digital computer design, digital communications, and the design of embedded computer systems.
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<tr>
<th>COMPUTER ENGINEERING PROGRAM: FIRST AND SECOND YEARS</th>
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<td>EARLY-STARTING STUDENTS</td>
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<th>SEMESTER I</th>
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<tr>
<td><strong>MATHEMATICS</strong></td>
<td>MATH V1101 (3)</td>
<td>MATH V1102 (3)</td>
<td>MATH V1201 (3)</td>
<td>MATH V1202 (3) and APMA E2101 (3)</td>
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<tr>
<td><strong>PHYSICS</strong> (three tracks, choose one)</td>
<td>C1401 (3)</td>
<td>C1402 (3)</td>
<td>Lab C1493 (3) or chem. lab C1500 (3)</td>
<td>C1401 (3) or chem. lab C1500 (3)</td>
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<td>C1601 (3.5)</td>
<td>C1602 (3.5)</td>
<td>Lab C1493 (3) or chem. lab C1500 (3)</td>
<td>C2801 (3.5) or chem. lab C1500 (3)</td>
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<td>C2801 (4.5)</td>
<td>C2802 (4.5)</td>
<td>Lab W3081 (2) or chem. lab C1500 (3)</td>
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<tr>
<td><strong>CHEMISTRY</strong></td>
<td>one-semester lecture (3–4)</td>
<td>ELEN E1201 (3.5)</td>
<td>ELEN E3801 (3.5)</td>
<td>ELEN E3081 (3.5) or E3082 (1)</td>
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<td>C1403 or C1404 or C3045 or C1604</td>
<td>Intro. to elec. eng. (either semester)</td>
<td>Signals &amp; systems</td>
<td>COMS W3137 (3) or W3139 (4) Data structures</td>
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<td>Lab C1500 (3) either semester or physics lab C1493 (3)</td>
<td>ELEN E3084 (1) Signals &amp; systems lab</td>
<td>ELEN E3082 (1) Digital systems lab</td>
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<tr>
<td><strong>CORE REQUIRED COURSES</strong></td>
<td>ELEN E1201 (3.5)</td>
<td>ELEN E3801 (3.5)</td>
<td>COMS W3137 (3) or W3139 (4) Data structures</td>
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<td>CSEE W3827 (3) Fund. of computer sys.</td>
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<tr>
<td><strong>REQUIRED LABS</strong></td>
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<td>ELEN E3084 (1) Signals &amp; systems lab</td>
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<td>ELEN E3082 (1) Digital systems lab</td>
</tr>
<tr>
<td><strong>ENGLISH COMPOSITION</strong></td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
<td></td>
</tr>
<tr>
<td>(three tracks, choose one)</td>
<td>Z1003 (0)</td>
<td>Z1003 (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>REQUIRED NONTECHNICAL ELECTIVES</strong></td>
<td>HUMA C1001, C0CI C1101, or Major Cultures (3–4)</td>
<td>HUMA W1121 or W1123 (3)</td>
<td>HUMA C1002, C0CI C1102, or Major Cultures (3–4)</td>
<td>ECON W1105 (4) and W1155 recitation (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>COMPUTER SCIENCE</strong></td>
<td>COMS W1004 (3)</td>
<td>COMS W1007 (3) or W1009</td>
<td>W3203 (3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Discrete math.</td>
<td></td>
</tr>
<tr>
<td><strong>PHYSICAL EDUCATION</strong></td>
<td>C1001 (1)</td>
<td>C1002 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GATEWAY LAB</strong></td>
<td>E1102 (4) either semester</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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1 Some of these courses can be postponed to the junior or senior year to make room for taking the required core computer engineering courses.
2 Only required if needed to prepare for COMS W1007/W1009.
3 APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2101.
Applicants are generally expected to have a bachelor’s degree in computer engineering, computer science, or electrical engineering with at least a 3.2 GPA in technical courses. The Graduate Record Examination (GRE), General Test only, is required of all applicants.

Students must take at least 30 points of courses at Columbia University at or above the 4000 level. These must include at least 15 points from the courses listed below that are deemed core to computer engineering. At least 6 points must be included from each department. CSEE and EECS courses can count toward either department minimum. Other courses may be chosen with the prior approval of a faculty adviser in the Computer Engineering Program.

### CORE COMPUTER ENGINEERING COURSES
- CSEE W4119: Computer networks
- CSEE W4140: Networking lab
- CSEE W4180: Network security
- CSEE W4823: Advanced logic design
- CSEE W4824: Computer architecture
- CSEE W4825: Digital systems design
- CSEE W4840: Embedded systems design
- CSEE W4861: Computer-aided design of digital systems
- CSEE E6180: Modeling and performance
- COMS E6181: Advanced internet services
- CSEE W6831: Sequential logic circuits
- CSEE W6832: Topics in logic design theory
- CSEE E6847: Distributed embedded systems
- ELEN E4321: Digital VLSI circuits
- ELEN E4332: VLSI design lab
- EECS E4340: Computer hardware design
- CSEE W6851: Computer-aided design of digital systems

### ELECTIVES

- **COURSE ENROLLMENT: CORE REQUIRED COURSES**

<table>
<thead>
<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIEO W3658 (3)</td>
<td>ELEN E3331 (3)</td>
<td>COMS W4118 (3)</td>
<td>COMS W4115 (3)</td>
</tr>
<tr>
<td>Probability</td>
<td>Electronic circuits</td>
<td>Operating systems</td>
<td>Programming lang.</td>
</tr>
<tr>
<td>COMS W3157 (3)</td>
<td>COMS W3261 (3)</td>
<td>or CSEE W4119 (3)</td>
<td>Computer networks</td>
</tr>
<tr>
<td>Advanced programming</td>
<td>Computer sci. theory</td>
<td>CSEE W4823 (3)</td>
<td></td>
</tr>
<tr>
<td>ELEN E3201 (3.5)</td>
<td>or CSEE W4840 (3)</td>
<td>Advanced logic design</td>
<td>ELEN E4340 (3)</td>
</tr>
<tr>
<td>Circuit analysis</td>
<td>or CSEE W4840 (3)</td>
<td>Embedded sys. design</td>
<td>or CSEE W4140 (4)</td>
</tr>
<tr>
<td></td>
<td>or CSEE W4840 (3)</td>
<td>Networking lab</td>
<td></td>
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- **REQUIRED LABS**

<table>
<thead>
<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEN E3081 (1)</td>
<td>ELEN E3083 (1)</td>
<td>ELEN E3083 (1)</td>
<td>ELEN E3083 (1)</td>
</tr>
<tr>
<td>Circuit analysis lab</td>
<td>Electronic circuits lab</td>
<td>Computer hardware design</td>
<td>Computer hardware design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>or CSEE W4840 (3)</td>
<td>or CSEE W4840 (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Embedded sys. design</td>
<td>Networking lab</td>
</tr>
<tr>
<td></td>
<td></td>
<td>or CSEE W4840 (3)</td>
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</table>

- **TOTAL POINTS**

<table>
<thead>
<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.5</td>
<td>17</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

For a discussion about programming languages used in the program, please see www.compeng.columbia.edu. Check the late-starting student chart for footnotes about various courses.

**Total points** assumes that 20 points of nontechnical electives and other courses are included.

ELEN E6761: Computer communication networks, I
ELEN E4898: Music signal processing
ELEN E6321: Advanced digital electronic circuits
ELEN E6762: Computer communication networks, II
ELEN E6850: Visual information systems
ELEN E6680: Advanced digital signal processing

The overall program must include at least 15 points of 6000-level ELEN, EECS, CSEE, or COMS courses (exclusive of seminars). No more than 9 points of research may be taken for credit. No more than 3 points of a nontechnical elective (at or above the 4000 level) may be included. A minimum GPA of at least 2.7 must be maintained, and all degree requirements must be completed within five years of the beginning of the first course credited toward the degree.

* Occasionally offered.
## Computer Engineering Program: First and Second Years
### Late-Starting Students

<table>
<thead>
<tr>
<th>Semester</th>
<th>Mathematics</th>
<th>Physics</th>
<th>Chemistry</th>
<th>Core Required Courses</th>
<th>English Composition</th>
<th>Required Nontechnical Electives</th>
<th>Computer Science</th>
<th>Physical Education</th>
<th>Gateway Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>MATH V1101 (3)</td>
<td>C1401 (3)</td>
<td>one-semester lecture (3–4)</td>
<td>ELEN E1201 (3.5)$^2$</td>
<td>C1010 (3)</td>
<td>HUMA C1001, COCI C1101, or Major Cultures (3–4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MATH V1102 (3)</td>
<td>C1402 (3)</td>
<td>C1403 or C1404 or C3045 or C1604</td>
<td>Intro. to elec. eng. (either semester)</td>
<td>Z1003 (0)</td>
<td>HUMA W1121 or W1123 (3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MATH V1201 (3)</td>
<td>C1601 (3.5)</td>
<td>C1602 (3.5)</td>
<td>HUMAN W1121 or W1123 (3)</td>
<td>Z0006 (0)</td>
<td>ECON W1105 (4) and W1155 recitation (0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MATH V1202 (3) and APMA E2101 (3)$^3$</td>
<td>C2801 (4.5)</td>
<td>C2802 (4.5)</td>
<td></td>
<td>C1010 (3)</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

1 Only required if needed to prepare for COMS W1007/W1009.
2 Transfer and combined-plan students are expected to have completed the equivalent of the first- and second-year program listed above before starting their junior year. Note that this includes some background in discrete math (see COMS W3203) and electronic circuits (see ELEN E1201). Transfer and combined-plan students are also expected to be familiar with Java before they start their junior year. If students must take the one-point Java course (COMS W3101-03) junior year, prerequisite constraints make it difficult to complete the remaining computer engineering program by the end of the senior year.
3 APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2010.
### COMPUTER ENGINEERING: THIRD AND FOURTH YEARS
#### LATE-STARTING STUDENTS

<table>
<thead>
<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CORE REQUIRED COURSES</strong></td>
<td><strong>REQUIRED LABS</strong></td>
<td><strong>TECH</strong></td>
<td><strong>NONTECH</strong></td>
</tr>
<tr>
<td>SIEO W3658 (3)(^1)</td>
<td>ELEN E3081 (1)(^2)</td>
<td>15 points required; see details on page 103(^4)</td>
<td>Complete 27-point requirement; see page 11 or <a href="http://www.seas.columbia.edu">www.seas.columbia.edu</a> for details (administered by the advising dean)</td>
</tr>
<tr>
<td>Probability</td>
<td>Circuit analysis lab</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMS W3137 (3) or W3139 (4)</td>
<td>ELEN E3084 (1)(^2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data structures</td>
<td>Signals &amp; systems lab</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELEN E3201 (3.5)</td>
<td>ELEN E3083 (1)(^2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circuit analysis</td>
<td>Electronic circuits lab</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELEN E3801 (3.5)</td>
<td>ELEN E3082 (1)(^2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signals &amp; systems</td>
<td>Digital systems lab</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL POINTS(^5)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>17</td>
<td>15</td>
<td>18</td>
</tr>
</tbody>
</table>

For a discussion about programming languages used in the program, please see www.compeng.columbia.edu.

\(^1\)SIEO W3600, SIEO W4105, STAT W4105, and SIEO W4150 can be used instead of SIEO W3658, but W3600 and W4150 may not provide enough probability background for elective courses such as ELEN E3701. Students completing an economics minor who want such a background can take SIEO W3658 and augment it with STAT W1211.

\(^2\)If possible, ELEN E3081 and ELEN E3084 should be taken along with ELEN E3201 and ELEN 3801 respectively, and ELEN E3083 and ELEN E3082 taken with ELEN E3331 and CSEE W3827 respectively.

\(^3\)COMS W3261 can be taken one semester later than pictured.

\(^4\)The total points of technical electives is reduced to 12 if APMA E2101 has been replaced by MATH E1210 and either APMA E3101 or MATH V2010.

\(^5\)Assuming technical electives taken Semesters VII and VIII, and 9 points of nontechnical electives taken Semesters VI, VII, and VIII.
The function and influence of the computer is pervasive in contemporary society. Today's computers process the daily transactions of international banks, the data from communications satellites, the images in video games, and even the fuel and ignition systems of automobiles.

Computer software is as commonplace in education and recreation as it is in science and business. There is virtually no field or profession that does not rely upon computer science for the problem-solving skills and the production expertise required in the efficient processing of information. Computer scientists, therefore, function in a wide variety of roles, ranging from pure theory and design to programming and marketing.

The computer science curriculum at Columbia places equal emphasis on theoretical computer science and mathematics and on experimental computer technology. A broad range of upper-level courses is available in such areas as artificial intelligence, computational complexity and the analysis of algorithms, combinatorial methods, computer architecture, computer-aided digital design, computer communications, databases, mathematical models for computation, optimization, and software systems.

Laboratory Facilities
The department has well-equipped lab areas for research in computer graphics, computer-aided digital design, computer vision, databases and digital libraries, data mining and knowledge discovery, distributed systems, mobile and wearable computing, natural-language processing, networking, operating systems, programming systems, robotics, user interfaces, and real-time multimedia.

The computer facilities include a shared infrastructure of Sun and Linux multiprocessor file servers, NetApp file servers, a student interactive teaching and research lab of high-end multimedia workstations, a Microsoft programming laboratory with 50 Windows XP workstations, a Unix/Linux laboratory with 45 Linux workstations, a large vonware system for teaching, a large cluster of

* Columbia Center for Computational Learning Systems
Linux servers for computational work, and a cluster of Sun servers. The research infrastructure includes hundreds of workstations and PCs running Solaris, Windows XP, Linux, and Mac OSX; 7 terabytes of disk space are backed up by a Sun StorEdge LT02 with a 100-tape library unit.

Research labs contain Puma 500 and IBM robotic arms; a UTAH-MIT dexterous hand; an Adept-1 robot; three mobile research robots; a real-time defocus range sensor; PC interactive 3-D graphics workstations with 3-D position and orientation trackers; prototype wearable computers, wall-sized stereo projection systems; see-through head-mounted displays; a networking testbed with three Cisco 7500 backbone routers, traffic generators, Ethernet switches, Sun Ray thin clients, and a 17-node (34CPU) IBM Netfinity cluster. The department uses a 3COM SIP IP phone system. The protocol was developed in the department.

The servers are connected on a gigabit network; all have remote consoles and remote power for easy maintenance after hours. The rest of the department’s computers are connected via a switched 100 Mb/s Ethernet network, which has direct connectivity to the campus OC-3 Internet and Internet2 gateways. The campus has 802.11a/b wireless LAN coverage.

The research facility is supported by a full-time staff of professional system administrators and programmers, aided by a number of part-time student system administrators.

**UNDERGRADUATE PROGRAM**

Computer science majors at Columbia study an integrated curriculum, partially in areas with an immediate relationship to the computer, such as programming languages, operating systems, and computer architecture, and partially in theoretical computer science and mathematics. A broad range of upper-level courses is available in topics such as artificial intelligence, natural language processing, computational complexity, analysis of algorithms, computer communications, combinational methods, computer architecture, computer-aided digital design, computer graphics, databases, mathematical models for computation, optimization, and programming environments. Thus, students obtain the background to pursue their interests both in applications and in theoretical developments.

Practical experience is an essential component of the computer science program. Undergraduate students are often involved in advanced faculty research projects using state-of-the-art computing facilities. Qualified majors sometimes serve as consultants at the Computer Center, which operates several labs with microcomputers and terminals available at convenient locations on the campus.

Upper-level students in computer science may assist faculty members with research projects, particularly in the development of software. Ongoing faculty projects include algorithmic analysis, computational complexity, software tool design, distributed computation, modeling and performance evaluation, computer networks, computer architecture, CAD for digital systems, computer graphics, programming environments, expert systems, natural language processing, computer vision, robotics, multicomputer design, user interfaces, VLSI applications, artificial intelligence, combinational modeling, virtual environments, and microprocessor applications. Students are strongly encouraged to arrange for participation by consulting individual faculty members.

Most graduates of the computer science program at Columbia step directly into career positions in computer science with industry or government, or continue their education in graduate degree programs. Many choose to combine computer science with a second career interest by taking additional programs in business administration, medicine, or other professional studies.

For further information on the undergraduate computer science program, please see the home page at www.cs.columbia.edu/education/undergrad and the Quick Guide at www.cs.columbia.edu/education/undergrad/seasguide.

**Technical Electives**

All technical electives except those noted in each track must be approved by the adviser. In every case, the technical elective course must be at the 3000 level or higher. All technical electives should be taken in computer science. With the adviser’s approval, however, courses in other departments may be taken as technical electives; in every such case, the subject of the course must have a strong and obvious con-
### COMPUTER SCIENCE PROGRAM: FIRST AND SECOND YEARS

<table>
<thead>
<tr>
<th></th>
<th>SEMESTER I</th>
<th>SEMESTER II</th>
<th>SEMESTER III</th>
<th>SEMESTER IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MATHEMATICS</strong></td>
<td>MATH V1101 (3)</td>
<td>MATH V1102 (3)</td>
<td>MATH V1201 (3)</td>
<td>COMS W3210 (3)</td>
</tr>
<tr>
<td><strong>PHYSICS</strong> (three tracks, choose one)</td>
<td>C1401 (3)</td>
<td>C1402 (3)</td>
<td>C1601 (3.5)</td>
<td>C1602 (3.5)</td>
</tr>
<tr>
<td></td>
<td>C2801 (4.5)</td>
<td>C2802 (4.5)</td>
<td>Chemistry or physics lab:</td>
<td>PHYS C1493 (3) or CHEM W3081 (2) or CHEM C1500 (3) or CHEM C3085 (4)</td>
</tr>
<tr>
<td><strong>CHEMISTRY</strong></td>
<td>one-semester lecture (3–4)</td>
<td>C1403 or C1404 or C3045 or C1604</td>
<td>Lab C1500 (3) either semester or physics lab</td>
<td></td>
</tr>
<tr>
<td><strong>ENGLISH COMPOSITION</strong> (three tracks, choose one)</td>
<td>C1010 (3)</td>
<td>Z1003 (0)</td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
</tr>
<tr>
<td></td>
<td>Z0006 (0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>REQUIRED NONTECHNICAL ELECTIVES</strong></td>
<td></td>
<td>ECON W1105 (4)</td>
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<td></td>
<td></td>
<td>and</td>
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<td></td>
<td></td>
<td>W1105 recitation (0)</td>
<td></td>
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<td></td>
<td></td>
<td>either semester</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>REQUIRED TECH ELECTIVES</strong></td>
<td>Professional-level course (3) (see page 12) either semester</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>COMPUTER SCIENCE</strong></td>
<td>COMS W1004 (3)</td>
<td>Intro. to computer science</td>
<td>COMS W1009 (3) or COMS W1007 (3)</td>
<td>Data structures and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>either semester</td>
<td>Object-oriented programming</td>
<td>COMS W3203 (3)</td>
</tr>
<tr>
<td><strong>PHYSICAL EDUCATION</strong></td>
<td>C1001 (1)</td>
<td>C1002 (1)</td>
<td>COMS W3137 (4)</td>
<td>COMS W3157 (4)</td>
</tr>
<tr>
<td><strong>GATEWAY LAB</strong></td>
<td>E1102 (4)</td>
<td></td>
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</tbody>
</table>

connection with computer science. COMS W4400: Computers and society and ELEN E4901: Telecommunication networks and applications are not acceptable as technical electives and are the only advanced computer science courses that cannot be taken as electives.

Students are encouraged to select one of the following five preapproved groupings of electives called "tracks." An advanced version of each track is available by invitation for qualified students who wish an extra opportunity for advanced learning.

The following courses are required as a preparation for all tracks: COMS W1004, W1007 (or W1009), W3137 (or W3139), W3157, W3203, W3210, W3251, W3261, CSEE W3827, and SIEO W4150 (SIEO W3600 is an accepted substitute for W4150). Collectively these courses are called the CS Core Curriculum.

Students who pass the Computer Science Advanced Placement (AP) Exam, either A or AB, with a 4 or 5 will receive 3 points of credit and exemption from COMS W1004.

Note: A maximum of one course passed with a grade of D may be counted toward the major or concentration.

**Track 1: Foundations of CS Track**

The foundations track is suitable for students who plan to concentrate on theoretical computer science in graduate school or in mathematical topics such as communications security or scientific computation in their career plans. Register for track course COMS E0001.

**REQUIRED:** 3 courses

- COMS W4231: Analysis of algorithms
- COMS W4236: Introduction to computational complexity
- COMS W4241: Numerical algorithms and complexity
### Computer Science: Third and Fourth Years

<table>
<thead>
<tr>
<th>Semester V</th>
<th>Semester VI</th>
<th>Semester VII</th>
<th>Semester VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Required Courses</strong></td>
<td><strong>Electives</strong></td>
<td><strong>Electives</strong></td>
<td><strong>Electives</strong></td>
</tr>
<tr>
<td>COMS W3251 (3) Computational lin. algebra</td>
<td>COMS W48xx course</td>
<td>3 points</td>
<td>6 points</td>
</tr>
<tr>
<td>COMS W3261 (3) Computer sci. theory</td>
<td>Any COMS 4000-level course except those countable toward the CS core or systems track</td>
<td>3 points</td>
<td>6 points</td>
</tr>
<tr>
<td>CSEE W3827 (3) Fund. of computer sys.</td>
<td>Any COMS 4000-level course except</td>
<td>3 points</td>
<td>12 points</td>
</tr>
<tr>
<td></td>
<td>those countable toward the CS core or</td>
<td>6 points</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>systems track</td>
<td></td>
<td>9 points</td>
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</table>

**Total Points**

<table>
<thead>
<tr>
<th>Semester V</th>
<th>Semester VI</th>
<th>Semester VII</th>
<th>Semester VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>15-16</td>
<td>15</td>
<td>9</td>
</tr>
</tbody>
</table>

The primary programming languages for the undergraduate major are C and Java, and students are expected to learn both at an early stage. The language for COMS W1004/W1007/W1009/W3137/W3139 is Java. COMS W1004 is waived for students who have had AP computer science in high school.

### Breadth: 2 courses

Any COMS 3000- or 4000-level courses except those countable toward the CS core or foundations of CS track

**Electives: any 5 courses from the following list**

- COMS W4203: Graph theory
- COMS W4205: Combinatorial theory
- COMS W4252: Computational learning theory
- COMS W4261: Introduction to cryptography
- COMS W4281: Quantum computing
- COMS W4444: Programming and problem solving
- COMS W4771: Machine learning
- COMS W4772: Advanced machine learning
- COMS W4995: Math foundations of machine learning
- COMS E6232: Analysis of algorithms, II
- COMS E6261: Advanced cryptography
- COMS E6717: Information theory
- COMS E6998: Approximation algorithms

### Track 2: Systems Track

The systems track is for students interested in the implementation of software and/or hardware systems. Register for track course COMS E0002.

**Required: 3 courses**

- COMS W4115: Programming languages and translators
- COMS W4118: Operating systems
- CSEE W4119: Networking

**Breadth: 2 courses**

Any COMS 3000- or 4000-level course except those countable for the CS core or systems track

**Electives: any 5 courses from the following list**

Any COMS W41xx course

### Track 3: Artificial Intelligence Track

The artificial intelligence track is for students interested in machine learning, robots, and systems capable of exhibiting "human-like" intelligence. A total of ten required, breadth, and elective courses are to be chosen from the following schedule. Register for track course COMS E0003.

**Required: 1 course**

COMS W4701: Artificial intelligence

### Plus any 2 courses from:

- COMS W4705: Natural language processing
- COMS W4731: Computer vision
- COMS W4733: Computational aspects of robotics
- COMS W4771: Machine learning

**Breadth: 2 courses**

Any 3-point COMS 3000- or 4000-level courses except those countable toward the CS core or elective courses for the artificial intelligence track

**Electives: up to 5 courses from the following list**

### Track 4: Applications Track

The applications track is for students interested in the implementation of interactive multimedia applications for the
Internet and wireless networks. Register for track course COMS E0004.

REQUIRED: 3 courses
COMS W4115: Programming languages and translators
COMS W4170: User interface design
COMS W4701: Artificial intelligence

BREADTH: 2 courses
Any COMS 3000- or 4000-level courses except those countable toward the CS core or applications tracks

ELECTIVES: 5 courses from the following list
Any COMS W41xx course
Any COMS W47xx course
COMS W3902: Undergraduate thesis
COMS W3998: Undergraduate projects in computer science
or COMS W4901: Projects in computer science
COMS W4995-W4996: Special topics in computer science, I and II (with adviser approval)

COMS E6901: Projects in computer science or other COMS E69xx course (with adviser approval)

Any COMS E69xx course (with adviser approval)
Note: No more than 6 units of project/thesis courses (COMS W3902, COMS W3998, COMS W4901, COMS E6901) can count toward the major.

Track 5: Vision and Graphics Track
Objective: The vision and graphics track exposes students to interesting new fields and focuses on visual information with topics in vision, graphics, human-computer interaction, robotics, modeling, and learning. Students learn about fundamental ways in which visual information is captured, manipulated, and experienced. Register for track course COMS E0005.

REQUIRED: 2 courses
COMS W4731: Computer vision
COMS W4160: Computer graphics

BREADTH: 2 courses
Any COMS 3000- or 4000-level courses except those countable toward the CS core or vision and graphics track

ELECTIVES: 6 courses from the following list
COMS W4162: Advanced computer graphics
COMS W4165: Pixel processing
COMS W4167: Computer animation
COMS W4170: User interface design
COMS W4172: 3D user interface design
COMS W4701: Artificial intelligence
COMS W4733: Computational aspects of robotics
COMS W4735: Visual interfaces to computers
COMS W4771: Machine learning
COMS W4995: Video game technology and design
COMS W3902: Undergraduate thesis
COMS W3998: Undergraduate projects in computer science

or COMS W4901: Projects in computer science
COMS W4995-W4996: Special topics in computer science, I and II (with adviser approval)

COMS E6901: Projects in computer science
Any COMS E691x course (with adviser approval)
Note: No more than 6 units of project/thesis courses (COMS W3902, COMS W3998, COMS W4901, COMS E6901) can count toward the major.

Track 6: Advanced
The advanced track of the B.S. in Computer Science provides extra opportunity for advanced learning. It comprises accelerated versions of the other five tracks. Entry is only by collective faculty invitation, extended to students who have already completed the core courses and the required courses for one of those tracks.

REQUIRED TRACK COURSES
A student designates one of the five other track areas and completes the set of required track courses for that track, prior to entry into the Advanced Track. There are two or three courses, depending on the designated area.

BREADTH REQUIREMENT
Two breadth courses of the designated track.

ELECTIVES
At least two 4000-level lecture courses from the menu for the designated track, plus two 6000-level courses in the designated track area.

THESIS
There is a required 6-point senior thesis.

INVITATION
Only the top 20% of computer science majors in course performance in computer science courses will be considered for invitation during the junior year. (A student in the advanced track who does not maintain this status may be required to return to his or her previously selected track area.)

GRADUATE PROGRAMS
The Department of Computer Science offers graduate programs leading to the degree of Master of Science, the professional degree of Computer Systems Engineer and the degree of Doctor of Philosophy. Both the Aptitude Test and Advanced Tests of the Graduate Record Examination (GRE) are required for admission to the department’s graduate programs. (Applicants for September admission should take the GREs by October of the preceding year. Applicants for January admission should take these exams by April of the preceding year.)

The course requirements in all programs are flexible, and each student is urged to design his or her own program under the guidance of a faculty adviser. The student’s program should focus on a particular field of computer science. Among the fields of graduate study in computer science are analysis of algorithms, artificial intelligence, expert systems, natural language understanding, computer vision, multicomputer design, VLSI applications, combinatorial modeling, combinatorial optimization, computational complexity, computer architecture and design, computer communications networks, computer graphics, database machines and systems, microprocessors, parallel computation, programming environments, programming languages, robotics, user interfaces, software design, computational biology, computer security, and machine learning.

Graduate students are encouraged actively to pursue research. Faculty members of the Department of Computer Science are engaged in experimental and theoretical research in most of the fields in which courses are offered. The degree of doctor of philosophy requires a dissertation based on the candidate’s original research, which is supervised by a faculty member.

The professional degree program also provides the student with the opportunity to specialize beyond the level of the Master of Science program. The program leading to the degree of Computer Systems Engineer is particularly suited to those who wish to advance their professional development after a period of industrial employment.

COURSES IN COMPUTER SCIENCE
COMS W1001x and y Introduction to information sciences
Lect: 3. 3 pts. Professor Cannon.
Basic introduction to concepts and skills in information sciences: human-computer interfaces, representing information digitally, organizing and searching information on the World Wide Web, principles of algorithmic problem solving, introduction to database concepts, introduction to programming in Python.

COMS W1003x or y Introduction to computer science and programming in C
Lect: 3. 3 pts. Instructor to be announced.
A general introduction to computer science concepts, algorithmic problem-solving capabilities,
and programming skills in C. Columbia University students may receive credit for only one of the following three courses: W1003, W1004, or W1005.

COMS W1004x or y Introduction to computer science and programming in Java
Lect: 3.3 pts. Professor Cannon.
A general introduction to computer science for science and engineering students interested in majoring in computer science or engineering. Covers fundamental concepts of computer science, algorithmic problem-solving capabilities, and introductory Java programming skills. Assumes no prior programming background. Columbia University students may receive credit for only one of the following three courses: W1003, W1004, or W1005.

COMS W1005x and y Introduction to computer science and programming in MATLAB
Lect: 3.3 pts. Paul Blaer.
A general introduction to computer science concepts, algorithmic problem-solving capabilities, and programming skills in MATLAB. Assumes no prior programming background. Columbia University students may receive credit for only one of the following three courses: W1003, W1004, or W1005.

COMS W1007x or y Object-oriented programming and design in Java
Lect: 3.3 pts. Professor Kender.
Prerequisites: COMS W1004 or AP Computer Science with a grade of 4 or 5. The second course for majors in computer science. A rigorous treatment of object-oriented concepts using Java as an example language. Development of sound programming and design skills, problem solving and modeling of real-world problems from science, engineering, and economics using the object-oriented paradigm.

COMS W1009x Honors introduction to computer science
Lect: 3.3 pts. Instructor to be announced.
Prerequisite: COMS W1004 or AP computer science with a grade of 4 or 5. An honors-level introduction to computer science, intended primarily for students considering a major in computer science. Computer science as a science of abstraction. Creating models for reasoning about and solving problems. The basic elements of computers and computer programs. Implementing abstractions using data structures and algorithms. Taught in Java.

ECBM E3060x Introduction to genomic information science and technology
Lect: 3.3 pts. Professor Anastassiou.
Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function and manipulation of the biomolecular sequences of nucleic acids and proteins. The role of enzymes and gene regulatory elements in natural biological functions as well as in biotechnology and genetic engineering. Recombination and other macromolecular processes viewed as mathematical operations with simulation and visualization using simple computer programming. This course shares lectures with ECBM E4060, but the work requirements differ somewhat.

COMS W3101x and y Programming languages
Lect: 1.1 pt. Instructors to be announced.
Prerequisite: fluency in at least one programming language. Introduction to a programming language. Each section is devoted to a specific language. Intended only for those who are already fluent in at least one programming language. Sections may meet for one hour per week for the whole term, for three hours per week for the first third of the term, or for two hours per week for the first six weeks. May be repeated for credit if different languages are involved.

COMS W3133x or y Data structures in C
Lect: 3.3 pts. Instructor to be announced.
Prerequisite: COMS W1003 or knowledge of C. Not intended for computer science majors. Data types and structures: arrays, stacks, singly and doubly linked lists, queues, trees, sets, and graphs. Programming techniques for processing such structures: sorting and searching, hashing, garbage collection. Storage management. Rudiments of the analysis of algorithms. Taught in C. Note: Due to significant overlap, students may receive credit for only one of the following four courses: COMS W3133, W3134, W3137, or W3139.

COMS W3134x or y Data structures in Java
Lect: 3.3 pts. Professor Hershkop.
Prerequisite: COMS W1004 or knowledge of Java. Not intended for computer science majors. Data types and structures: arrays, stacks, singly and doubly linked lists, queues, trees, sets, and graphs. Programming techniques for processing such structures: sorting and searching, hashing, garbage collection. Storage management. Rudiments of the analysis of algorithms. Taught in Java. Note: Due to significant overlap, students may receive credit for only one of the following four courses: COMS W3133, W3134, W3137, or W3139.

COMS W3137x and y Data structures and algorithms
Lect: 3.4 pts. x: Professor Allen; y: Instructor to be announced.
Prerequisite: COMS W1007. Corequisite: COMS W3203. An honors introduction to data types and structures: arrays, stacks, singly and doubly linked lists, queues, trees, sets, and graphs. Programming techniques for processing such structures: sorting and searching, hashing, garbage collection. Storage management. Design and analysis of algorithms. Taught in Java. Note: Due to significant overlap, students may receive credit for only one of the following four courses: COMS W3133, W3134, W3137, or W3139.

COMS W3139y Honors data structures and algorithms
Lect: 4.4 pts. Instructor to be announced.
Prerequisite: COMS W3137. Corequisite: COMS W3203. An honors introduction to data types and structures: arrays, stacks, singly and doubly linked lists, queues, trees, sets, and graphs. Programming techniques for processing such structures: sorting and searching, hashing, garbage collection. Storage management. Design and analysis of algorithms. Taught in C++. Note: Due to significant overlap, students may receive credit for only one of the following four courses: COMS W3133, W3134, W3137, or W3139.

COMS W3157x or y Advanced programming
Lect: 4.4 pts. Professor Schuldinser.
Prerequisite: COMS W1007 or W1009. Practical, hands-on introduction to programming techniques and tools for professional software construction, including learning how to write code to given specifications as well as document the results. Provides introductory overview of C and C++ in a UNIX environment, for students with Java background. Also introduces scripting languages (perl) and basic Web programming. UNIX programming utilities are also covered. Lab required.

COMS W3203x or y Discrete mathematics: introduction to combinatorics and graph theory
Lect: 3.3 pts. x: Professor Gross; y: Professor Grunschlag.
Prerequisite: any introductory course in computer programming. Logic and formal proofs, sequences and summation, mathematical induction, binomial coefficients, elements of finite probability, recurrence relations, equivalence relations and partial orderings, and topics in graph theory (including isomorphism, traversability, planarity, and colorings).

COMS W3210y Scientific computation
Lect: 3.3 pts. Professor Traub.

COMS W3251x Computational linear algebra
Lect: 3.3 pts. Professor Papageorgiou.
Prerequisite: two terms of calculus. Computational linear algebra, solution of linear systems, sparse linear systems, least squares, eigenvalue problems, and numerical solution of other multivariate problems as time permits.

COMS W3261x or y Computer science theory
Lect: 3.3 pts. Professor Pasik.
Prerequisites: COMS W3139 and W3203. Regular languages: deterministic and nondeterministic, finite automata, regular expressions. Context-free languages: context-free grammars, push-down automata. Turing machines, the Chomsky hierarchy, and the Church-Turing thesis. Introduction to complexity theory and NP completeness.
COMS W3902x or y Undergraduate thesis
1 to 6 pts.
Prerequisite: agreement by a faculty member to serve as thesis adviser. An independent theoretical or experimental investigation by an undergraduate major of an appropriate problem in computer science carried out under the supervision of a faculty member. A formal written report is mandatory and an oral presentation may also be required. May be taken over more than one term, in which case the grade is deferred until all 6 points have been completed. Consult the department for section assignment.

COMS W3995x or y Special topics in computer science
Lect: 3.3 pts. Instructor to be announced.
Prerequisite: the instructor’s permission. Consult the department for section assignment. Special topics arranged as the need and availability arise. Topics are usually offered on a one-time basis. Since the content of this course changes each time it is offered, it may be repeated for credit.

COMS W3998x or y Undergraduate projects in computer science
1 to 3 pts. Instructor to be announced.
Prerequisite: approval by a faculty member who agrees to supervise the work. Consult the department for section assignment. Independent project involving laboratory work, computer programming, analytical investigation, or engineering design. May be repeated for credit, but not for a total of more than 3 points of degree credit.

ECBM E4060x Introduction to genomic information science and technology
Lect: 3.3 pts. Professor Anastassiou.
Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function, and manipulation of the biomolecular sequences of nucleic acids and proteins. The role of enzymes and gene regulatory elements in natural biological functions as well as in biotechnology and genetic engineering. Recombination and other macromolecular processes viewed as mathematical operations with simulation and visualization using simple computer programming. This course shares lectures with ECBM E3060, but the work requirements differ somewhat.

COMS W4101x or y Topics in computer science technology
1.5 pts. Instructor to be announced.
Prerequisites: Fluency in at least one programming language and familiarity with computer systems. Introduction to current topics in computer science technology. Each section will be devoted to a specific technology. Sections may meet for 1.5 hours per week for the whole term or 3 hours per week for a half term. May be repeated for credit if different technologies are involved.

COMS W4111x and y Database systems
Lect: 3.3 pts. x: Professor Gravano; y: instructor to be announced.
Prerequisites: COMS W3137 or W3134, fluency in Java; or the instructor’s permission. The fundamentals of database design and application development using databases: entity-relationship modeling, logical design of relational databases, relational data definition and manipulation languages, SQL, XML, query processing, physical database tuning, transaction processing, security. Programming projects are required.

COMS W4112y Database system implementation
Lect: 2.5. 3 pts. Professors Gravano or Ross
Prerequisites: COMS W4111; fluency in Java or C++. COMS W3827 is recommended. The principles and practice of building large-scale database management systems. Storage methods and indexing, query processing and optimization, materialized views, transaction processing and recovery, object-relational databases, parallel and distributed databases, performance considerations. Programming projects are required.

COMS W4115x and y Programming languages and translators
Lect: 3.3 pts. x: Professor Edwards; y: Professor Aho.
Prerequisites: COMS W3137 or the equivalent, W3261, and CSSE W3827, or the instructor’s permission. Modern compiler implementation and programming language design. Language styles including imperative, object-oriented, declarative, functional, and scripting languages. Language design issues including syntax, control structures, data types, procedures and parameters, binding, scope, run-time organization, and exception handling. Implementation of language translation tools including compilers and interpreters. Language translation concepts including lexical, syntactic, and semantic analysis; code generation; and an introduction to code optimization. Teams implement a language and its compiler.

COMS W4117x or y Compilers and interpreters
Lect: 3.3 pts. Instructor to be announced.
Prerequisite: COMS W4115 or the instructor’s permission. Continuation of COMS W4115, with broader and deeper investigation into the design and implementation of contemporary language translators, be they compilers or interpreters. Topics include: parsing, semantic analysis, code generation and optimization, run-time environ-
COMS W4160y Computer graphics
Lect: 3.3 pts. Professor Ramamoothi.
Prerequisites: COMS 3137 or 3139; 4156 is recommended. Strong programming background and some mathematical familiarity including linear algebra is required. Introduction to computer graphics. Topics include 3D viewing and projections, geometric modeling using spline curves, graphics systems such as OpenGL, lighting and shading, and global illumination. Significant implementation is required; the final project involves writing an interactive 3D video game in OpenGL.

COMS W4162x or y Advanced computer graphics
Lect: 3.3 pts. Professor Ramamoothi.
Prerequisites: COMS 4160 or the equivalent, or the instructor’s permission. A second course in computer graphics covering more advanced topics including image and signal processing, geometric modeling with meshes, advanced image synthesis including ray tracing and global illumination, and other topics as time permits. Emphasis will be placed both on implementation of systems and important mathematical and geometric concepts such as Fourier analysis, mesh algorithms and subdivision, and Monte Carlo sampling for rendering. Note: Course will be taught every two years.

COMS W4165x Computational techniques in pixel processing
Lect: 3.3 pts. Instructor to be announced.
Prerequisites: COMS W3137, W3251 (recommended), and a good working knowledge of UNIX and C. Intended for graduate students and advanced undergraduates. An intensive introduction to image processing—digital filtering theory, image enhancement, image reconstruction, antialiasing, warping, and the state of the art in special effects. Topics form the basis of high-quality rendering in computer graphics and of low-level processing for computer vision, remote sensing, and medical imaging. Emphasizes computational techniques for implementing useful image-processing functions.

COMS W4167x or y Computer animation
Lect: 3.3 pts. Professor Grinspun.
Prerequisites: COMS W3137 or W3139, and W4156 is recommended. Previous familiarity with C is recommended. Intensive introduction to computer animation, including fundamental theory and algorithms for computer animation, keyframing, kinematic rigging, simulation, dynamics, free-form animation, behavioral/procedural animation, particle systems, postproduction; small groups implement a significant animation project; advanced topics as time permits.

COMS W4170x User interface design
Lect: 3.3 pts. Professor Feiner.
Prerequisite: COMS W3137. Introduction to the theory and practice of computer user interface design, emphasizing the software design of graphical user interfaces. Topics include basic interaction devices and techniques, human factors, interaction styles, dialogue design, and software infrastructure. Design and programming projects are required.

COMS W4172x or y 3D user interfaces
Lect: 3.3 pts. Professor Feiner.
Prerequisite: COMS W4160 or COMS W4170, or the instructor’s permission. Design, development, and evaluation of 3D user interfaces. Interaction techniques and metaphors, from desktop to immersive. Selection and manipulation. Travel and navigation. Symbolic, menu, gestural, and multimodal interaction. Dialogue design. 3D software support. 3D interaction devices and displays. Virtual and augmented reality. Tangible user interfaces. Review of relevant 3D math.

COMS W4180x or y Network security
Lect: 3.3 pts. Professor Bellovin.
Prerequisite: COMS W3137 or W3139, and W4119, or the instructor’s permission. Introduction to network security concepts and mechanisms; measures employed in countering such threats. Concepts and tools available in order to assume an appropriate security posture. Foundations of network security and an in-depth review of commonly used security mechanisms and techniques; security threats and network-based attacks, applications of cryptography, authentication, access control, intrusion detection and response, security protocols (IPsec, SSL, Kerberos), denial of service attacks and defenses; viruses and worms, software vulnerabilities, Web security, wireless security, and privacy.

COMS W4187x or y Security architecture and engineering
Lect: 3.3 pts. Professor Bellovin.
Prerequisites: COMS W4118; W4180 and/or W4119 recommended. Secure programming, Cryptographic engineering and key handling. Access controls. Tradeoffs in security design. Design for security.

COMS W4203y Graph theory
Lect: 3.3 pts. Professor Gross.
Prerequisite: COMS W3203. General introduction to graph theory. Isomorphism testing, algebraic specification, symmetries, spanning trees, traversability, planarity, drawings on higher-order surfaces, colorings, extremal graphs, random graphs, graphical measurement, directed graphs, Burnside-Polya counting, voltage graph theory.

COMS W4205x Combinatorial theory
Lect: 3.3 pts. Professor Gross.
Prerequisites: W3203 and a course in calculus. Sequences and recursions, calculus of finite differences and sums, elementary number theory, permutation group structures, binomial coefficients, Stirling numbers, harmonic numbers, generating functions.

COMS W4231x Analysis of algorithms, I
Lect: 3.3 pts. Professor Yannakakis.
Prerequisites: COMS W3137 or W3139, and W3203, or the instructor’s permission. Introduction to the design and analysis of efficient algorithms. Topics include models of computation, efficient sorting and searching, algorithms for algebraic problems, graph algorithms, dynamic programming, probabilistic methods, approximation algorithms, and NP-completeness. Note: This course is the same as CSOR W4231 (CS and IEOR departments).

COMS W4236y Introduction to computational complexity
Lect: 3.3 pts. Professor Yannakakis and Professor Servedio.
Prerequisite: COMS W3261. Develops a quantitative theory of the computational difficulty of problems in terms of the resources (e.g., time, space) needed to solve them. Classification of problems into complexity classes, reductions, and completeness. Power and limitations of different modes of computation such as nondeterminism, randomization, interaction, and parallelism.

COMS W4241y Numerical algorithms and complexity
Lect: 3.3 pts. Professor Traub.
Prerequisite: Knowledge of a programming language. Some knowledge of scientific computation is desirable. Modern theory and practice of computation on digital computers. Introduction to concepts of computational complexity. Design and analysis of numerical algorithms. Applications to computational finance, computational science, and computational engineering.

COMS W4252x or y Introduction to computational learning theory
Lect: 3.3 pts. Professor Servedio.
Prerequisite: COMS W4231 (or W4236), or COMS W3203 and the instructor’s permission, or W3261 and the instructor’s permission. Possibilities and limitations of performing learning by computational agents. Topics include computational models of learning, polynomial time learnability, learning from examples, and learning from queries to oracles. Computational and statistical limitations of learning. Applications to Boolean functions, geometric functions, automata.

COMS W4261x or y Introduction to cryptography
Lect: 2.5, 3 pts. Professor Malkin.
Prerequisites: Comfort with basic discrete math and probability. Recommended: COMS W3261 or W4231. An introduction to modern cryptography, focusing on the complexity-theoretic foundations of secure computation and communication in adversarial environments; a rigorous approach, based on precise definitions and provably secure protocols. Topics include private and public key encryption schemes, digital signatures, authentication, pseudorandom generators and functions, one-way functions, trapdoor functions, number theory and computational hardness, identification and zero knowledge protocols.

COMS W4281x or y Introduction to quantum computing
Lect: 3.3 pts. Prof. Wozniakowski.
Prerequisites: Knowledge of linear algebra. Prior
knowledge of quantum mechanics is not required although helpful. Introduction to quantum computing. Shor’s factoring algorithm, Grover’s database search algorithm, the quantum summation algorithm. Relationship between classical and quantum computing. Potential power of quantum computers.

EECS W4340x Computer hardware design
Lect: 3. 3 pts. Instructor to be announced.
Prerequisites: ELEN E3331 and CSEE W3827. Practical aspects of computer hardware design through the implementation, simulation, and prototyping of a PDP-8 processor. High-level and assembly languages, I/O, interrupts, datapath and control design, pipelining, busses, memory architecture. Programmable logic and hardware prototyping with FPGAs. Fundamentals of VHDL for register-transfer level design. Testing and validation of hardware. Hands-on use of industry CAD tools for simulation and synthesis. Lab required.

COM S W4701x or y Artificial intelligence
Lect: 3. 3 pts. Professor McKeown; y: Professor Stolfo.
Prerequisite: COMS W3139. Provides a broad understanding of the basic techniques for building intelligent computer systems. Topics include state-space problem representations, problem reduction and-and-or graphs, game playing and heuristic search, predicate calculus, and resolution theorem proving. AI systems and languages for knowledge representation, machine learning, and concept formation and other topics such as natural language processing may be included as time permits.

COMS W4705x Natural language processing
Lect: 3. 3 pts. Professor Hirschberg.
Prerequisite: COMS W3133, W3134, W3137, or W3139, or the instructor’s permission. Computational approaches to natural language generation and understanding. Recommended preparation: some previous or concurrent exposure to AI or machine learning. Topics include information extraction, summarization, machine translation, dialogue systems, and emotional speech. Particular attention is given to robust techniques that can handle understanding and generation for the large amounts of text on the Web or in other large corpora. Programming exercises in several of these areas.

COMS W4706x Spoken language processing
Lect: 3. 3pts. Professor Hirschberg.
Prerequisites: COMS W3133, W3134, W3137, or W3139, or the instructor’s permission. Computational approaches to speech generation and understanding. Topics include speech recognition and understanding, speech analysis for computational linguistics research, and speech synthesis. Speech applications including dialogue systems, data mining, summarization, and translation. Exercises involve data analysis and building a small text-to-speech system.

COMS W4725x or y Knowledge representation and reasoning
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: COMS 4701. General aspects of knowledge representation (KR). The two fundamental paradigms (semantic networks and frames) and illustrative systems. Topics include hybrid systems, time, action/plans, defaults, abduction, and case-based reasoning. Throughout the course particular attention will be paid to design tradeoffs between language expressiveness and reasoning complexity, and issues relating to the use of KR systems in larger applications.

COMS W4731x or y Computer vision
Lect: 3. 3 pts. Professor Nayar.
Prerequisites: the fundamentals of calculus, linear algebra, and C programming. Students without any of these prerequisites are advised to contact the instructor prior to taking the course. Introductory course in computer vision. Topics include image formation and optics, image sensing, binary images, image processing and filtering, edge extraction and boundary detection, region growing and segmentation, pattern classification methods, brightness and reflectance, shape from shading and photometric stereo, texture, binocular stereo, optical flow and motion, 2-D and 3-D object representation, object recognition, vision systems and applications.

COMS W4733x or y Computational aspects of robotics
Lect: 3. 3 pts. Professor Allen.
Prerequisite: COMS W3137 or W3139. Introduction to robotics from a computer science perspective. Topics include coordinate frames and kinematics, computer architectures for robotics, integration and use of sensors, world modeling systems, design and use of robotic programming languages, and applications of artificial intelligence for planning, assembly, and manipulation.

COMS W4735x or y Visual interfaces to computers
Lect: 3. 3 pts. Instructor to be announced.
Prerequisites: COMS W3137 or W3139. Visual input as data and for control of computer systems. Survey and analysis of architecture, algorithms, and underlying assumptions of commercial and research systems that recognize and interpret human gestures, analyze imagery such as fingerprint or iris patterns, generate natural language descriptions of medical or map imagery. Explores foundations in human psychophysics, cognitive science, and artificial intelligence.

COMS W4737x or y Biometrics
Lect: 3. 3 pts. Professor Belhumeur.
Prerequisite: A background at the sophomore level in computer science, engineering, or like discipline. In this course we will explore the latest advances in biometrics as well as the machine learning techniques behind them. Students will learn how these technologies work and how they are sometimes defeated. Grading will be based on homework assignments and a final project. There will be no midterm or final exam. This course shares lectures with COMS E6737. Students taking COMS E6737 are required to complete additional homework problems and undertake a more rigorous final project. Students will only be allowed to earn credit for COMS W4737 or COMS E6737 and not both.

CBMF W4761x or y Computational genomics
Lect: 3. 3 pts. Instructor to be announced.
Prerequisites: Either (1) EBCM E4060 or (2) COMS W1003, W1004, or W1007 and SIEO W4150, or SIEO W3600. Computational techniques for analyzing and understanding genomic data, including DNA, RNA, protein and gene expression data. Basic concepts in molecular biology relevant to these analyses. Emphasis on techniques from artificial intelligence and machine learning. String-matching algorithms, dynamic programming, hidden Markov models, expectation-maximization, neural networks, clustering algorithms, support vector machines. Students with life sciences backgrounds who satisfy the prerequisites are encouraged to enroll.
COMS W4771y Machine learning
Lect: 3. 3 pts. Professor Jebara.
Prerequisites: Any introductory course in linear algebra and any introductory course in statistics are both required. Highly recommended: COMS W4701 or knowledge of artificial intelligence.
Topics from generative and discriminative machine learning including least squares methods, support vector machines, kernel methods, neural networks, Gaussian distributions, linear classification, linear regression, maximum likelihood, exponential family distributions, Bayesian networks, Bayesian inference, mixture models, the EM algorithm, graphical models, and hidden Markov models. Algorithms implemented in Matlab.

COMS W4772x Advanced machine learning
Lect: 3. 3 pts. Professor Jebara.
Prerequisites: COMS W4771 or the instructor’s permission; knowledge of linear algebra and introductory probability or statistics is required. An exploration of advanced machine learning tools for perception and behavior learning. How can machines perceive, learn from, and classify human activity computationally? Topics include appearance-based models, principal and independent components analysis, dimensionality reduction, kernel methods, manifold learning, latent models, regression, classification, Bayesian methods, maximum entropy methods, real-time tracking, extended Kalman filters, time series prediction, hidden Markov models, factorial HMMs, input-output HMMs, Markov random fields, variational methods, dynamic Bayesian networks, and Gaussian/Dirichlet processes. Links to cognitive science.

CSEE W4823x or y Advanced logic design
Lect: 3. 3 pts. Professor Nowick.
Prerequisite: CSEE W3827 or a half-semester introduction to digital logic, or the equivalent. An introduction to modern digital system design. Advanced topics in digital logic: controller synthesis (Mealy and Moore machines); adders and multipliers; structured logic blocks (PLDs, PALs, ROMs); iterative circuits. Modern design methodology: register transfer level modelling (RTL); architectural state machines (ASMs); introduction to hardware description languages (VHDL or Verilog); system-level modelling and simulation; design examples.

CSEE W4824x or y Computer architecture
Lect: 3. 3 pts. Professor Carloni.

CSEE W4825y Digital systems design
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: CSEE W3827. Dynamic logic, field programmable gate arrays, logic design languages, multipliers. Special techniques for multi-level NAND and NOR gate circuits. Clocking schemes for one- and two-phase systems. Fault checking; scan method, built-in test. Survey of logic simulation methods. Other topics to be added as appropriate.

CSEE W4840y Embedded systems
Lect: 3. 3 pts. Professor Edwards.
Prerequisite: CSEE W4823. Embedded system design and implementation combining hardware and software, I/O, interfacing, and peripherals. Weekly laboratory sessions and term project on design of a microprocessor-based embedded system including at least one custom peripheral. Knowledge of C programming and digital logic required. Lab required.

CSEE W4861y Computer-aided design of digital systems
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: CSEE W3827 and COMS W3133, W3134, W3137, W3139, or the equivalent. Topics include hands-on design projects using commercial CAD tools; the theory behind the tools; modern digital system design (the VHDL language, register-transfer level modeling, algorithmic state machines, designing a microarchitecture); controller synthesis and optimization (FSMs); exact and heuristic two-level logic minimization; multilevel logic optimization; technology mapping; binary decision diagrams (BDDs), and introduction to testability.

COMS W4901x or y Projects in computer science
1 to 3 pts. Instructor to be announced.
Prerequisite: approval by a faculty member who agrees to supervise the work. A second-level independent project involving laboratory work, computer programming, analytical investigation, or engineering design. May be repeated for credit, but not for a total of more than 3 points of degree credit. Consult the department for section assignment.

COMS W4956x y Special topics in computer science, I
Lect: 3. 3 pts. x: Professor Belhumeur; y: instructor to be announced.
Prerequisite: the instructor’s permission. Special topics arranged as the need and availability arises. Topics are usually offered on a one-time basis. Since the content of this course changes each time it is offered, it may be repeated for credit. Consult the department for section assignment.

COMS W4995x y Special topics in computer science, II
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: the instructor’s permission. A continuation of COMS W4995 when the special topic extends over two terms.

COMS W4999y Computing and the humanities
Lect: 3. 3 pts. Instructor to be announced.

Text databases. Language applications, such as machine translation, information and retrieval, computational stylistics (determining authorship). Digital library applications, including issues in text acquisition, text markup, networking display, and user interfaces. Educational applications. Legal reasoning, history applications involving inferencing and databases.

COMS E6111y Advanced database systems
Lect: 2. 3 pts. Professor Gravano.
Prerequisite: COMS W4111 and knowledge of C++ or Java, or the instructor’s permission. Continuation of COMS W4111, covers the latest trends in both database research and in industry: object-relational databases, multimedia databases, information retrieval, Web search, Web databases, multidimensional databases, data mining, decision support, OLAP, distributed databases, heterogeneous databases, digital libraries. Programming projects are required.

COMS E6113y Topics in database systems
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: COMS W4111. Concentration on some database paradigm, such as deductive, heterogeneous, or object-oriented, and/or some database issue, such as data modeling, distribution, query processing, semantics, or transaction management. A substantial project is typically required. May be repeated for credit with instructor’s permission.

COMS E6117x y Topics in programming languages and translators
Lect: 2. 3 pts. Professor Aho.
Prerequisite: COMS W4115 or the instructor’s permission. Concentration on the design and implementation of programming languages and tools focused on advanced applications in new areas in software verification, distributed systems, programming in the large, and Web computing. A substantial project is typically required. May be repeated for credit.

COMS E6118y Operating systems, II
Lect: 2. 3 pts. Professor Nieh.
Prerequisite: COMS W4118. Corequisite: COMS W4119. Continuation of COMS W4118, with emphasis on distributed operating systems. Topics include interfaces to network protocols, distributed run-time binding, advanced virtual memory issues, advanced means of interprocess communication, file system design, design for extensibility, security in a distributed environment. Investigation is deeper and more hands-on than in COMS W4118. A programming project is required.

COMS E6123x or y Programming environments and software tools (PEST)
Lect: 2. 3 pts. Professor Kaiser.
Prerequisite: At least one COMS W41xx or COMS E61xx course and/or COMS W4444, or the instructor’s permission. Strongly recommended: COMS W4156. Software methodologies and
Introduction to queueing analysis and simulation techniques. Evaluation of time-sharing and multi-processor systems. Topics include priority queueing, buffer storage, disk access, interference and bus contention problems, and modeling of program behaviors.

**COMS E6206x or y Topics in combinatorial theory**

*Lect: 2. 3 pts. Professor Gross.*

Prerequisite: COMS W4203 or W4205, or the instructor’s permission. Concentration on some aspect of combinatorial theory. Content varies from year to year. This course may be repeated for credit.

**COMS E6232x or y Analysis of algorithms, II**

*Lect: 2. 3 pts. Instructor to be announced.*

Prerequisite: COMS W4231. Continuation of COMS W4231.

**COMS E6253y Advanced topics in computational learning theory**

*Lect: 3. 3 pts. Professor Servedio.*

Prerequisite: COMS W4261 or equivalent; COMS W4252 or W4236 helpful but not required. In-depth study of inherent abilities and limitations of computationally efficient learning algorithms. Algorithms for learning rich Boolean function classes in online, Probably Approximately Correct, and exact learning models. Connections with computational complexity theory emphasized. Substantial course project or term paper required.

**COMS E6261x or y Advanced cryptography**

*Lect: 3. 3 pts. Professor Malkin.*

Prerequisite: COMS W4261. A study of advanced cryptographic research topics, such as secure computation, zero knowledge, privacy, anonymity, cryptographic protocols. Concentration on theoretical foundations, rigorous approach, and provable security. Contents varies between offerings. May be repeated for credit.

**COMS E6291x or y Theoretical topics in computer science**

*Lect: 3. 3 pts. Instructor to be announced.*

Prerequisite: the instructor’s permission. Concentration on some theoretical aspect of computer science. Content varies from year to year. May be repeated for credit.

**COMS E6732x or y Computational imaging**

*Lect: 3. 3 pts. Professor Nayar.*

Prerequisite: COMS W4731 or the instructor’s permission. Computational imaging uses a combination of novel imaging optics and a computational module to produce new forms of visual information. Survey of the state of the art in computational imaging. Review of recent papers on omni directional and panoramic imaging, catadioptric imaging, high dynamic range imaging, mosaicing and superresolution. Classes are seminars with the instructor, guest speakers, and students presenting papers and discussing them.

**COMS E6733x or y 3-D photography**

*Lect: 2. 3pts. Professor Allen.*

Prerequisite: Experience with at least one of the following topics: computer graphics, computer vision, pixel processing, robotics, or computer-
Prerequisite: CS EEW38 27 or any introduction to logic circuits. Generation and manipulation of self-timed systems using 4-phase or 2-phase handshakes.

CSEE E6832x or y Topics in logic design theory
Lect: 3.3 pts. Professor Theoibald and Ivancic.
Prerequisite: CSEE W3827 or any introduction to logic circuits. A list of topics for each offering of the course is available in the department office one month before registration. May be taken more than once if topics are different. Iterative logic circuits applied to pattern recognition. Finite state machines; alternative representations, information loss, linear circuits, structure theory. Reliability and testability of digital systems.

COMS E6735y Visual databases
Lect: 3. 3 pts. Professor Kender.
Prerequisites: COMS W3133, W3134, W3137, or W3139 required; COMS W4731 or COMS W4735 helpful but not required. Contact instructor if uncertain. The analysis and retrieval of large collections of image and video data, with emphasis on visual semantics, human psychology, and user interfaces. Low-level processing: features and similarity measures; shot detection; key frame selection; machine learning methods for classification. Middle-level processing: organizational rules for videos, including unedited (home, educational), semidirected (sports, talk shows), edited (news, drama); human memory limits; progressive refinement; visualization techniques; incorporation of audio and text. High-level processing: extraction of thematic structures; ontologies, semantic filters, and learning; personalization of summaries and interfaces; detection of pacing and emotions. Examples and demonstrations from commercial and research systems throughout. Substantial course project or term paper required.

COMS E673x or y Biometrics
Lect: 3. 3 pts. Professor Belhumeur.
Prerequisites: A background at the sophomore level in computer science, engineering, or like discipline. In this course we will explore the latest advances in biometrics as well as the machine learning techniques behind them. Students will learn how these technologies work and how they are sometimes defeated. Grading will be based on homework assignments and a final project. There will be no midterm or final exam. This course shares lectures with COMS W4737. Students taking COMS E6737 are required to complete additional homework problems and undertake a more rigorous final project. Students will only be allowed to earn credit for COMS W4737 or COMS E6737 and not both.

CSEE E6831y Sequential logic circuits
Lect: 3. 3 pts. Professor Unger.

COMS E6902x and y Thesis
1 to 9 pts. Instructor to be announced.
Available to MS and CSE candidates. An independent investigation of an appropriate problem in computer science carried out under the supervision of a faculty member. A formal written report is essential and an oral presentation may also be required. May be taken over more than one semester, in which case the grade will be deferred until all 9 points have been completed. No more than 9 points of COMS E6902 may be taken. Consult the department for section assignment.

COMS E6998x and y Topics in computer science, I
3 pts. Instructor to be announced.
Prerequisite: the instructor’s permission. Selected topics in computer science. Content varies from year to year. May be repeated for credit.

COMS E6999x and y Topics in computer science, II
3 pts. Instructor to be announced.
Prerequisite: COMS E6998. Continuation of COMS E6998.

COMS E9800x and y Directed research in computer science
1 to 15 pts. Instructor to be announced.
Prerequisite: submission of an outline of the proposed research for approval by the faculty member who will supervise. The department must approve the number of points. May be repeated for credit. This course is only for Eng.Sc.D. candidates.

COMS E9910x and y Graduate research, I
1 to 6 pts. Instructor to be announced.
Prerequisite: submission of an outline of the proposed research for approval by the faculty member who will supervise. The department must approve the number of credits. May be repeated for credit. This course is only for MS candidates holding GRA or TA appointments. Note: It is not required that a student take Graduate research, I prior to taking Graduate research, II. Consult the department for section assignment.

COMS E9911x and y Graduate research, II
1 to 15 pts. Instructor to be announced.
Prerequisites: submission of an outline of the proposed research for approval by the faculty member who will supervise. The department must approve the number of points. May be repeated for credit. This course is only for MS/PhD track students. Note: It is not required that a student take Graduate research, I prior to taking Graduate research, II. Consult the department for section assignment.
Earth and Environmental Engineering at the Henry Krumb School of Mines fosters excellence in education and research for the development and application of science and technology to maximize the quality of life for all, through the sustainable use and responsible management of Earth’s resources.

Our Mission

EARTH RESOURCES AND THE ENVIRONMENT

The Earth and environmental engineering program fosters education and research in the development and application of technology for the sustainable development, use, and integrated management of Earth’s resources. Resources are identified as minerals, energy, water, air, and land, as well as the physical, chemical, and biological components of the environment. There is close collaboration with other engineering disciplines, the Lamont-Doherty Earth Observatory, the International Research Institute for Climate Prediction, the Center for Environmental Research and Conservation, and other Columbia Earth Institute units.

THE HENRY KRUMB SCHOOL OF MINES AT COLUMBIA UNIVERSITY

The School of Mines of Columbia University was established in 1864 and was the first mining and metallurgy department in the U.S. It became the foundation for Columbia’s School of Engineering and Applied Sciences and has been a pioneer in many areas of mining and metallurgy, including the first mining (Peele) and mineral processing (Taggart) handbooks, flotation, chemical thermodynamics and kinetics, surface and colloid chemistry, and materials science.

Nearly one hundred years after its formation, the School of Mines was renamed Henry Krumb School of Mines (HKSM) in honor of the generous Columbia benefactor of the same name. The Henry Krumb School of Mines (SEAS) supports three components:

- The Department of Earth and Environmental Engineering (EEE), one of the nine departments of SEAS.
- Columbia’s interdepartmental program in Materials Science and Engineering (MSE). This program, administered by the Department of Applied Physics and Applied Mathematics, is described in another section of this bulletin.

- The Earth Engineering Center. The current research areas include energy, materials, and water resources.

EARTH AND ENVIRONMENTAL ENGINEERING (EEE)

Starting in 1996, the educational programs of Columbia University in mining and mineral engineering were transformed into the present program in Earth and environmental engineering (EEE). This program is concerned with the environmentally sound extraction and processing of primary materials (minerals, fuels, water), the management and development of land and water resources, and the recycling or disposal of used materials. EEE offers the Bachelor of Science (B.S.) in Earth and Environmental Engineering, the Master of Science (M.S.) in Earth Resources Engineering, the professional degrees of Engineer of Mines and Metallurgical Engineer, and the doctorate degrees (Ph.D., Eng.Sc.D.) in EEE.
The EEE program welcomes Combined Plan students. An EEE minor is offered to all Columbia engineering students who want to enrich their academic record by concentrating some of their technical electives on Earth/environment subjects. There is close collaboration between EEE and the Departments of Civil Engineering and Earth and Environmental Sciences, including several joint appointments.

EEE and the Earth Engineering Center are the contributions of The Fu Foundation School of Engineering and Applied Science to the Earth Institute of Columbia University, a major education and research initiative of the University. Earth and Environmental Engineering combines the longstanding and proud tradition of Columbia’s School of Mines with forward-thinking courses and programs, innovative research, and a deep concern for the environment.

RESEARCH CENTERS ASSOCIATED WITH EARTH AND ENVIRONMENTAL ENGINEERING

Columbia Water Center. The Columbia Water Center, in collaboration with other Earth Institute units and external partners, is leading intellectual inquiry into an assessment, prediction, and solution of the potentially global crisis of freshwater scarcity. Goals are to:

- develop multiscale predictive capabilities (e.g., new data sets and modeling tools) for local, regional, and global water resource assessment, recognizing changing climate, demographic, and usage dynamics
- target analyses toward public and private investment in future water resource development, local and regional ecosystem services provided by water and the essential life-support water needs of societies
- identify and test appropriate technologies for the storage, treatment, and conveyance of water to improve reliable, cost-efficient access
- identify and compare locally appropriate policy instruments that facilitate the implementation of selected incentives for higher-value, higher-efficiency water use, while promoting equity of use and life support functions
- test and demonstrate the applicability of the policy and technology developments in real-world settings, working with local institutions and private-sector developers or users in an open and public process
- develop and disseminate the knowledge base that results from our activities to support global water resource development and decision making, including the development of a forum, the Global Roundtable on Water (GROW), to facilitate international policy and technical action to improve our collective water future.

For more information: www.water.columbia.edu

Earth Engineering Center. The mission of the Earth Engineering Center is to develop and promote engineering methodologies that provide essential material to humanity in ways that maintain the overall balance between the constantly increasing demand for materials, the finite resources of the Earth, and the need for clean water, soil, and air. The Center is dedicated to the advancement of industrial ecology, i.e., the reconfiguring of industrial activities and products with full knowledge of the environmental consequences. Research is being conducted on a variety of geoenvironmental issues with the intent to quantify, assess, and ultimately manage adverse human effects on the environment. Research areas include management of water and energy resources, hydrology and hydrogeology, numerical modeling of estuarine flow and transport processes, and integrated waste management. For more information: refer to its Web site: www.columbia.edu/cu/earth/

Environmental Tracer Group. The Environmental Tracer Group uses natural and anthropogenic (frequently transient) tracers, as well as deliberately released tracers, to investigate the physics and chemistry of transport in environmental systems. The tracers include natural or anthropogenically produced isotopes (e.g., tritium or radioactive hydrogen, helium and oxygen isotopes, or radiocarbon), as well as noble gases and chemical compounds (e.g., CFCs and SF6). The ETG analytical facilities include four mass spectrometric systems that can be used in the analysis of tritium and noble gases in water, sediments, and rocks. In addition to the mass spectrometric systems, there are several gas chromatographic systems equipped with electron capture detectors that are used for measurements of SF6 in continental waters and CFCs and SF6 in the atmos-
International Research Institute for Climate Prediction (IRI). The IRI (iri.columbia.edu) is the world’s leading institute for the development and application of seasonal to interannual climate forecasts. The mission of the IRI is to enhance society’s capability to understand, anticipate, and manage the impacts of seasonal climate fluctuations, in order to improve human welfare and the environment, especially in developing countries. This mission is to be conducted through strategic and applied research, education and capacity building, and provision of forecast and information products, with an emphasis on practical and verifiable utility and partnerships.

Langmuir Center for Colloids and Interfaces (LCCI). This Center brings together experts from mineral engineering, applied chemistry, chemical engineering, biological sciences, and chemistry to probe complex interactions of colloids and interfaces with surfactants and macromolecules. LCCI activities involve significant interaction with industrial sponsors and adopt an interdisciplinary approach toward state-of-the-art research on interfacial phenomena. Major areas of research at LCCI are thin films, surfactant and polymer adsorption, environmental problems, enhanced oil recovery, computer tomography, corrosion and catalyst mechanisms, membrane technology, novel separations of minerals, biocolloids, microbial surfaces, and interfacial spectroscopy.

Lenfest Center for Sustainable Energy. The mission of the Lenfest Center for Sustainable Energy is to develop technologies and institutions to ensure a sufficient supply of environmentally sustainable energy for all humanity. To meet this goal, the Center supports research programs in energy science, engineering, and policy across Columbia University to develop technical and policy solutions that will satisfy the world’s future energy needs without threatening to destabilize the Earth’s natural systems.

The mission of the Lenfest Center is shaped by two global challenges. First, the Center seeks to reduce the emission of carbon dioxide into the atmosphere and to forestall a disruption of global climate systems that would impose negative consequences for human welfare. Second, the Center seeks to create energy options that will meet the legitimate energy demands of a larger and increasingly wealthy world population. In order to meet these two challenges, the Center seeks to develop new sources, technologies, and infrastructures.

The Lenfest Center focuses primarily on the technological and institutional development of the three energy resources sufficient to support the world’s projected population in 2100 without increased carbon emissions: solar, nuclear, and fossil fuels combined with carbon capture and storage. Although each of these options can, in theory, be developed on a scale to satisfy global demand, they each face a combination of technological and institutional obstacles that demand research and development before they can be deployed.

The Center’s main activities are based within the range of natural science and engineering disciplines. At the same time, it integrates technological research with analysis of the institutional, economic, and political context within which energy technologies are commercialized and deployed.

NSF Industry/University Cooperative Center for Surfactants (IUCRC). This Center is sponsored by fifteen companies and has as its aim to develop and characterize novel surfactants for industrial applications, such as coatings, dispersions, personal car products, soil decontamination, and waste treatment. For more information: www.columbia.edu/ cu/iucrc.

SCHOLARSHIPS, FELLOWSHIPS, AND INTERNSHIPS
The department arranges for undergraduate Earth engineering summer internships after the sophomore and junior years. Undergraduates can also participate in graduate research projects under the study program. Graduate research and teaching assistantships, as well as fellowships funded by the Department, are available to qualified graduate students. GRE scores are required of all applicants for graduate studies.

UNDERGRADUATE PROGRAM
The Bachelor of Science (B.S.) degree in Earth and environmental engineering prepares students for careers in the public and private sector concerned with primary materials (minerals, fuels, water) and the environment. Graduates are also prepared to continue with further studies in Earth/environmental sciences and engineering, business, public policy, international studies, law, and medicine. The EEE program is accredited as an environmental engineering program by the Accreditation Board for Engineering and Technology (ABET).

What Is Earth and Environmental Engineering?
It is now recognized by the U.S. and other nations that continuing economic development must be accompanied by intelligent use of Earth’s resources and that engineers can contribute much to the global efforts for sustainable development. The technologies that have been developed for identifying, extracting, and processing primary materials are also being applied to the twenty-first-century problems of resource recovery from used materials, pollution prevention, and environmental remediation. The EEE undergraduate program encompasses these technologies.

Undergraduate Program Objectives
1. Graduates equipped with the necessary tools (mathematics, chemistry, physics, Earth sciences, and engineering science) will understand and implement the underlying principles used in the engineering of processes and systems.

2. Graduates will be able to pursue careers in industry, government agencies, and other organizations concerned with the environment and the provision of primary and secondary materials and energy, as well as continue their education as graduate students in related disciplines.

3. Graduates will possess the basic skills needed for the practice of Earth and
environmental engineering, including measurement and control of material flows through the environment; assessment of environmental impact of past, present, and future industrial activities; and analysis and design of processes for remediation, recycling, and disposal of used materials.

4. Graduates will practice their profession with excellent written and communication skills and with professional ethics and responsibilities.

The Curriculum
The first two years of the EEE program are similar to those of other engineering programs. Students are provided with a strong foundation in basic sciences and mathematics, as well as the liberal arts core. Specific to the EEE program is an early and sustained introduction to Earth science and environmental engineering, and options for a number of science courses to meet the specific interests of each student. The junior and senior years of the program consist of a group of required courses in engineering science and a broad selection of technical electives organized into three distinct concentrations, representing major areas of focus within the department. Several Columbia departments, such as Civil Engineering, Mechanical Engineering, and Earth and Environmental Sciences (Lamont-Doherty Earth Observatory), as well as the Mailman School of Public Health, contribute courses to the EEE program. EEE students are strongly encouraged to work as summer interns in industry or agencies on projects related to Earth and environmental engineering. The department helps students get summer internships.

Technical Elective Concentrations
Students majoring in Earth and environmental engineering select one of the following three preapproved technical elective concentrations. Note that the eight-course sequence for each preapproved concentration includes two science courses during sophomore year (fall semester) and six technical elective courses during junior and senior years. Any deviations from a preapproved concentration must be approved by an undergraduate faculty adviser. Alternatives for junior/senior electives within each concentration are listed, and others may be considered among 3000- to 4000-level courses of any SEAS department, as well as courses listed in the section "Courses in Other Divisions" in this bulletin. However, at least four of the six junior/senior electives must consist of engineering topics. Alternatives for sophomore-year science courses are shown in the EEE program table.

A student may also choose to develop an individual concentration conforming to his/her specific interests, provided that it satisfies ABET engineering accreditation criteria. Therefore, this must be developed in close consultation with and approved by a faculty adviser.

Water Resources and Climate Risks Concentration
Preapproved course sequence:

PHYS C1403: Introduction to classical and quantum waves (SEM III)
EE SC V2100: Climate system (SEM III)
EAEE E4006: Field methods for environmental engineering (SEM VI)
EAEE E4009: GIS for resource, environmental, and infrastructure management (SEM VII)
EAEE E4350: Planning and management of urban hydrologic systems (SEM VII)
EAEE E4257: Environmental data analysis and modeling (SEM VIII)
ECIA W4100: Management and development of water systems (SEM VIII)
CIEE E4257: Contaminant transport in subsurface systems (SEM VIII)

Alternatives for junior/senior electives:

EAEE E4001: Industrial ecology of Earth resources
CIEE E4260: Urban ecology studio
CIEE E4163: Environmental engineering: wastewater
CIEN E4250: Waste containment design and practice
CIEN E4255: Flow in porous media
APPH E4200: Physics of fluids
EE SC W4008: Introduction to atmospheric science
EE SC W4401: Quantitative models of climate-sensitive natural and human systems
EE SC W4404: Regional dynamics, climate and climate impacts

Sustainable Energy and Materials Concentration
Preapproved course sequence:

CHEM C3443: Organic chemistry (SEM III)
EE SC V2200: Solid earth system (SEM III)
MECE E3311: Heat transfer (SEM VI)
EAEE E4001: Industrial ecology of Earth resources (SEM VII)

EAEE E4900: Applied transport and chemical rate phenomena (SEM VII)
MCEC E4302: Advanced thermodynamics (SEM VIII)
EE SC W3015: The Earth’s carbon cycle (SEM VIII)
MECE E4211: Energy: sources and conversion (SEM VII)

Alternatives for junior/senior electives:

CHEN E3110: Transport phenomena I
CHEN E3120: Transport phenomena II
EAEE E3101: Earth resource production systems
MESA E3103: Elements of materials science
CHEM C3071: Introduction to organic chemistry
CHEM G4230: Statistical thermodynamics
EAEE E4550: Catalysis for emissions control
EE SC W4008: Introduction to atmospheric science

EAEE E4560: Particle technology

Environmental Health Engineering Concentration
Preapproved course sequence:

CHEM C3443: Organic chemistry (SEM III)
EE SC V2100: Climate system (SEM III)
EAEE E4006: Field methods for environmental engineering (SEM VI)
EAEE E4009: GIS for resource, environmental and infrastructure management (SEM VII)
EHSC P6300: Environmental health sciences (SEM VII)
EAEE E4257: Environmental data analysis and modeling (SEM VIII)
EAEE E4150: Air pollution prevention and control (SEM VIII)
EHSC P6309: Biochemistry basic to environmental health (SEM VIII)

Alternatives for junior/senior electives:

EAEE E4001: Industrial ecology of Earth resources
EAEE E4900: Applied transport and chemical rate phenomena
EAEE E4950: Environmental biochemical processes
CIEE E4257: Contaminant transport in subsurface systems

GRADUATE PROGRAMS
M.S. in Earth Resources Engineering (MS-ERE)
The MS-ERE program is designed for engineers and scientists who plan to pursue, or are already engaged in, environmental management/development careers. The focus of the program is the environmentally sound mining and processing of primary materials (minerals, energy, and water) and the recycling or proper disposal of used materials. The program also includes technologies for assessment and remediation of past damage to the environment. Students can choose a pace that allows them...
to complete the MS-ERE requirements while being employed.

MS-ERE graduates are specially qualified to work for engineering, financial, and operating companies engaged in mineral processing ventures, the environmental industry, environmental groups in all industries, and for city, state, and federal agencies responsible for the environment and energy/resource conservation. At the present time, the U.S. environmental industry comprises nearly 30,000 big and small businesses with total revenues of over $150 billion.

Sustainable development and environmental quality has become a top priority of government and industry in the United States and many other nations.

This M.S. program is offered in collaboration with the Departments of Civil Engineering and Earth and Environmental Sciences. Many of the teaching faculty are affiliated with Columbia’s Earth Engineering Center.

For students with a B.S. in engineering, at least 30 points (ten courses) are required. For students with a nonengineering B.S. or a B.A., preferably with a science major, up to 48 points (total of sixteen courses) may be required for makeup courses. All students are required to carry out a research project and write a thesis worth 3–6 points. A number of areas of study are available for the MSW-ERE, and students may choose courses that match their interest and career plans. The areas of study include:

- alternative energy and carbon management
- climate risk assessment and management
- environmental health engineering
- integrated waste management
- natural and mineral resource development and management
- novel technologies: surficial and colloid chemistry and nanotechnology
- urban environments and spatial analysis

Additionally, there are four optional concentrations in the program, in each of which there are a number of required specific core courses and electives. In each case, students are required to carry out a research project and write a thesis (3–6 points). The concentrations are described briefly below; details and the lists of specific courses for each track are available from the department.

**Water Resources and Climate Risks**

Climate-induced risk is a significant component of decision making for the planning, design, and operation of water resource systems, and related sectors such as energy, health, agriculture, ecological resources, and natural hazards control. Climatic uncertainties can be broadly classified into two areas: (1) those related to anthropogenic climate change; (2) those related to seasonal-to-century-scale natural variations. The climate change issues impact the design of physical, social, and financial infrastructure systems to support the sectors listed above. The climate variability and predictability issues impact systems operation, and hence design. The goal of the M.S. concentration in water resources and climate risks is to provide (1) a capacity for understanding and quantifying the projections for climate change and variability in the context of decisions for water resources and related sectors of impact; and (2) skills for integrated risk assessment and management for operations and design, as well as for regional policy analysis and management. Specific areas of interest include:

- numerical and statistical modeling of global and regional climate systems and attendant uncertainties
- methods for forecasting seasonal to interannual climate variations and their sectoral impacts
- models for design and operation of water resource systems, considering climate and other uncertainties
- integrated risk assessment and management across water resources and related sectors

**Sustainable Energy**

Building and shaping the energy infrastructure of the twenty-first century is one of the central tasks for modern engineering. The purpose of the sustainable energy concentration is to expose students to modern energy technologies and infrastructures and to the associated environmental, health, and resource limitations. Emphasis will be on energy generation and use technologies that aim to overcome the limits to growth that are experienced today. Energy and economic well-being are tightly coupled. Fossil fuel resources are still plentiful, but access to energy is limited by environmental and economic constraints.

A future world population of 10 billion people trying to approach the standard of living of the developed nations cannot rely on today’s energy technologies and infrastructures without severe environmental impacts. Concerns over climate change and changes in ocean chemistry require reductions in carbon dioxide emissions, but most alternatives to conventional fossil fuels, including nuclear energy, are too expensive to fill the gap. Yet access to clean, cheap energy is critical for providing minimal resources: water, food, housing, and transportation.

Concentration-specific classes will sketch out the availability of resources, their geographic distribution, the economic and environmental cost of resource extraction, and avenues for increasing energy utilization efficiency, such as cogeneration, district heating, and distributed generation of energy. Classes will discuss technologies for efficiency improvement in the generation and consumption sector; energy recovery from solid wastes; alternatives to fossil fuels, including solar and wind energy, and nuclear fission and fusion; and technologies for addressing the environmental concerns over the use of fossil fuels and nuclear energy. Classes on climate change, air quality, and health impacts focus on the consequences of energy use. Policy and its interactions with environmental sciences and energy engineering will be another aspect of the concentration. Additional specialization may consider region specific energy development.

**Integrated Waste Management (IWM)**

Humanity generates nearly 2 billion tons of municipal solid wastes (MSW) annually. Traditionally, these wastes have been discarded in landfills that have a finite lifetime and then must be replaced by converting more greenfields to landfills. This method is not sustainable because it wastes land and valuable resources. Also, it is a major source of greenhouse gases and of various several contaminants of air and water. In addition to MSW, the U.S. alone generates billions of tons of industrial and extraction wastes. Also, the by-product of water purification is a sludge or cake that must be disposed in
some way. The IWM concentration prepares engineers to deal with the major problem of waste generation by exposing them to environmentally better means for dealing with wastes: waste reduction, recycling, composting, and waste-to-energy via combustion, anaerobic digestion, or gasification. Students are exposed not only to the technical aspects of integrated waste management but also to the associated economic, policy, and urban planning issues.

Since the initiation of the Earth and environmental engineering program in 1996, there have been several graduate research projects and theses that exemplify the engineering problems that will be encompassed in this concentration:

- design of an automated materials recovery facility
- analysis of the bioreactor landfill
- generation of methane by anaerobic digestion of organic materials
- design of corrosion inhibitors
- flocculation modeling
- analysis of formation of dioxins in high-temperature processes
- combination of waste-to-energy and anaerobic digestion
- application of GIS in siting new WTE facilities
- corrosion phenomena in WTE combustion chambers
- mathematical modeling of transport phenomena in a combustion chamber
- effect of oxygen enrichment on combustion of paper and other types of solid wastes
- feasibility study and design of WTE facilities

Environmental Health Engineering

The purpose of this concentration is to train professionals who can address both the public health and engineering aspects of environmental problems. The identification and evaluation of environmental problems frequently revolve around the risks to human health, whereas the development of remediation or prevention strategies frequently involves engineering approaches. Currently, these two critical steps in addressing environmental problems are handled by two separate groups of professionals, public health practitioners and engineers, who usually have very little understanding of the role of the other profession in this process. The goal is to train those specialists collaboratively, through the Departments of Earth and Environmental Engineering and Environmental Health Sciences.

Joint Degree Programs

The Graduate School of Business and the School of Engineering and Applied Science offer a joint program leading to the M.B.A. degree from the Graduate School of Business and the M.S. degree in Earth resources engineering from the School of Engineering and Applied Science. The purpose of this program is to train students who wish to pursue Earth resource management careers. Students are expected to register full time for three terms in the Graduate School of Business and for two terms in the School of Engineering and Applied Science. It is possible, however, to study in the School of Engineering and Applied Science part time. Interested persons should contact Professor Yegulalp at 212-854-2984 or by e-mail to yegulalp@columbia.edu.

Doctoral Programs

EEE offers two doctoral degrees:

1. the Eng.Sc.D. degree, administered by The Fu Foundation School of Engineering and Applied Science; and
2. the Ph.D. degree, administered by the Graduate School of Arts and Sciences. Qualifying examinations and all other intellectual and performance requirements for these degrees are the same. All applicants should use the School of Engineering forms. The scope includes the design and use of sensors for measurement at molecular scale; the understanding of surface, colloid, aqueous, and high-temperature phenomena; the integrated management of multiple resources and the mitigation of natural and environmental hazards, at regional to global scales. The management of the interaction between human activities, Earth resources, and ecosystems is of primary interest.

The engineering objectives of EEE research and education include:

- **provision and disposal of materials:** environmentally sustainable extraction and processing of primary materials; manufacturing of derivative products; recycling of used materials; management of industrial residues and used products; materials-related application of industrial ecology.
- **management of water resources:** understanding, prediction, and management of the processes that govern the quantity and quality of water resources, including the role of climate; development/operation of water resource facilities; management of water-related hazards.
- **energy resources and carbon management:** mitigation of environmental impacts of energy production; energy recovery from waste materials; advancement of energy efficient systems; new energy sources; development of carbon sequestration strategies.
- **sensing and remediation:** understanding of transport processes at different scales and in different media; containment systems; modeling flow and transport in surface and subsurface systems; soil/water decontamination and bioremediation.

The Professional Degrees

The department offers the professional degrees of Engineer of Mines (E.M.) and Metallurgical Engineer (Met.E.). In order to gain admission to both degree programs, students must have an undergraduate degree in engineering and complete at least 30 credits of graduate work beyond the M.S. degree, or 60 credits of graduate work beyond the B.S. degree. These programs are planned for engineers who wish to do advanced work beyond the level of the M.S. degree but who do not desire to emphasize research.

The professional degrees are awarded for satisfactory completion of a graduate program at a higher level of course work than is normally completed for the M.S. degree. Students who find it necessary to include master’s-level courses in their professional degree program will, in general, take such courses as deficiency courses. A candidate is required to maintain a grade-point average of at least 3.0. A student who, at the end of any term, has not attained the grade-point average required for the degree may be asked to withdraw. The final
### Earth and Environmental Engineering Program: First and Second Years

<table>
<thead>
<tr>
<th>Semester I</th>
<th>Semester II</th>
<th>Semester III</th>
<th>Semester IV</th>
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<tbody>
<tr>
<td><strong>Mathematics</strong></td>
<td>Math V1101 (3)</td>
<td>Math V1102 (3)</td>
<td>Math V1201 (3)</td>
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<td>Or Honors Math I (3)</td>
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<td>Or Honors Math I (3)</td>
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<td>Honors Math III (4)</td>
<td>Honors Math IV (4) and ODE (3)</td>
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<td><strong>Physics</strong></td>
<td>C1401 (3)</td>
<td>C1402 (3)</td>
<td>Chem C3443 (3.5)</td>
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<td>Or C1601 (3.5)</td>
<td>C1602 (3.5)</td>
<td>Phys C1403 (3)</td>
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<td>Or C2801 (4.5)</td>
<td>C2802 (4.5)</td>
<td>Phys C2601 (3.5)</td>
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<td>Or C1403 (3.5) and Lab C1500 (3)</td>
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<td>Biol C2005 (4)</td>
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<td>Or C1604 (3.5)</td>
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<td>Or C3045 (3.5)</td>
<td>C3046 (3.5) and Lab C2507 (3)</td>
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<tr>
<td><strong>Required Non-Technical Electives</strong></td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
<td>HUMA C1001, C0CI C1101, or Major Cultures (3–4)</td>
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<td>Or Z1003 (4)</td>
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<td>Or C1010 (3)</td>
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<td>Or ALP0006 (0)</td>
<td>Z1003 (4)</td>
<td>Or ECON W1105 (4) and W1155 recitation (0)</td>
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<td><strong>Required Professional and Technical Electives</strong></td>
<td>EAE E1100 (3) A better planet by design or other departmental professional-level course</td>
<td>EESC W4001 (4)</td>
<td>HUMA C1002, C0CI C1102, or Major Cultures (3–4)</td>
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<td>Or EESC V2100 (4.5)</td>
<td>EESC V2200 (4.5)</td>
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<td>Or EAE E2002 (3) Alternative energy sources</td>
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**Computer Science**

- Computer language: COMS W1003 (3) or W1004 (3) any semester

**Physical Education**

- C1001 (1)
- C1002 (1)

**Gateway Lab**

- E1102 (4) either semester

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30 credits required for the professional degree must be completed in no more than five years.

Specific requirements for both professional degrees include a set of core courses and a number of electives appropriate for the specific area of concentration. All course work must lead to the successful completion of a project in mining engineering. A list of core courses and electives is available at the department office.

COURSES IN EARTH AND ENVIRONMENTAL ENGINEERING

See also courses in applied chemistry in the section in this chapter titled “Chemical Engineering.”
**EARTH AND ENVIRONMENTAL ENGINEERING PROGRAM: THIRD AND FOURTH YEARS**

<table>
<thead>
<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
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<tr>
<td>EAAE E3103 (3) Energy, minerals, and material systems</td>
<td>CIEE E3255 (3) Environmental control and pollution reduction systems</td>
<td>EAAE E3998 (2) Undergraduate design project</td>
<td>EAAE E3999 (2) Undergraduate design project</td>
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<tr>
<td>CIEE E4252 (3) Environmental engineering</td>
<td>CIEE E3250 (3) Hydrosystems engineering</td>
<td>EAAE E4003 (3) Aquatic chemistry</td>
<td>EAAE E4160 (3) Solid and hazardous waste management</td>
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<tr>
<td>ENME E3161 (4) Fluid mechanics or MECE E3100 (3) Introduction to mechanics of fluids</td>
<td>SIEO W3600 (4) Introduction to probability and statistics</td>
<td>EAAE E3801 (2) Earth and environmental engineering lab, II</td>
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<tr>
<td>CIEE E3010 (4) Principles of chemical engineering thermodynamics or MSAE E3111 (3) Thermodynamics, kinetic theory, and statistical mechanics or MECE E3301 (3) Thermodynamics</td>
<td>EAAE E3800 (2) Earth and environmental engineering lab, I</td>
<td>EAAE E3901 (3) Environmental microbiology</td>
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<tr>
<td>TECHNICAL ELECTIVES</td>
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<td>6 points</td>
<td>9 points</td>
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<tr>
<td>NONTECHNICAL ELECTIVES</td>
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<td>TOTAL POINTS</td>
<td>15–17</td>
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**EAAE E1100y A better planet by design**

Lect: 3.3 pts. Professors Lall and Park.

Development of the infrastructure for providing safe and reliable resources (energy, water, and other materials, transportation services) to support human societies while attaining environmental objectives. Introduction of a typology of problems by context and common frameworks for addressing them through the application of appropriate technology and policy. An interdisciplinary perspective that focuses on the interaction between human and natural systems is provided. Alternatives for resource provision and forecasts of their potential environmental impacts through a context provided by real-world applications and problems.

**EAAE E2002x Alternative energy resources**

Lect: 3.3 pts. Professors Walker and Lackner.

Unconventional, alternative energy resources. Technological options and their role in the world energy markets. Comparison of conventional and unconventional, renewable and nonrenewable energy resources and analysis of the consequences of various technological choices and constraints. Economic considerations, energy availability, and the environmental consequences of large-scale, widespread use of each particular technology. Introduction to carbon dioxide capture and carbon dioxide disposal as a means of sustaining the fossil fuel option.

**EAAE E3103x Energy, minerals and materials systems**

Lect: 3.3 pts. Professors Lackner and Yegulalp.

Prerequisite: MSAE E3111 or MECE E3301 and ENME E3161 or MECE E3100 or the equivalent. Overview of energy resources, resource management from extraction and processing to recycling and final disposal of wastes. Resource availability and resource processing in the context of the global natural and anthropogenic material cycles; thermodynamic and chemical conditions including nonequilibrium effects that shape the resource base; extractive technologies and their impact on the environment and the biogeochemical cycles; chemical extraction from mineral ores, and metalurgical processes for extraction of metals. In analogy to metallurgical processing, power generation and the refining of fuels are treated as extraction and refining processes. Large scale of power generation and a discussion of its impact on the global biogeochemical cycles.
MSAE E3111x Thermodynamics, kinetic theory, and statistical mechanics
Lect: 3. 3 pts. Professor Duby.
An introduction to the basic thermodynamics of systems, including concepts of equilibrium, entropy, thermodynamic functions, and phase changes. Basic kinetic theory and statistical mechanics, including diffusion processes, concept of phase space, classical and quantum statistics, and applications thereof.

EAEE E312y Introduction to rock mechanics
Prerequisites: EAEE E3101 and ENME E3111, or their equivalents. Rock as an engineering material, geometry and strength of rock joints, geotechnical classification of rock masses, strength and failure of rock, field investigations prior to excavation in rock, rock reinforcement, analysis and support of rock slopes and tunnels, and case histories.

MSAE E3141y Processing of metals and semiconductors
Lect: 3. 3 pts. Professor Duby.
Prerequisites: MSAE E3103 or equivalent. Synthesis and production of metals and semiconductors with engineered microstructures for desired properties. Includes high-temperature, aqueous, and electrochemical processing; thermal and mechanical processing of metals and alloys; casting and solidification; diffusion, microstructural evolution, and phase transformations; modification and processing of surfaces and interfaces; deposition and removal of thin films. Processing of Si and other materials for elemental and compound semiconductor-based electronic, magnetic, and optical devices.

EAEE E3185y Summer fieldwork for Earth and environmental engineers
0.5 pts. Instructor to be announced.
Undergraduates in Earth and environmental engineering may spend up to 3 weeks in the field under staff direction. The course consists of mine, landfill, plant, and major excavation site visits and brief instruction of surveying methods. A final report is required.

EAEE E3221x Environmental geophysics
Lect: 3. 3 pts. Instructor to be announced.
Introduction to applied and environmental geophysics methods. Overview of principles of geophysics, geophysical methods and techniques (seismic, ground penetrating radar, resistivity, frequency em, and magnetics), and theory and practical aspects of data processing and inversion. Examination of geophysical case studies for engineering and environmental purposes.

CIEE E3250x Hydrologic and hydraulics systems
Lect: 3. 3 pts. Professor Gong.
Prerequisite: CHEN E3110 or ENME E3161 or the equivalent, SIEO W3600 or the equivalent, or the instructor’s permission. A quantitative introduction to hydrologic and hydraulic systems, with a focus on integrated modeling and analysis of the water cycle and associated mass transport for water resources and environmental engineering. Coverage of unit hydrologic processes such as precipitation, evaporation, infiltration, runoff generation, open channel and pipe flow, subsurface flow and well hydraulics in the context of example watersheds, and specific integrative problems such as risk-based design for flood control, provision of water, and assessment of environmental impact or potential for non-point source pollution. Spatial hydrologic analysis using GIS and watershed models.

CIEE E3255y Environmental control and pollution reduction systems
Lect: 3. 3 pts. Professor Castaldi.
Prerequisites: ENME E3161 or MECE E3100. Review of engineered systems for prevention and control of pollution. Fundamentals of material and energy balances and reaction kinetics. Analysis of engineered systems to address environmental problems, including solid and hazardous waste, air, water, soil, and noise pollution. Life cycle assessments and emerging technologies.

EAEE E3800y Earth and environmental engineering laboratory, I
Lect: 1. Lab: 3. 2 pts. Professors Duby, Chandran, and Castaldi.
Prerequisite: CHEE E3010. Corequisite: EAEE E3255. Students will learn the theoretical concepts learned in class.

EAEE E3801x Earth and environmental engineering laboratory, II
Lect: 1. Lab: 3. 2 pts. Professors Duby, Chandran, and Castaldi.
Prerequisite: EAEE E3800. Corequisite: EAEE E4003. A continuation of EAEE E3800, with emphasis on the principles underlying water analysis for inorganic, organic, and bacterial contaminants.

EAEE E3901y Environmental microbiology
Lect: 3. 3 pts. Professor Chandran.
Prerequisite: CHEM C1404 or the equivalent. Fundamentals of microbiology, genetics and molecular biology, principles of microbial nutrition, energetics and kinetics, application of novel and state-of-the-art techniques in monitoring the structure and function of microbial communities in the environment, engineered processes for biochemical waste treatment and bioremediation, microorganisms and public health, global microbial elemental cycles.

EAEE E3998x-E3999y Undergraduate design project
Lect: 1. Lab: 2. 2 pts (each semester). The staff.
Prerequisite: senior standing. Students must enroll for both E3998x and E3999y during their senior year. Selection of an actual problem in Earth and environmental engineering, and design of an engineering solution including technical, economic, environmental, ethical, health and safety, and social issues. Use of software for design, visualization, economic analysis, and report preparation. Students may work in teams. Presentation of results in a formal report and public presentation.

EAEE E4000x or y GIS lab access
Students must sign up for this class in order to gain access to EEE GIS lab. A laboratory fee of $50 is collected.

EAEE E4001x Industrial ecology of Earth resources
Lect: 3. 3 pts. Instructor to be announced.
Industrial ecology examines how to reconfigure industrial activities so as to minimize the adverse environmental and material resource effects on the planet. Engineering applications of methodology of industrial ecology in the analysis of current processes and products and the selection or design of environmentally superior alternatives. Home assignments of illustrative quantitative problems.

EAEE E4003x Introduction to aquatic chemistry
Lect: 3. 3 pts. Professor Duby.
Prerequisite: CHEN E3010 or the equivalent. Principles of physical chemistry applied to equilibria and kinetics of aqueous solutions in contact with minerals and anthropogenic residues. The scientific background for addressing problems of aqueous pollution, water treatment, and sustainable production of materials with minimum environmental impact. Hydrolysis, oxidation-reduction, complex formation, dissolution and precipitation, predominance diagrams; examples of natural water systems, processes for water treatment and for the production of inorganic materials from minerals.
EAAE E4004x Physical processing and recovery of solids
Generalized treatment of processes for solids separation. Applications to materials processing and handling; mining; solid waste, recycling, and resource recovery; construction materials and debris; scrap materials, yard and park wastes. Economic considerations and context. Relevant materials properties and bulk materials analyses. Process system flow-sheets and analysis. Solid/solid, solid/liquid, and solid/gas separation processes. Liberation, concentration, and auxiliary processes. Design of separation machines: types and intensities of force involved; scaling-up factors. Laboratory demonstrations and a field trip will be included.

EAAE E4005x Near-surface engineering geophysics
Geophysical methods as applicable to engineering problems. Principles of geophysics and noninvasive imaging techniques (inversion technology) and benefits and pitfalls of geophysics vs. direct imaging methods. Discussion of theory of each method. Discussion of data acquisition, processing, and interpretation for each method. Treatment of several case studies. Class-wide planning and execution of small-scale geophysical survey.

EAAE E4006y Field methods for environmental engineering
Lect: 1.5. Lab: 2. 3 pts. Professor McGillis.
Principles and methods for designing, building, and testing systems to sense the environment. Monitoring the atmosphere, water bodies and boundary interfaces between the two. Sensor systems for monitoring heat and mass flows, chemicals, and biota. Measurements of velocity, temperature, flux and concentration in the field. The class will involve planning and execution of a study to sense a local environmental system.

EAAE E4007y Environmental geophysics field studies
Lect: 3. 3 pts. Instructor to be announced.
Application of geophysical methods to noninvasive assessment of the near surface. First part consists of series of two-hour lectures of physics and math involved in instrumental methods and data acquisition and processing. In the field (nine field days) students plan surveys; collect and analyze geophysical data in teams; learn how to integrate geophysical data with invasive data, hydrological, geological, engineering, and contaminant transport models; and develop a comprehensive and justifiable model of the subsurface. Geophysical methods include GPR (Ground Penetrating Radar), conductivity, and magnetic and seismic methods. Field applications include infrastructure/environmental assessment, archeological studies, and high resolution geology.

EAAE E4009x Geographic information systems (GIS) for resource, environmental, and infrastructure management
Lect: 3. 3 pts. Professor Gorokhovich.
Prerequisite: The instructor’s permission. Basic concepts of geomatics, spatial data representation and organization, and analytical tools that comprise GIS are introduced and applied to a variety of problems including watershed protection, environmental risk assessment, material mass balance, flooding, asset management, and emergency response to natural or man-made hazards. Technical content includes geography and map projections, spatial statistics, database design and use, interpolation and visualization of spatial surfaces and volumes from irregularly spaced data, and decision analysis in an applied setting. Taught in a laboratory setting using ArcGIS. Access to New York City and other standard databases. Term projects emphasize information synthesis toward the solution of a specific problem.

EAAE E4011y Industrial ecology for manufacturing
Prerequisite: EAAE E4001 or the instructor’s permission. Application of industrial ecology to Design for Environment (DFE) of processes and products using environmental indices of resource consumption and pollution loads. Introduction of methodology for Life Cycle Assessment (LCA) of manufactured products. Analysis of several DFE and LCA case studies. Term project required on use of DFE/LCA on a specific product/process: (a) product design complete with materials and process selection, energy consumption, and waste loadings; (b) LCA of an existing industrial or consumer product using a commercially established method.

CHEE E4050x Industrial and environmental electrochemistry
Lect: 3. 3 pts. Professor Duby.
Prerequisite: CHEN E3010 or the equivalent. A presentation of the basic principle underlying electrochemical processes. Thermodynamics, electrode kinetics, and ionic mass transport. Examples of industrial and environmental applications illustrated by means of laboratory experiments: electroplating, refining, and winning in aequous solutions and in melt salts; electrolytic treatment of wastes; primary, secondary, and fuel cells.

ECIA W4100y Management and development of water systems
Lect: 3. 3 pts. Professor Lall and Dr. Arumugam.
Decision analytic framework for operating, managing, and planning water systems, considering changing climate, values, and needs. Public and private sector models explored through U.S.-international case studies on topics ranging from integrated watershed management to the analysis of specific projects for flood mitigation, water and wastewater treatment, or distribution system evaluation and improvement.

EAAE E4150y Air pollution prevention and control
Lect: 3. 3 pts. Professor Pfenaklis.
Adverse effects of air pollution, sources and transport media, monitoring and modeling of air quality, collection and treatment techniques, pollution prevention through waste minimization and clean technologies, laws, regulations, standards, and guidelines.

EAAE E4160y Solid and hazardous waste management
Lect: 3. 3 pts. Professor Somasundaran.

CIEE E4163x Environmental engineering: wastewater
Lect: 3. 3 pts. Professor Becker.
Prerequisites: Introductory chemistry (with lab) and fluid mechanics. Fundamentals of water pollution and wastewater characteristics. Chemistry, microbiology, and reaction kinetics. Design of primary, secondary, and advanced treatment systems. Small community and residential systems.

EAAE E4200y Production of inorganic materials
Lect: 3. 3 pts. Professor Duby.
Prerequisite: CHEN E3010 or the equivalent. Production and recycling of inorganic materials in aqueous and high-temperature systems. Industrial and environmental applications of hydrometallurgy, pyrometallurgy, and electrometallurgy. Reactor systems for, e.g., leaching, precipitation, and solvent extraction, bath and flash smelting reactors, rotary kilns, and fluid bed reactors. Thermodynamic and kinetic factors and material/energy balances involved in the design and performance of such reactors in typical applications.

EAAE E4241x Solids handling and transport systems
Analysis and design of transportation systems for bulk solids in tunnels, mines, and large excavations. Design of hoisting, cable transport, rail and trackless haulage systems, conveyor belts, selection of loaders, excavators, off-highway trucks, and draglines for large excavations.

CHEE E4252x Introduction to surface and colloid chemistry
Lect: 3. 3 pts. Professor Somasundaran.
Prerequisite: elementary physical chemistry. Thermodynamics of surfaces, properties of surfactant solutions and surface films, electrostatic and electrokinetic phenomena at interfaces, adsorption; interfacial mass transfer and modern experimental techniques.

CIEE E4252y Environmental engineering
Lect: 3. 3 pts. Professor Gong.
Prerequisites: CHEM C1403, or the equivalent; ENME E3161 or the equivalent. Engineering
aspects of problems involving human interaction with the natural environment. Review of fundamental principles that underlie the discipline of environmental engineering, i.e., constituent transport and transformation processes in environmental media such as water, air, and ecosystems. Engineering applications for addressing environmental problems such as water quality and treatment, air pollution emissions, and hazardous waste remediation. Presented in the context of current issues facing the practicing engineers and government agencies, including legal and regulatory framework, environmental impact assessments, and natural resource management.

CIEE E4257y Groundwater contaminant transport and remediation
Lect: 3.3 pts. Professor Mutch.
Prerequisite: CIEE E3250 or the equivalent. Single- and multiple-phase transport in porous media; contaminant transport in variably saturated heterogeneous geologic media; physically based numerical models of such processes.

EAAE E4257y (section 001) Environmental data analysis and modeling
Lect: 3.3 pts. Professors Yegulalp, Lall, and Gorokhovich.
Prerequisite: SIEO W3600 or SIEO W4250, or the equivalent. Statistical methods for the analysis of the space and time structure in environmental data. Application to problems of climate variation and change; hydrology; air, water, and soil pollution dynamics; disease propagation; ecological change; and resource assessment. Applications are developed using the ArcView Geographical Information System (GIS), integrated with currently available statistical packages. Team projects that lead to publication-quality analyses of data in various environmental fields of interest. An interdisciplinary perspective is emphasized in this applications-oriented class.

EAAE E4350x Planning and management of urban hydrologic systems
Lect: 3.3 pts. Professor Rangarajan.
Prerequisite: ENME E3161 or the equivalent. Introduction to runoff and drainage systems in an urban setting, including hydrologic and hydraulic analyses, flow and water quality monitoring, common regulatory issues, and mathematical modeling. Applications to problems of climate variation, land use changes, infrastructure operation and receiving water quality, developed using statistical packages, public-domain models, and Geographical Information Systems (GIS). Team projects that can lead to publication-quality analyses in relevant fields of interest. Emphasis on the unique technical, regulatory, fiscal, policy, and other interdisciplinary issues that pose a challenge to effective planning and management of urban hydrologic systems.

EAAE E4361y Economics of Earth resource industries
Lect: 3.3 pts. Professor Yegulalp.
Prerequisite: EAAE E3101 or the instructor’s permission. Definition of terms. Survey of Earth resource industries: resources, reserves, production, global trade, consumption of mineral commodities and fuels. Economics of recycling and substitution. Methods of project evaluation: estimation of operating costs and capital requirements, project feasibility, risk assessment, and environmental compliance. Cost estimation for reclamation/remediation projects. Financing of reclamation costs at abandoned minesites and waste-disposal postclosure liability.

CHEE E4530y Corrosion of metals
Lect: 3.3 pts. Professor Duby.
Prerequisite: CHEN E3010 or the equivalent. The theory of electrochemical corrosion, corrosion tendency, rates, and passivity. Application to various environments. Cathodic protection and coatings. Corrosion testing.

EAAE E4550x Catalysis for emissions control
Lect: 3.3 pts. Professors Castaldi and Farrutto. Prerequisite: ENME E3161 and MSAE E3111 or the equivalent. Fundamentals of heterogeneous catalysis, including modern catalytic preparation techniques. Analysis and design of catalytic emissions control systems. Introduction to current industrial catalytic solutions for controlling gaseous emissions. Introduction to future catalytically enabled control technologies.

EAAE E4560x Particle technology (section 1)
Lect: 3.3 pts. Professor Park.
Prerequisite: ENME E3161 and MSAE E3111 or the equivalent. Introduction to engineering processes involving particulates and powders. The fundamentals of particle characterization, multiphase flow behavior, particle formation, processing and utilization of particles in various engineering applications with examples in energy and environment related technologies. Engineering of functionalized particles and design of multiphase reactors and processing units with emphasis on fluidization technology. Particle technology is an interdisciplinary field. Due to the complexity of particulate systems, particle technology is often treated as art rather than science. In this course, the fundamental principles governing the key aspects of particle science and technology will be introduced, along with various industrial examples.

EAAE E4901y Environmental microbiology
Lect: 3.3 pts. Professor Chandran.
Basic microbiological principles; microbial metabolism; identification and interactions of microbial populations responsible for the biotransformation of pollutants; mathematical modeling of microbially mediated processes; biotechnology and engineering applications using microbial systems for pollution control.

EAAE E4950x Environmental biochemical processes
Lect: 3.3 pts. Professor Chandran.
Prerequisites: EAAE E4901 or CIEE E4252 or EAAE E4003 or the instructor’s approval. Qualitative and quantitative considerations in engineered environmental biochemical processes. Characterization of multiple microbial reactions in a community and techniques for determining associated kinetic and stoichiometric parameters. Engineering design of several bioreactor configurations employed for biochemical waste treatment. Mathematical modeling of engineered biological reactors using state-of-the-art simulation packages.

EAAE E4980 Urban environmental technology and policy
Progress of urban pollution engineering via contaminant abatement technology, government policy, and public action in urban pollution. Pollutant impact on modern urban environmental quality, natural resources, and government, municipal, and social planning and management programs. Strong emphasis on current and twentieth-century waste management in New York City.

EAAE E6132y Numerical methods in geomechanics
Prerequisite: EAAE E3112 and CIEN E4241, or the instructor’s permission. A detailed survey of numerical methods used in geomechanics, emphasizing the Finite Element Method (FEM). Review of the behavior of geological materials. Water and heat flow problems. FEM techniques for solving nonlinear problems, and simulating incremental excavation and loading on the surface and underground.

EAAE E6151y Applied geophysics

EAAE E6200y Theory and applications of extreme value statistics in engineering and Earth sciences
Lect: 3.3 pts. Professor Yegulalp.
Prerequisite: STAT G 4107 or equivalent background in probability and statistical inference, or the instructor’s permission. Introduction of fundamental concepts in extreme value statistics. The exact and asymptotic theory of extremes. Development of statistical methodology for estimating the parameters of asymptotic extremal distributions from experimental data. Examples of applications of extreme value statistics to regional and global earthquake forecasting, laboratory testing of rocks and metals, fatigue failure, floods, droughts, extreme wind velocities, and rainfall.

**EAEE E6208y Combustion chemistry and processes**
Lect: 3 pts. Professor Castaldi.
Prerequisite: EAEE E4900 or the equivalent, or the instructor’s permission. The fundamentals of combustion phenomena and the intrinsic chemistry of combustion processes. The theory of the essential combustion processes such as ignition, sustained reaction, stability, and flame quenching. Processes that govern reactant consumption and product formation, in particular by-products that are formed that result in pollutant emissions and the impacts and implications that combustion has locally and globally on the environment. Detailed examination of the entire range of combustion systems from diffusion flame processes to current developing technologies including millisecond catalytic combustion processes, noncarbon fuel combustion, fuel cells and plasma combustion.

**EAEE E6210x Quantitative environmental risk analysis**
Lect: 3 pts. Professor Yegulalp.
Prerequisite: EAEE E3101, SIEO W4150, or the equivalent. Comprises the tools necessary for technical professionals to produce meaningful risk analyses. Review of relevant probability and statistics; incorporation of probability in facility failure analysis. Availability, assessment, and incorporation of risk-related data. Contaminant transport to exposed individuals; uptake, morbidity, and mortality. Computational tools necessary to risk modeling. Use and applicability of resulting measurements of risk, and their use in public policy and regulation.

**EAEE E6212x Carbon sequestration**
Lect: 3 pts. Professor Lackner.
Prerequisite: EAEE E4900 or the equivalent, or the instructor’s permission. New technologies for capturing carbon dioxide and disposing of it away from the atmosphere. Detailed discussion of the extent of the human modifications to the natural carbon cycle, the motivation and scope of future carbon management strategies, and the role of carbon sequestration. Introduction of several carbon sequestration technologies that allow for the capture and permanent disposal of carbon dioxide. Engineering issues in their implementation, economic impacts, and the environmental issues raised by the various methods.

**EAEE E6220x Remedial and corrective action**
Lect: 3. 3 pts. Not given in 2008–2009. Prerequisite: EAEE E4160 or the equivalent. Integrates the engineering aspects of cleanup of hazardous materials in the environment. Site assessment/investigation. Site closure, containment, and control techniques and technologies. Techniques used to treat hazardous materials in the environment, in situ and removal for treatment, focusing on those aspects that are unique to the application of those technologies in an uncontrolled natural environment. Management, safety, and training issues.

**CHEE E6220y Equilibria and kinetics in hydrometallurgical systems**
Lect: 3. 3 pts. Professor Duby.
Prerequisite: CHEE E4050 or EAEE E4003. Detailed examination of chemical equilibria in hydrometallurgical systems. Kinetics and mechanisms of homogeneous and heterogeneous reactions in aqueous solutions.

**EAEE E6228y Theory of flotation**
Lect: 3. 3 pts. Not given in 2008–2009. Prerequisite: CHEE E4252 or the instructor’s permission. A detailed study of the physicochemical principles of the flotation process.

**EAEE E6240x or y Physical hydrology**
Lect: 3. 3 pts. Professor Gong.
Prerequisite: Engineering hydrology or the equivalent. Spatial/temporal dynamics of the hydrologic cycle and its interactions with landforms and vegetation. Hydroclimatology at regional to planetary scales, focusing on mechanisms of organization and variation of water fluxes as a function of season, location, reservoir (ocean, atmosphere, land), and time scale. Land-atmosphere interaction and the role of vegetation and soil moisture. Topography as an organizing principle for land-water fluxes. Geomorphology and the evolution of river networks. Sedimentation, erosion, and hill slope hydrology. Dynamics of water movement over land, in rivers, and in the subsurface, with an emphasis on modeling interfaces. Integrated models and the scale problem. Emphasis on data-based spatial/temporal modeling and exploration of outstanding theoretical challenges.

**CHEE E6252y Applied surface and colloid chemistry**
Lect: 2. Lab: 3. 3 pts. Professors Somasundaran and Farinato.
Prerequisite: CHEE E4252. Applications of surface chemistry principles to wetting, flocculation, flotation, separation techniques, catalysis, mass transfer, emulsions, foams, aerosols, membranes, biological surfactant systems, microbial surfaces, enhanced oil recovery, and pollution problems. Appropriate individual experiments and projects. Lab required.

**EAEE E6255x-E6256y Methods and applications of analytical decision making in mineral industries**
Lect: 3. 3 pts. Not given in 2008–2009. Prerequisite: the instructor’s permission. Advanced study of decision-making problems with critical survey and applications of quantitative decision-making techniques in mineral industries. Systematic development of methods of the formulation, analysis, and resolution of these problems.

**EAEE E8229x Selected topics in processing minerals and waste**
Lect: 2. Lab: 3. 3 pts. Professors Somasundaran and Nagarat.
Prerequisite or corequisite: CHEE E4252 or the instructor’s permission. Critical discussion of current research topics and publications in the area of flotation, flocculation, and other mineral processing techniques, particularly mechanisms of adsorption, interactions of particles in solution, thinning of liquid films, and optimization techniques.

**EAEE E8231x and y Selected topics in hydro- and electrometallurgy**
Lect: 3. 3 pts. Professor Duby.
Prerequisite: EAEE E4003 and CHEE E4050, or the instructor’s permission. Review of current research and literature in the field of hydrometallurgy, electrometallurgy, and corrosion. Topics will be selected by the instructor to illustrate the application of thermodynamics and rate phenomena to the design and control of electrochemical engineering processes.

**EAEE E8233x and y Research topics in particle processing**
Points: 0 to 1. Professor Somasundaran.
Emergent findings in the interactions of particles with reagents and solutions, especially inorganics, surfactants, and polymers in solution, and their role in grinding, flotation, agglomeration, filtration, enhanced oil recovery, and other mineral processing operations.

**EAEE E8273x-E8274y Mining engineering reports**
0 to 4 pts. Professor Yegulalp.
May be substituted for formal thesis, EAEE E9271, upon recommendation of the student’s adviser.

**EAEE E9271x and y, and s Earth and environmental engineering thesis**
0 to 6 pts. The staff.
Research work culminating in a creditable dissertation on a problem of a fundamental nature selected in conference between student and adviser. Wide latitude is permitted in choice of a subject, but independent work of distinctly graduate character is required in its handling.

**EAEE E9273x-E9274y Earth and environmental engineering reports**
0 to 4 pts. The staff.
May be substituted for the formal thesis, EAEE E9271, upon recommendation of the department.
COURSES IN MATERIALS SCIENCE AND ENGINEERING
(HENRY KRUMB SCHOOL OF MINES)

For complete course descriptions, see the section “Materials Science and Engineering Program.”

MSAE E1001y Atomic-scale engineering of new materials
Lect: 3. 3 pts. Professor Bailey.

MSAE E3103x Elements of materials science
Lect: 3. 3 pts. Professor Noyan.

MSAE E3104y Laboratory in materials science
Lect: 1. Lab. 4. 3 pts. Professor Noyan.

MSAE E3111x Thermodynamics, kinetic theory, and statistical mechanics
Lect: 3. 3 pts. Professor Bailey.

MSAE E3114y Processing of metals and semiconductors
Lect: 3. 3 pts. Professor Duby.

MSAE E3142y Processing of ceramics and polymers
Lect: 3. 3 pts. Instructor to be announced.

MSAE E3156x-E3157y Design project
3 pts. Members of the faculty.

MSAE E3900x and y Undergraduate research in materials science
0 to 4 pts. Members of the faculty.

MSAE E4090x Nanotechnology

MSAE E4101x Structural analysis of materials
Lect: 3. 3 pts. Professor Chan.

MSAE E4132y Fundamentals of polymers and ceramics

MSAE E4202y Thermodynamics and reactions in solids
Lect: 3. 3 pts. Professor Im.

MSAE E4206x Electronic and magnetic properties of solids
Lect: 3. 3 pts. Professor Bailey.

MSAE E4207y Lattice vibrations and crystal defects
Lect: 3. 3 pts. Professor Chan.

MSAE E4215y Mechanical behavior of materials
Lect: 3. 3 pts. Professor Noyan.

MSAE E4250x Ceramics and composites
Lect: 3. 3 pts. Offered in alternate years. Professor Guha.

MSAE E4301x and y Materials science laboratory
1 to 3 pts. Instructor to be announced.

MSAE E4900x and y Special topics in materials science and engineering
Lect: 3. 3 pts. Instructors to be announced.

MSAE E6020y Electronic ceramics

MSAE E6081x Solid state physics, I
Lect: 3. 3 pts. Professor Pinczuk.

MSAE E6082y Solid state physics, II
Lect: 3. 3 pts. Professor Aleiner.

MSAE E6091y Magnetism and magnetic materials
Lect: 3. 3 pts. Offered in alternate years. Instructor to be announced.

MSAE E6120x Grain boundaries and interfaces

MSAE E6220x Crystal physics

MSAE E6221x Introduction to dislocation theory

MSAE E6225y Techniques in x-ray and neutron diffraction

MSAE E6229x Energy and particle beam processing of materials

MSAE E6230x Kinetics of phase transformations

MSAE E6251y Thin films and layers
Lect: 2. 3 pts. Professor Chan.

MSAE E6273x and y, and s Materials science reports
0 to 6 pts. Members of the faculty.

MSAE E8235x and y Selected topics in materials science
Lect: 3. 3 pts. Instructor to be announced.

MSAE E8236y Anelastic relaxations in crystals

MSAE E8900x and y Materials science and engineering colloquium
0 pts. Members of the faculty.

MSAE E8925x-E8926y Research topics in materials science and metallurgical engineering
Lect: 1. 1 pt. Members of the faculty.

MSAE E9301x and y, and s Doctoral research
0 to 15 pts. Members of the faculty.

MSAE E9309x and y, and s Proposal of research for the doctorate
0 to 3 pts. Members of the faculty.

MSAE E9600x and y, and s Doctoral research instruction
3, 6, 9, or 12 pts. Members of the faculty.

MSAE E9900x and y, and s Doctoral dissertation
0 pts. Members of the faculty.
Contemporary electrical engineering is a broad discipline that encompasses a wide range of activities. A common theme is the use of electrical and electromagnetic signals for the generation, transmission, processing, storage, conversion, and control of information and energy. An equally important aspect is the human interface and the role of individuals as the sources and recipients of information. The rates at which information is transmitted today range from megabits per second to gigabits per second and in some cases, as high as terabits per second. The range of frequencies over which these processes are studied extends from direct current (i.e., zero frequency), to microwave and optical frequencies.

The need for increasingly faster and more sophisticated methods of handling information poses a major challenge to the electrical engineer. New materials, devices, systems, and network concepts are needed to build the advanced communications and information handling systems of the future. Previous innovations in electrical engineering have had a dramatic impact on the way in which we work and live: the transistor, integrated circuits, computers, radio and television, satellite transmission systems, lasers, fiber optic transmission systems, and medical electronics.

The faculty of the Electrical Engineering Department at Columbia University is dedicated to the continued development of further innovations through its program of academic instruction and research. Our undergraduate academic program in electrical engineering is designed to prepare the student for a career in industry or business by providing her or him with a thorough foundation of the fundamental concepts and analytical tools of contemporary electrical engineering. A wide range of elective courses permits the student to emphasize specific disciplines such as telecommunications, microelectronics, digital systems, or photonics.
Solid-state device research is conducted in the Columbia Microelectronics Sciences Laboratories. This is an interdisciplinary facility, involving aspects of electrical engineering and applied physics. It includes the study of semiconductor physics and devices, optical electronics, and quantum optics. The emphasis is on laser processing and diagnostics for submicron electronics, fabrication of compound semiconductor optoelectronic devices by molecular beam epitaxy, physics of superlattices and quantum wells, and interface devices such as Schottky barriers, MOS transistors, heterojunctions, and bipolar transistors. Another area of activity is the physics and chemistry of microelectronics packaging.

Research in photonics includes development of semiconductor light sources such as LEDs and injection lasers, fabrication and analysis of quantum confined structures, photo conductors, pin diodes, avalanche photodiodes, optical interconnects, and quantum optics. A major effort is the picosecond optoelectronics program, focusing on the development of new devices and their applications to high-speed optoelectronic measurement systems, photonic switching, and optical logic. In addition, research is being performed in detection techniques for optical communications and radar. Members of the photonics group play a leading role in a multi-university consortium: The National Center for Integrated Photonics Technology.

Integrated systems research involves the analysis and design of analog, digital, and mixed-signal microelectronic circuits and systems. These include novel signal processors and related systems, data converters, radio frequency circuits, low noise and low power circuits, and fully integrated analog filters that share the same chip with digital logic. VLSI architectures for parallel computation, packet switching, and signal processing are also under investigation. Computer-aided design research involves the development of techniques for the analysis and design of large-scale integrated circuits and systems.

Electromagnetics research ranges from the classical domains of microwave generation and transmission and wave propagation in various media to modern applications involving lasers, optical fibers, plasmas, and solid-state devices. Problems relevant to controlled thermonuclear fusion are under investigation.

**Laboratory Facilities**

Current research activities are fully supported by more than a dozen well-equipped research laboratories run by the Department. Specifically, laboratory research is conducted in the following laboratories: Multimedia Networking Laboratory, Lightwave Communications Laboratory, Systems Laboratory, Image and Advanced Television Laboratory, Laser Processing Laboratory, Molecular Beam Epitaxy Laboratory, Surface Analysis Laboratory, Microelectronics Fabrication Laboratory, Device Measurement Laboratory, Ultrafast Optoelectronics Laboratory, Columbia Integrated Systems Laboratory (CISL), Lightwave Communications Laboratory, Photonics Laboratory, Plasma Physics Laboratory (in conjunction with the Department of Applied Physics).

Laboratory instruction is provided in the Introduction to Electrical Engineering Laboratory, Marcellus-Hartley Electronics Laboratory, Microprocessor Laboratory, Microwave Laboratory, Optical Electronics Laboratory, Solid-State Laboratory, VLSI Design Laboratory, and Student Projects Laboratory, all on the twelfth floor of the S. W. Mudd Building.

**UNDERGRADUATE PROGRAM**

The undergraduate program in Electrical Engineering at Columbia University has five formal educational objectives:

A. Produce graduates with a strong foundation in the basic sciences and mathematics that will enable them to identify and solve electrical engineering problems.

B. Provide our students with a solid foundation in electrical engineering that prepares them for life-long careers and professional growth in fields of their choice.

C. Provide our students with the basic skills to communicate effectively and to develop the ability to function as
members of multi-disciplinary teams. D. Provide our students with a broad-based education so that they can appreciate diversity of opinion, better understand ethical issues, and develop a perspective of our profession.

E. Provide our students with a relevant engineering design experience that is integrated across the four year curriculum. Through these experiences, our students will develop an understanding of the relationship between theory and practice.

The B.S. program in electrical engineering at Columbia University seeks to provide a broad and solid foundation in the current theory and practice of electrical engineering, including familiarity with basic tools of math and science, an ability to communicate ideas, and a humanities background sufficient to understand the social implications of engineering practice. Graduates should be qualified to enter the profession of engineering, to continue toward a career in engineering research, or to enter other fields in which engineering knowledge is essential. Required nontechnical courses cover civilization and culture, philosophy, economics, and a number of additional electives. English communication skills are an important aspect of these courses. Required science courses cover basic chemistry and physics, whereas math requirements cover calculus, differential equations, probability, and linear algebra. Basic computer knowledge is also included, with an introductory course on using engineering workstations and two rigorous introductory computer science courses. Core electrical engineering courses cover the main components of modern electrical engineering and illustrate basic engineering principles. Topics include a sequence of two courses on circuit theory and electronic circuits, one course on semiconductor devices, one on electromagnetics, one on signals and systems, one on digital systems, and one on communications or networking. Engineering practice is developed further through a sequence of laboratory courses, starting with a first-year course to introduce hands-on experience early and to motivate theoretical work. Simple creative design experiences start immediately in this first-year course. Following this is a sequence of lab courses that parallel the core lecture courses. Opportunities for exploring design can be found both within these lab courses and in the parallel lecture courses, often coupled with experimentation and computer simulation, respectively. The culmination of the laboratory sequence and the design experiences introduced throughout earlier courses is a senior design course (capstone design course), which includes a significant design project that ties together the core program, encourages creativity, explores practical aspects of engineering practice, and provides additional experience with communication skills in an engineering context. Finally, several technical electives are required, chosen to provide both breadth and depth in a specific area of interest. More detailed program objectives and outcomes are posted at www.ee.columbia.edu/academics/undergrad.

The program in electrical engineering leading to the B.S. degree is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

There is a strong interaction between the Department of Electrical Engineering and the Departments of Computer Science, Applied Physics and Applied Mathematics, Industrial Engineering and Operations Research, Physics, and Chemistry.

EE Core Curriculum

All Electrical Engineering (EE) students must take a set of core courses, which collectively provide the student with fundamental skills, expose him/her to the breadth of EE, and serve as a springboard for more advanced work, or for work in areas not covered in the core. These courses are explicitly shown on the charts on pages 138–141.

Technical Electives

The 18-point technical elective requirement for the electrical engineering program consists of three components: depth, breadth, and other. A general outline is provided here, and more specific course restrictions can be found under “EE Curriculum” at www.ee.columbia.edu/academics/undergrad. For any course not clearly listed there, adviser approval is necessary.

The depth component must consist of at least 6 points of electrical engineering courses in one of four defined areas: (a) photonics, solid-state devices, and electromagnetics; (b) circuits and electronics; (c) signals and systems; and (d) communications and networking. The depth requirement provides an opportunity to pursue particular interests and exposure to the process of exploring a discipline in depth—an essential process that can be applied later to other disciplines, if desired.

The breadth component must consist of at least 6 additional points of engineering courses that are outside of the chosen depth area. These courses can be from other departments within the school. The breadth requirement precludes overspecialization. Breadth is particularly important today, as innovation requires more and more of an interdisciplinary approach, and exposure to other fields is known to help one’s creativity in one’s own main field. Breadth also reduces the chance of obsolescence as technology changes.

Any remaining technical elective courses, beyond the minimum 12 points of depth and breadth, do not have to be engineering courses (except for students without ELEN E1201 or approved transfer credit for ELEN E1201) but must be technical. Generally, math and science courses that do not overlap with courses used to fill other requirements are allowed.

Starting Early

The EE curriculum is designed to allow students to start their study of EE in their first year. This motivates students early and allows them to spread non-technical requirements more evenly. It also makes evident the need for advanced math and physics concepts, and motivates the study of such concepts. Finally, it allows more time for students to take classes in a chosen depth area, or gives them more time to explore before choosing a depth area. Students can start with ELEN E1201: Introduction to electrical engineering in the second semester of their first year, and can continue with other core courses one semester after that, as shown in the “early-starting students” chart. It is
emphasized that both the early- and late-starting sample programs shown in the charts are examples only; schedules may vary depending on student preparation and interests.

Transfer Students
Transfer students coming to Columbia as juniors with sufficient general background can complete all requirements for the B.S. degree in electrical engineering. Such students fall into one of two categories:

**Plan 1:** Students coming to Columbia without having taken the equivalent of ELEN E1201 must take this course in their junior year. This requires postponing the core courses in circuits and electronics until the senior year, and thus does not allow taking electives in that area; thus, such students cannot choose circuits and electronics as a depth area.

**Plan 2:** This plan is for students who have taken a course equivalent to ELEN E1201 at their school of origin, including a laboratory component. See the bulletin for a description of this course. Many pre-engineering programs and physics departments at four-year colleges offer such courses. Such students can start taking circuits at Columbia immediately, and thus can choose circuits and electronics as a depth area.

It is stressed that ELEN E1201 or its equivalent is a key part of the EE curriculum. The preparation provided by this course is essential for a number of other core courses.

Sample programs for both Plan 1 and Plan 2 transfer students can be found at www.ee.columbia.edu/ academics/undergrad.

**GRADUATE PROGRAMS**

The Department of Electrical Engineering offers graduate programs leading to the degree of Master of Science (M.S.), the graduate professional degree of Electrical Engineer (E.E.), and the degrees of Doctor of Engineer-ing Science (Eng.Sc.D.) and Doctor of Philosophy (Ph.D.). The Graduate Record Examination (General Test only) is required of all applicants except special students. An undergraduate grade point average equivalent to B or better from an institution comparable to Columbia is expected.

Applicants who, for good reasons, are unable to submit GRE test results by the deadline date but whose undergraduate record is clearly superior may file an application without the GRE scores. An explanatory note should be added to ensure that the application will be processed even while incomplete. If the candidate’s admissibility is clear, the decision may be made without the GRE scores; otherwise, it may be deferred until the scores are received.

There are no prescribed course requirements in any of the regular graduate degree programs. Students, in consultation with their faculty advisers, design their own programs, focusing on particular fields of electrical engineering. Among the fields of graduate study are microelectronics, communications and signal processing, integrated circuit and system analysis and synthesis, photonics, electromagnetic theory and applications, plasma physics, and quantum electronics.

Graduate course charts for several focus areas can be found at www.ee.columbia.edu/academics/masters.

**Master of Science Degree**

Candidates for the M.S. degree in electrical engineering must complete 30 points of credit beyond the bachelor’s degree. A minimum of 15 points of credit must be at the 6000 level or higher. No credit will be allowed for undergraduate courses (3000 or lower). At least 15 points must be taken in EE courses (i.e., courses listed by the Electrical Engineering Department) or courses designated COMS, of which at least 10 points must be EE courses. Courses to be credited toward the M.S. degree can be taken only upon prior approval of a faculty adviser in the Department of Electrical Engineering. This applies to the summer session as well as the autumn and spring terms. Certain 4000-level courses will not be credited toward the M.S. degree, and no more than 6 points of research may be taken for credit. Up to 3 points of credit for approved graduate courses outside of engineering and science may be allowed. The general school requirements listed earlier in this bulletin, such as minimum GPA, must also be satisfied. All degree requirements must be completed within five years of the beginning of the first course credited toward the degree. More details and a checklist for adviser approvals can be found at www.ee.columbia.edu/academics/masters.

**Professional Degree**

The professional degree in electrical engineering is intended to provide specialization beyond the level of the M.S. degree, in a focused area of electrical engineering selected to meet the professional objectives of the candidate. A minimum of 30 points of credit is required. The prospective E.E. candidate follows a program of study formulated in consultation with, and approved by, a faculty adviser. At least three courses will be in a specific, focused area of electrical engineering, and at least two-thirds of the entire program will be in electrical engineering or computer science. No thesis is required, but the program may optionally include a seminar or project or research for which a report is produced; up to 6 points of such projects may be credited toward the degree. The level of the courses will generally be higher than is typical of a master’s degree program, although courses at the 4000 level may be included to prepare for more advanced work. A candidate is required to maintain a grade-point average of at least 3.0. All degree requirements must be completed within five years of the beginning of the first course credited toward the degree.

**Doctoral Degree**

The requirements for the Ph.D. and Eng.Sc.D. degrees are identical. Both require a dissertation based on the candidate’s original research, conducted under the supervision of a faculty member. The work may be theoretical or experimental or both. Students who wish to become candidates for the doctoral degree in electrical engineering have the option of applying for admission to the Eng.Sc.D. program or the Ph.D. program. Students who elect the Eng.Sc.D. degree register in the School of Engineering and Applied Science; those who elect the Ph.D. degree regis-
ter in the Graduate School of Arts and Sciences. Doctoral candidates must obtain a minimum of 60 points of formal course credit beyond the bachelor's degree. A master's degree from an accredited institution may be accepted as equivalent to 30 points. A minimum of 30 points beyond the master's degree must be earned while in residence in the doctoral program. More detailed information regarding the requirements for the doctoral degree may be obtained in the department office and at www.ee.columbia.edu/academics/phd.

Optional M.S. Concentrations

Students in the electrical engineering M.S. program often choose to use some of their electives to focus on a particular field. Students may pick one of a number of optional, formal concentration templates or design their own M.S. program in consultation with an adviser. These concentrations are not degree requirements. They represent suggestions from the faculty as to how one might fill one's programs so as to focus on a particular area of interest. Students may wish to follow these suggestions, but they need not. The degree requirements are quite flexible and are listed in the Master of Science Degree section, above. All students, whether following a formal concentration template or not, are expected to include breadth in their program. Not all of the elective courses listed here are offered every year. For the latest information on available courses, contact the Department of Electrical Engineering or visit the Electrical Engineering home page at www.ee.columbia.edu.

Concentration in Multimedia Networking

Advisers: Prof. Henning Schulzinne, Prof. Predrag Jelenkovic

1. Satisfy M.S. degree requirements.
2. Both ELEN E6711: Stochastic signals and noise and ELEN E6761: Computer communication networks, I.
3. Either COMS W4118: Operating systems or COMS W4111: Database systems.
4. COMS E6181: Advanced Internet services.

With an adviser's approval, any of the courses above can be replaced by the following closely related subjects: CSEE E4140: Networking laboratory; CSEE W4119: Computer networks; COMS W4180: Network security; ELEN E6762: Computer communication networks, II; ELEN E6850: Visual information systems; ELEN E6950: Wireless and mobile networking, I; ELEN E6951: Wireless and mobile networking, II.

Concentration in Telecommunications Engineering

Advisers: Prof. Henning Schulzinne, Prof. Predrag Jelenkovic, Prof. Ed Coffman, Prof. Nicholas Maxemchuk, Prof. Dan Rubenstein, Prof. Gil Sussman

1. Satisfy the M.S. degree requirements.
2. One basic hardware or software course such as: ELEN E4321: Digital VLSI circuits; ELEN E4411: Fundamentals of photonics; COMS W4118: Operating systems, I; COMS W4111: Database systems.
3. One basic course system course as: ELEN E4702: Communication theory; ELEN E4703: Wireless communications; CSEE W4119: Computer networks; ELEN E6761: Computer communication networks, I.
4. At least two approved courses from a focus area such as Signal/Image Processing and Telecommunications/Multimedia Networks.

Concentration in Media Engineering

Advisers: Prof. Shi-Fu Chang, Prof. Dan Ellis, Prof. Xiaodong Wang

1. Satisfy the basic M.S. degree requirements.
4. At least two advanced courses such as: ELEN E4896: Music signal processing; ELEN E6820: Speech and audio processing and recognition; ELEN E6850: Visual information systems; ELEN E6860: Advanced digital signal processing; ELEN E688x: Topics in signal processing; ELEN E6762: Computer communication networks, II; ELEN E6717: Information theory; COMS E6181: Advanced internet services; ELEN E6950: Wireless and mobile networking, I; or ELEN E6001-E6002: Advanced projects in electrical engineering with an appropriate project.

A cross-disciplinary project in areas related to new media technology is especially encouraged.

Concentration in Lightwave (Photonics) Engineering

Advisers: Prof. Keren Bergman, Prof. Paul Diament, Prof. Richard Osgood, Prof. Amiya Sen, Prof. Tony Heinz

1. Satisfy the M.S. degree requirements.
2. Take both ELEN E4411: Fundamentals of photonics and ELEN E6403: Classical electromagnetic theory (or an equivalent, such as APPH E4300: Applied electrodynamics or PHYS G6092: Electromagnetic theory).
3. One more device/circuits/photonics course such as: ELEN E4401: Wave transmission and fiber optics; ELEN E6412: Lightwave devices; ELEN E6413: Lightwave systems; ELEN E4405: Classical nonlinear optics; ELEN E6414: Photonic integrated circuits; ELEN E4314: Communication circuits; ELEN E4501: Electromagnetic devices and energy conversion.
4. At least two approved courses in photonics or a related area.

Concentration in Wireless and Mobile Communications

Adviser: Prof. Gil Sussman

1. Satisfy M.S. degree requirements.
2. One basic circuits course such as: ELEN E4312: Analog electric circuits; ELEN E4314: Communication circuits; ELEN E6314: Advanced communication circuits; ELEN E6312: Advanced analog ICs.
3. Two communications or networking courses such as: CSEE W4119: Computer networks; ELEN E4702: Digital communications; ELEN E4703: Wireless communications; ELEN E6711: Stochastic signals and noise; ELEN E4810: Digital signal processing; ELEN E6950: Wireless and mobile networking, I; ELEN E6951: Wireless and mobile networking, II; ELEN E6761: Computer communication networks, I; ELEN E6712: Communication theory; ELEN E6713: Topics in communications; ELEN E6717: Information theory.
4. At least two approved courses in wireless communications or a related area.

Concentration in Microelectronic Circuits
Advisers: Prof. Yannis Tsividis, Prof. Charles Zukowski, Prof. Kenneth Shepard, Prof. Peter Kinget
1. Satisfy M.S. degree requirements.
3. One analog course such as: ELEN E4312: Analog electronic circuits; ELEN E4215: Analog filter synthesis and design; ELEN E6312: Advanced analog integrated circuits; ELEN E6316: Analog circuits and systems in VLSI; ELEN E4314: Communication circuits; ELEN E6314: Advanced communication circuits.
4. One additional course such as: ELEN E4332: VLSI design laboratory; ELEN E6211: Circuit theory; ELEN E6261: Computational methods of circuit analysis; ELEN E6304: Topics in electronic circuits; ELEN E6318: Microwave circuit design.
5. At least two additional approved courses in circuits or a related area.

Concentration in Microelectronic Devices
Advisers: Prof. Wen Wang, Prof. Richard Osgood, Prof. Ioannis (John) Kymissis
1. Satisfy M.S. degree requirements.
2. One basic course such as: ELEN E4301: Introduction to semiconductor devices or ELEN E4411: Fundamentals of photonics.
3. One advanced course such as: ELEN E4193: Modern display science and...
### ELECTRICAL ENGINEERING: THIRD AND FOURTH YEARS
#### EARLY-STARTING STUDENTS

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<tr>
<td>C2601 (3.5)</td>
<td>Solid-state devices &amp; materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab C1494 (3)</td>
<td>ELEN E3401 (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab C2699 (3)</td>
<td>Electromagnetics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab W3081 (2)</td>
<td>ELEN E3701 (3)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Intro. to communication systems or CSEE W4119 (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Computer networks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **EE REQUIRED LABS** | **OTHER REQUIRED COURSES** | | |
| | SIEO W3658 or W41055; and COMS W3137 (or W3133, W3134, or W3139) | | |
| | (Some of these courses are not offered both semesters. Students with an adequate background can take some of these courses in the sophomore year) | | |

| **EE DEPTH TECH** | | | |
| | At least two technical electives in one depth area. The four depth areas are: (a) photonics, solid-state devices, and electromagnetics; (b) circuits and electronics; (c) signals and systems; and (d) communications and networking. | | |
| | (For details, see www.ee.columbia.edu/academics/undergrad) | | |

| **BREADTH TECH** | | | |
| | At least two technical electives outside the chosen depth area; must be engineering courses (see www.ee.columbia.edu/academics/undergrad) | | |

| **OTHER TECH** | | | |
| | Additional technical electives (consisting of more depth or breadth courses, or further options listed at www.ee.columbia.edu/academics/undergrad) as required to bring the total points of technical electives to 185 | | |

| **NONTECH** | | | |
| | Complete 27-point requirement; see page 11 or www.seas.columbia.edu for details (administered by the advising dean) | | |

| **TOTAL POINTS** | 16.5 | 17 | 18 | 15 |

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1. Chemistry lab (CHEM 1500) may be substituted for physics lab, although this is not generally recommended.
2. These courses can be taken in the sophomore year if the prerequisites/corequisites are satisfied.
3. The capstone design course provides ELEN majors with a “culminating design experience.” As such, it should be taken near the end of the program and involve a project that draws on material from a range of courses.
4. SIEO W3600 and W4150 cannot generally be used to replace SIEO W3658 or W4105. ELEN majors completing an economics minor can augment their probability course with STAT W1211.
5. The total points of technical electives is reduced to 15 if APMA E2101 has been replaced by MATH E1210 and either APMA E3101 or MATH V2010.
6. “Total points” assumes that 20 points of nontechnical electives and other courses are included.

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**Consulting Professor:** Prof. Dimitris Anastassiou, Prof. Ed Coffman, Prof. Pedrag Jelenkovic, Prof. Aurel Lazar, Prof. Kenneth Shepard, Prof. Xiaodong Wang, Prof. Charles Zukowski

**Concentration in Systems Biology Advisers:**

1. Satisfy M.S. degree requirements.
### ELECTRICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS
#### LATE-STARTING STUDENTS

<table>
<thead>
<tr>
<th>SEMESTER I</th>
<th>SEMESTER II</th>
<th>SEMESTER III</th>
<th>SEMESTER IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MATHEMATICS</strong></td>
<td>MATH V1101(3)</td>
<td>MATH V1102(3)</td>
<td>MATH V1201 (3)</td>
</tr>
<tr>
<td><strong>PHYSICS</strong> (three tracks, choose one)</td>
<td>C1401 (3) C1601 (3.5) C2801 (4.5)</td>
<td>C1402 (3) C1602 (3.5) C2802 (4.5)</td>
<td>C1403 (3) C2601 (3.5) Lab W3081 (2)</td>
</tr>
<tr>
<td><strong>CHEMISTRY</strong></td>
<td>one-semester lecture (3–4) C1403 or C1404 or C3045 or C1604</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ELECTRICAL ENGINEERING</strong></td>
<td>ELEN E1201 (3.5) either semester</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ENGLISH COMPOSITION</strong> (three tracks, choose one)</td>
<td>C1010 (3) Z1003 (0) Z0006 (0)</td>
<td>C1010 (3) Z1003 (0)</td>
<td></td>
</tr>
<tr>
<td><strong>REQUIRED NONTECHNICAL ELECTIVES</strong></td>
<td></td>
<td>HUMA C1001, C0CI C1101, or Major Cultures (3–4)</td>
<td></td>
</tr>
<tr>
<td><strong>COMPUTER SCIENCE</strong></td>
<td>COMS W1007 (3) either semester</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHYSICAL EDUCATION</strong></td>
<td>C1001 (1)</td>
<td>C1002 (1)</td>
<td></td>
</tr>
<tr>
<td><strong>GATEWAY LAB</strong></td>
<td>E1102 (4) either semester</td>
<td></td>
<td></td>
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</tbody>
</table>

1. Transfer students and 3–2 Combined Plan students who have not taken ELEN E1201 prior to the junior year are expected to have taken a roughly equivalent course when they start ELEN E3201.
2. COMS W1007 may be replaced by COMS W1003, W1004, or W1009, but impact on later options should be considered (see www.ee.columbia.edu/academics/undergrad).
3. APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2010.
4. Chemistry lab (CHEM C1500) may be substituted for physics lab, although this is not generally recommended.

### COURSES IN ELECTRICAL ENGINEERING

**ELEN E1101x or y The digital information age**

Lect: 3. 3 pts. Professor Vallancourt.

An introduction to information transmission and storage, including technological issues. Binary numbers; elementary computer logic; digital speech and image coding; basics of compact disks, telephones, modems, faxes, UPC bar codes, and the World Wide Web. Projects include implementing simple digital logic systems and Web pages. Intended primarily for students outside the School of Engineering and Applied Science. The only prerequisite is a working knowledge of elementary algebra.

**ELEN E1201y Introduction to electrical engineering**

Lect: 3. Lab: 1. 3.5 pts. Professor Vallancourt.

Prerequisite: MATH V1101. Basic concepts of electrical engineering. Exploration of selected topics and their application. Electrical variables, circuit laws, nonlinear and linear elements, ideal and real sources, transducers, operational amplifiers in simple circuits, external behavior of diodes and transistors, first order RC and RL circuits. Digital representation of a signal, digital logic gates, flipflops. A lab is an integral part of the course. Required of electrical engineering and computer engineering majors.
**ELECTRICAL ENGINEERING: THIRD AND FOURTH YEARS**

**LATE-STARTING STUDENTS**

<table>
<thead>
<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EE CORE REQUIRED COURSES</strong></td>
<td>ELEN E3106 (3.5) Solid-state devices &amp; materials</td>
<td>CSEE W3827(3) Fund. of computer sys.</td>
<td>One capstone design course° (ELEN E3390, ELEN E4332, EECU E4340, or CSEE W4840)</td>
</tr>
<tr>
<td></td>
<td>ELEN E3201 (3.5) Circuit analysis</td>
<td>ELEN E3331 (3) Electronic circuits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ELEN E3801 (3.5) Signals &amp; systems</td>
<td>ELEN E3401 (4) Electromagnetics</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ELEN E3701 (3) Intro. to communication systems or CSEE W4119 (3) Computer networks</td>
<td></td>
</tr>
<tr>
<td><strong>EE REQUIRED LABS</strong></td>
<td>ELEN E3081 (1)(^2) Circuit analysis lab</td>
<td>ELEN E3083 (1)(^2) Electronic circuits lab</td>
<td></td>
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<tr>
<td></td>
<td>ELEN E3084 (1)(^2) Signals &amp; systems lab</td>
<td>ELEN E3082 (1)(^2) Digital systems lab</td>
<td></td>
</tr>
<tr>
<td><strong>OTHER REQUIRED COURSES</strong></td>
<td>SIEO W3658 or W4105(^5); and COMS W3137 (or W3133, W3134, or W3139)</td>
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<tr>
<td>(Some of these courses are not offered both semesters)</td>
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<tr>
<td><strong>ELECTIVES</strong></td>
<td>At least two technical electives in one depth area. The four depth areas are (a) photonics, solid-state devices, and electromagnetics; (b) circuits and electronics; (c) signals and systems; and (d) communications and networking (For details, see <a href="http://www.ee.columbia.edu/academics/undergrad">www.ee.columbia.edu/academics/undergrad</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BREADTH TECH</strong></td>
<td>At least two technical electives outside the chosen depth area; must be engineering courses (see <a href="http://www.ee.columbia.edu/academics/undergrad">www.ee.columbia.edu/academics/undergrad</a>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OTHER TECH</strong></td>
<td>Additional technical electives (consisting of more depth or breadth courses, or further options listed at <a href="http://www.ee.columbia.edu/academics/undergrad">www.ee.columbia.edu/academics/undergrad</a>) as required to bring the total points of technical electives to 18(^6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NONTECH</strong></td>
<td>Complete 27-point requirement; see page 11 or <a href="http://www.seas.columbia.edu">www.seas.columbia.edu</a> for details (administered by the advising dean)</td>
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<tr>
<td><strong>TOTAL POINTS(^6)</strong></td>
<td>15.5</td>
<td>15</td>
<td>18</td>
</tr>
</tbody>
</table>

\(^1\)This chart shows one possible schedule for a student who takes most of his or her major program in the final two years. Please refer to the previous chart for a recommended earlier start.

\(^2\)If possible, these labs should be taken along with their corresponding lecture courses.

\(^3\)The capstone design course provides ELEN majors with a “culminating design experience.” As such, it should be taken near the end of the program and involve a project that draws on material from a range of courses.

\(^4\)SIEO W3600 and W4150 cannot generally be used to replace SIEO W3658 or W4105. ELEN majors completing an economics minor can augment their probability course with STAT W1211.

\(^5\)The total points of technical electives is reduced to 15 if APMA E2101 has been replaced by MATH E1210 and either APMA E3101 or MATH V2010.

\(^6\)“Total points” assumes that 8 points of nontechnical electives are included.
ELEN E3043x Solid state, microwave, and fiber optics laboratory
Prerequisites: ELEN E3106, and E3401. Optical electronics and communications. Microwave circuits. Physical electronics.

ECBM E3060x Introduction to genomic information science and technology
Lect: 3. 3 pts. Professor Anastassiou.
Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function, and manipulation of the biomolecular sequences of nucleic acids and proteins. The role of enzymes and gene regulatory elements in natural biological functions as well as in biotechnology and genetic engineering. Recombination and other macromolecular processes viewed as mathematical operations with simulation and visualization using simple computer programming. This course shares lectures with ECBM E4060, but the work requirements differ somewhat.

ELEN E3081x Circuit analysis laboratory
Lab: 3. 1 pt. Professor Zukowski.
Prerequisite: ELEN E1201 or the equivalent. Corequisite: ELEN E3201. Companion lab course for ELEN E3201. Experiments cover such topics as: use of measurement instruments; HSPICE simulation; basic network theorems; linearization of nonlinear circuits using negative feedback; op amp circuits; integrators; second-order RLC circuits. The lab generally meets on alternate weeks.

ELEN E3082y Digital systems laboratory
Lab: 3. 1 pt. Instructor to be announced.
Corequisite: CSEE W3827. Recommended preparation: ELEN E1201 or the equivalent. Companion lab course for CSEE W3827. Experiments cover such topics as logic gates; flip-flops; shift registers; counters; combinational logic circuits; sequential logic circuits; programmable logic devices. The lab generally meets on alternate weeks.

ELEN E3083y Electronic circuits laboratory
Lab: 3. 1 pt. Professor Vallancourt.
Prerequisite: ELEN E3081. Corequisite: ELEN E3331. Companion lab course for ELEN E3331. Experiments cover such topics as: introduction and use of MATLAB for numerical and symbolic calculations; linearity and time invariance; continuous-time convolution; Fourier-series expansion and signal reconstruction; impulse response and transfer function; forced response. The lab generally meets on alternate weeks.

ELEN E3043x Solid-state devices and materials
Lect: 3. Recit. 1. 3.5 pts. Professor Bergman.
Prerequisite: MATH V1201 or the equivalent. Corequisite: PHYS C1403 or PHYS C2601 or equivalent. Crystal structure and energy band theory of solids. Carrier concentration and transport in semiconductors. P-n junction and junction transistors. Semiconductor surface and MOS transistors. Optical effects and optoelectronic devices.

ELEN E3201x Circuit analysis
Lect: 3. Recit. 1. 3.5 pts. Professor Zukowski.

ELEN E3331y Electronic circuits
Lab: 3. 3 pts. Professor Vallancourt.
Prerequisites: ELEN E3082, E3083, E3331, E3401, and E3801. Advanced circuit design laboratory. Students work in teams to specify, design, implement, and test an engineering prototype. The work involves technical as well as nontechnical considerations, such as manufacturability, impact on the environment, and economics. The project is chosen by the instructor and may change from year to year.

ELEN E3390y Electronic circuit design laboratory
Lab: 6. 3 pts. Professor Vallancourt.
Prerequisites: ELEN E3082, E3083, E3331, E3401, and E3801. Advanced circuit design laboratory. Students work in teams to specify, design, implement, and test an engineering prototype. The work involves technical as well as nontechnical considerations, such as manufacturability, impact on the environment, and economics. The project is chosen by the instructor and may change from year to year.

ELEN E3401y Electromagnetics
Lab: 3. 4 pts. Professor Diament.

EEME E3601x Classical control systems
Lect. 3. 3 pts. Professor Longman.
Prerequisite: MATH E1210. Analysis and design of feedback control systems. Transfer functions; block diagrams; proportional, rate, and integral controllers; hardware; implementation. Routh stability criterion, root locus, Bode and Nyquist plots, compensation techniques.

ELEN E3701y Introduction to communication systems
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: ELEN E3801. Corequisite: SIEO W3658. A basic course in communication theory, stressing modern digital communication systems. Nyquist sampling, PAM and PCM/DCM systems, time division multiplexing, high frequency digital (ASK, OOK, FSK, PSK) systems, and AM and FM systems are among the topics covered. Also included is an introduction to noise processes, detecting signals in the presence of noise, Shannon’s theorem on channel capacity, and elements of coding theory.

CSEE W3827x and y Fundamentals of computer systems
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: An introductory programming course (COMS W1007 or W1009 or the equivalent). Fundamentals of computer organization and digital logic. Boolean algebra, Karnaugh maps, basic gates and components, flipflops and latches, counters and state machines, basics of combinational and sequential digital design. Assembly language, instruction sets, ALUs, single-cycle and multi-cycle processor design, introduction to pipelined processors, caches, and virtual memory.

ELEN E3998x and y Projects in electrical engineering
0 to 3 pts.
May be repeated for credit, but no more than 3 total points may be used for degree credit. Prerequisite: approval by a faculty member who agrees to supervise the work. Independent project involving laboratory work, computer programming, analytical investigation, or engineering design.

BMCE W4011x Computational neuroscience: Circuits in the brain
Lect: 3. 3 pts. Professors Lazaro and Yuste.
Prerequisite: ELEN E3801 or BIOL W3004. Biophysics of computation, the Hodgkin-Huxley neuron, modeling and analysis of ion channels, basic dendritic integration. Integrate-and-fire and other spiking neuron models, stimulus representation and the neural code, time encoding and stimulus recovery, information representation with time encoding machines, fast algorithms for stimulus recovery, elements of spike processing and neural computation. Modeling synapses and synaptic transmission, synaptic plasticity and learning algorithms. Projects in Matlab.
ECBM E4060x Introduction to genomic information science and technology
Lect: 3. 3 pts. Professor Anastassiou.
Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function, and manipulation of the biomolecular sequences of nucleic acids and proteins. The role of enzymes and gene regulatory elements in natural biological functions as well as in biotechnology and genetic engineering. Recombination and other macromolecular processes viewed as mathematical operations with simulation and visualization using simple computer programming. This course shares lectures with ECBM E3060, but the work requirements differ somewhat.

CSEE W4119x and y Computer networks
Lect: 3. 3 pts. Professors Misra and Rubenstein Corequisite: SIEO W3658 or W3660 or the equivalent. Introduction to computer networks and the technical foundations of the Internet, including applications, protocols, local area networks, algorithms for routing and congestion control, security, elementary performance evaluation. Several written and programming assignments required.

CSEE W4140x or y Networking laboratory
Lect: 3. 4 pts. Prerequisite: CSEE W4119 or the equivalent. In this course, students will learn how to put “principles into practice,” in a hands-on networking lab course. The technologies and protocols of the Internet will be covered, using equipment currently available to large Internet service providers such as CISCO routers and end systems. A set of laboratory experiments will provide hands-on experience with engineering wide-area networks and will familiarize students with the Internet Protocol (IP), Address Resolution Protocol (ARP), Internet Control Message Protocol (ICMP), User Datagram Protocol (UDP), Transmission Control Protocol (TCP), the Domain Name System (DNS), routing protocols (RIP, OSPF, BGP), network management protocols (SNMP), and application-level protocols (FTP, TELNET, SMTP).

ELEN E4139x Modern display science and technology
Lect: 3. 3 pts. Professor Kymissis. Prerequisites: Linear algebra, differential equations, and basic semiconductor physics. Introduction to modern display systems in an engineering context. The basis for visual perception, image representation, color space, metrics of illumination, Physics of luminescence, propagation and manipulation of light in anisotropic media, emissive displays, and spatial light modulators. Fundamentals of display addressing, the Alt-Pleshko theorem, multiple line addressing. Large area electronics, fabrication, and device integration of commercially important display types. A series of short laboratories will reinforce material from the lectures. Enrollment may be limited.

ELEN E4301y Introduction to semiconductor devices

ELEN E4312x Analog electronic circuits
Lect: 3. 3 pts. Professor Tsividis. Prerequisites: ELEN E3331 and E3801. Differential and multistage amplifiers; small-signal analysis; biasing techniques; frequency response; negative feedback; stability criteria; frequency compensation techniques. Analog layout techniques. An extensive design project is an integral part of the course.

ELEN E4314y Communication circuits
Lect: 3. 3 pts. Professor Tsividis. Prerequisite: ELEN E4312. Principles of electronic circuits used in the generation, transmission, and reception of signal waveforms, as used in analog and digital communication systems. Nonlinearity and distortion; power amplifiers; tuned amplifiers; oscillators; multipliers and mixers; modulators and demodulators; phase-locked loops. An extensive design project is an integral part of the course.

ELEN E4321x Digital VLSI circuits

EECS E4340y Computer hardware design
Lect: 2. Lab: 3. 3 pts. Instructor to be announced. Prerequisites: ELEN E3331 and CSEE W3827. Practical aspects of computer hardware design through the implementation, simulation, and prototyping of a PDP-8 processor. High-level and assembly languages, I/O, interrupts, datapath and control design, pipelining, busses, memory architecture. Programmable logic and hardware prototyping with FPGAs. Fundamentals of VHDL for register-transfer level design. Testing and validation of hardware. Hands-on use of industry CAD tools for simulation and synthesis. Lab required.

ELEN E4401x Wave transmission and fiber optics

ELEN E4411x Fundamentals of photonics
Lect: 3. 3 pts. Instructor to be announced. Prerequisite: ELEN E3401 or the equivalent. Planar resonators. Photons and photon streams. Photons and atoms: energy levels and band structure; interactions of photons with matter; absorption, stimulated and spontaneous emission; thermal light, luminescence light. Laser amplifiers; gain, saturation, and phase shift; rate equations; pumping. Lasers: theory of oscillation; laser output characteristics. Photons in semiconductors: generation, recombination, and injection; heterostructures; absorption and gain coefficients. Semiconductor photon sources: LEDs; semiconductor optical amplifiers; homojunction and heterojunction laser diodes. Semiconductor photon detectors: p-n, p-i-n, and heterostructure photo diodes; avalanche photodiodes.

ELEN E4486x Optical systems
Lect: 3. 3 pts. Professor Bergman. Prerequisite: ELEN E4301 or the equivalent. Introduction to optical systems based on physical design and engineering principles. Fundamental geometrical and wave optics with specific emphasis on developing analytical and numerical tools used in optical engineering design. Focus on applications that employ optical systems and networks, including examples in holographic imaging, tomography, Fourier imaging, confocal microscopy, optical signal processing, fiber optic communication systems, optical interconnects, and networks.

ELEN E4501x Electromagnetic devices and energy conversion
Lect: 3. 3 pts. Instructor to be announced. Prerequisite: ELEN E4301. Linear and nonlinear magnetic circuits. Electric and magnetic energy storage, loss, and transfer. Circuit behavior of energy storage and transfer devices. Field theory of moving bodies. Dynamical equations of an electromechanical system. Electromechanical and thermo-electric sensors and actuators. Rotating electric energy converters. Superconductivity and applications.

ELEN E4503x Sensors, actuators, and electromechanical systems
**ELEN E4801y Digital control systems**
Lect: 3. 3 pts. Professor Longman.

**ELEN E4702x or y Digital communications**
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: ELEN E3701 or the equivalent. Digital communications for both point-to-point and switched applications is further developed. Optimum receiver structures and transmitter signal shaping for both binary and M-ary signal transmission. An introduction to block codes and convolutional codes, with application to space communications.

**ELEN E4703y Wireless communications**
Lect: 3. 3 pts. Professor Diamant.

**ELEN E4810x Digital signal processing**
Lect: 3. 3 pts. Professor Ellis.
Prerequisite: ELEN E3801. Digital filtering in time and frequency domain, including properties of discrete-time signals and systems, sampling theory, transform analysis, system structures, IIR and FIR filter design techniques, the Discrete Fourier Transform, Fast Fourier Transforms.

**ELEN E4815y Random signals and noise**
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: SIEO W3658 or the equivalent. Characterization of stochastic processes as models of signals and noise; stationarity, ergodicity, correlation functions, and power spectra. Gaussian processes as models of noise in linear and nonlinear systems; linear and nonlinear transformations of random processes; orthogonal series representations. Applications to circuits and devices, to communication, control, filtering, and prediction.

**CSEE W4823x or y Advanced logic design**
Lect: 3. 3 pts. Professor Nowick.
Prerequisite: CSEE W3827 or the equivalent. An introduction to modern digital system design. Advanced topics in digital logic: controller synthesis (Mealy and Moore machines); adders and multipliers; structured logic blocks (PLDs, PALs, ROMs); iterative circuits. Modern design methodology: register transfer level modeling (RTL); algorithmic state machines (ASMs); introduction to hardware description languages (VHDL or Verilog); system-level modeling and simulation; design examples.

**CSEE W4824x or y Computer architecture**
Lect: 3. 3 pts. Professor Carloni.

**ELEN E4830y Digital image processing**
Lect: 3. 3 pts. Professor Chang.
Introduction to the mathematical tools and algorithmic implementation for representation and processing of digital still and moving pictures. Topics include image representation, thresholding, halftoning, linear and nonlinear filtering, edge detection, image transforms, enhancement, restoration, segmentation, motion analysis, and coding for data compression.

**ELEN E4840y Embedded systems**
Lect: 3. 3 pts. Professor Edwards.
Prerequisite: CSEE W4823 or the equivalent. Embedded system design and implementation combining hardware and software. I/O, interfacing, and peripherals. Weekly laboratory sessions and term project on design of a microprocessor-based embedded system including at least one custom peripheral. Knowledge of C programming and digital logic required. Lab required.

**CSEE W4861y Computer-aided design of digital systems**
Lect: 3. 3 pts. Professor Nowick.
Prerequisites: CSEE W3827 plus COMS W3133, W3134, W3137, W3139, or the equivalent. Topics include hands-on design projects using commercial CAD tools; the theory behind the tools; modern digital system design (the VHDL language, register-transfer level modeling, algorithmic state machines, designing a microarchitecture); controller synthesis and optimization (FSMs); exact and heuristic two-level logic minimization; multi-level logic optimization; technology mapping; binary decision diagrams (BDDs), and introduction to testability.

**ELEN E4896y Music signal processing**
Lect: 3. 3 pts. Professor Eleftheriadis.
Prerequisites: A course on discrete-time signal processing (at the level of ELEN E3801 or, preferably, E4810). An introductory course on the applications of signal processing to music, suitable to seniors and first-year graduate students in electrical engineering, computer science, or music. Emphasis is placed on the signal processing operations in both recording and live environments. Topics covered include audio and room acoustics; microphones and loudspeakers; A/D conversion, dithering, and digital audio formats; analog and digital audio mixers; audio effects algorithms; sequencers, samplers, and Digital Audio Workstations (DAW); mastering for CD and DVD production; and sound synthesis algorithms. Throughout the course case studies of real systems will be examined in detail. The course includes a site visit to a state-of-the-art professional recording facility.

**ELEN E4998x and y Intermediate projects in electrical engineering**
0 to 3 pts.
Prerequisite: the instructor’s permission. May be repeated for credit, but no more than 3 total points may be used for degree credit. Substantial independent project involving laboratory work, computer programming, analytical investigation, or engineering design.

**ELEN E6001x-E6002y Advanced projects in electrical engineering**
1 to 4 pts.
May be repeated for up to 6 points of credit. Graduate-level projects in various areas of electrical engineering and computer science. In consultation with an instructor, each student designs his or her project depending on the student’s previous training and experience. Students should consult with a professor in their area for detailed arrangements no later than the last day of registration.

**ELEN E6010y Systems biology: Design principles for biological circuits**
Lect: 3. 4.5 pts. Instructor to be announced.

**EEBM E6020y Methods of computational neuroscience**
Lect: 3. 4.5 pts. Professor Lazar.
Prerequisite: BMED W4011 or the instructor’s permission. Formal methods in computational neuroscience, including methods of signal processing, communications theory, information theory, systems and control, system identification and machine learning. Molecular models of transduction pathways. Robust adaptation and integral feedback. Stimulus representation and groups. Stochastic and dynamical systems models of spike generation. Neural diversity and ensemble encoding. Time encoding machines and neural codes. Stimulus recovery with time decoding machines. MIMO models of neural computation. Synaptic plasticity and learning algorithms. Major project(s) in Matlab.
BMEE E6030y Neural modeling and neuroengineering
Lect: 3. 3 pts. Instructor to be announced.
Prerequisites: APMA E3101, ELEN E3801, and
BMEB W4011, or the equivalent, or the instruc-
tor’s permission. Engineering perspective on the
study of multiple levels of brain organization, from
single neurons to cortical modules and systems.
Mathematical models of spiking neurons, neural
dynamics, neural coding, and biologically based
computational learning. Architectures and learning
principles underlying both artificial and biological
neural networks. Computational models of cortical
processing, with an emphasis on the visual sys-
tem. Applications of principles in neuroengin-
eering; neural prostheses, neuromorphic systems
and biomimetics. Course will include a computer
simulation laboratory.

ELEN E6080-6089x or y Topics in systems biology
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: the instructor’s permission. Selected
advanced topics in systems biology. Content
varies from year to year, and different topics
rotate through the course numbers 6080-6089.

EEBM E6090-6099x or y Topics in computa-
tional neuroscience and neuroengineering
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: The instructor’s permission.
Selected advanced topics in computational neuro-
science and neuroengineering. Content varies
from year to year, and different topics rotate
through the course numbers 6090-6099.

CSEE E6180x or y Modeling and performance
evaluation
Lect: 2. 3 pts. Instructor to be announced.
Prerequisites: COMS W4118 and SIEO W4150
or permission of the instructor. Introduction to
queueing analysis and simulation techniques.
Evaluation of time-sharing and multiprocessor
systems. Topics include priority queueing, buffer
storage, disk access, interference and bus con-
tention problems, and modeling of program behaviors.

ELEN E6201x Linear system theory
Lect: 3. 3 pts. Instructor to be announced.
Prerequisites: ELEN E3801 and APMA E3101, or
the equivalents. Abstract objects, the concepts of
state. Definition and properties of linear systems.
Characterization of linear continuous time and dis-
crete-time, fixed, and time-varying systems. State-
space description; fundamental matrix, calculation
by computer and matrix methods. Modes in linear
systems. Adjoint systems. Controllability and
observability. Canonical forms and decompositions.
State estimators. Lyapunov’s method and stability.

ELEN E6312y Advanced analog integrated circuits
Lect: 3. 4.5 pts. Professor Kinget.
Prerequisite: ELEN E4312. Integrated circuit
device characteristics and models; temperature-
and supply-independent biasing; IC operational
amplifier analysis and design; feedback amplifiers,
stability and frequency compensation techniques;
noise in circuits; low-noise design. Computer-
aided analysis techniques are extensively used.
An extensive design project is an integral part of the
course.

ELEN E6314x Advanced communication circuits
Lect: 3. 4.5 pts. Instructor to be announced.
Prerequisites: ELEN E4314 and E6312. Overview
of communication systems, modulation and
detection schemes. Receiver and transmitter
architectures. Noise, sensitivity, and dynamic
range. Nonlinearity and distortion. Low-noise
amplifiers, mixers, and oscillators. Phase-locked
loops and frequency synthesizers. Power amplifi-
ters. Typical applications include wireless trans-
ceivers and optical links. Computer-aided analysis
techniques are extensively used. An extensive
design project is an integral part of the course.

ELEN E6318x or y Microwave circuit design
Lect: 3. 3 pts. Instructor to be announced.
Prerequisites: ELEN E3331 and E3401, or the
equivalents. Introduction to microwave engineer-
ing and microwave circuit design. Review of
transmission lines. Smith chart, S-parameters,
microwave impedance matching, transformation
and power combining networks, active and pas-
sive microwave devices, S-parameter–based
design of RF and microwave amplifiers. A
microwave circuit design project (using micro-
wave CAD) is an integral part of the course.

ELEN E6321y Advanced digital electronic
Lect: 3. 4.5 pts. Professor Shepard.
Prerequisite: ELEN E4321. Advanced topics in
the design of digital integrated circuits. Clocked
and nonclocked combinational logic styles. Timing
circuits: latches and flip-flops, phase-locked loops,
delay-locked loops. SRAM and DRAM memory
circuits. Modeling and analysis of on-chip inter-
connect. Power distribution and power-supply noise.
Clocking, timing, and synchronization issues.
Circuits for chip-to-chip electrical communication.
Advanced technology issues that affect circuit
design. The class may include a team circuit-
design project.

ELEN E6331y Principles of semiconductor
physics, I
Lect: 2. 3 pts. Prerequisite: ELEN E4301.
Designed for students interested in research in
semiconductor materials and devices. Topics
include energy bands; nearly free electron and
tight-binding approximations, the k.p. method,
quantitative calculation of band structures and
their applications to quantum structure transistors,
photodetectors, and lasers; semiconductor statis-
tics, Boltzmann transport equation, scattering
processes, quantum effect in transport phenome-
na, properties of heterostructures. Quantum
mechanical treatment throughout.

ELEN E6332y Principles of semiconductor
physics, II
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: ELEN E6331. Optical properties
including absorption and emission of radiation,
electron-phonon interactions, radiative and
phonon-mediated processes, excitons, plasmons,
polaritons, carrier recombination and generation,
and related optical devices, tunneling phenomena,
superconductivity. Quantum mechanical treatment
throughout, heavy use of perturbation theory.

ELEN E6333y Semiconductor device physics
Lect: 2. 3 points. Instructor to be announced.
Prerequisite: ELEN E4301 or the equivalent.
Physics and properties of semiconductors.
Transport and recombination of excess carriers.
Schottky, P-N, MOS, and heterojunction diodes.
Field effect and bipolar junction transistors.
Dielectric and optical properties. Optical devices
including semiconductor lamps, lasers, and detectors.

ELEN E6412y Lightwave devices
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: ELEN E4411. Electro-optics: princi-
ples; electro-optics of liquid crystals and photo-
 refractive materials. Nonlinear optics: second-order
nonlinear optics; third-order nonlinear optics; pulse
propagation and solitons. Acousto-optics: interaction
of light and sound; acousto-optic devices. Photonic
switching and computing: photonic switches; all-
 optical switches; bistable optical devices. Intro-
duction to fiber-optic communications: components
of the fiber optic link; modulation, multiplexing and
coupling; system performance; receiver sensitivity;
coherent optical communications.

ELEN E6413y Lightwave systems
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: ELEN E4411. Recommended prepa-
ration: ELEN E6412. Fiber optics. Guiding, dis-
persion, attenuation, and nonlinear properties of
fibers. Optical modulation schemes. Photonic
components, optical amplifiers. Semiconductor
laser transmitters. Receiver design. Fiber optic
telecommunication links. Nonregenerative trans-
mission using erbium-doped fiber amplifier
Advanced topics in light wave networks.

ELEN E6488y Optical interconnects and inter-
connection networks
Lect: 2. 3 pts. Professor Bergman
Prerequisite: ELEN E4411 or E4488, or an equiv-
 alent photonics course. Introduction to optical
interconnects and interconnection networks for
digital systems. Fundamental optical intercon-
nects technologies, optical interconnection net-
work design, characterization, and performance
evaluation. Enabling photonic technologies,
including free-space structures, hybrid and mono-
lithic integration platforms for photonic on-chip,
chip-to-chip, backplane, and node-to-node inter-
connects, as well as photonic networks on-chip.
EEME E6601x Introduction to control theory
Lect: 3. 3 pts. Professor Longman.
Prerequisite: MATH E1210. A graduate-level intro-
duction to classical and modern feedback control
that does not presume an undergraduate back-
ground in control. Scalar and matrix differential
equation models, and solutions in terms of state
transition matrices. Transfer functions and trans-
fer function matrices, block diagram manipula-
tions, closed-loop response. Proportional, rate,
and integral controllers, and compensators. Design
by root locus and frequency response. Controllability,
observability. Luenberger observers, pole place-
mnt, and linear-quadratic cost controllers.

EEME E6602y Modern control theory
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: EEME E6601 or EME E4601 or
ELEN E6201, or the instructor’s permission.
Singular value decomposition. ARX model and
state-space model system identification. Recursive
least squares filters and Kalman filters. LQR, H∞,
linear robust control, predictive control. Learning
control, repetitive control, adaptive control. Liapunov
and Popov stability. Nonlinear adaptive control,
nonlinear robust control, sliding mode control.

ELEN E6711x Stochastic models in informa-
tion systems
Lect: 3. 4.5 pts. Instructor to be announced.
Prerequisite: SIEO W3658. Foundations: proba-
bility review, Poisson processes, discrete-time
Markov models, continuous-time Markov models,
stationarity, and ergodicity. The course presents a
sample-path (time domain) treatment of stochastic
models arising in information systems, including
at least one of the following areas: communica-
tions networks (queuing systems), biological
networks (hidden Markov models), Bayesian
restoration of images (Gibbs fields), and electric
networks (random walks).

ELEN E6712x Communication theory
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: ELEN E4815 or the equivalent, or
the instructor’s permission. Representation of
band-limited signals and systems. Coherent
and incoherent communications over Gaussian
channels. Basic digital modulation schemes.
Intersymbol interference channels. Fading multipath
channels. Carrier and clock synchronization.

ELEN E6717x Information theory
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: SIEO W3658 or a course in stochas-
tic processes. Corequisite: ELEN E4815. Mutual
information and entropy. The source coding theo-
rem. The capacity of discrete memoryless chan-
nels and the noisy channel coding theorem. The
rate distortion function. Discrete memoryless
sources and single-letter distortion measures.
Bhattacharya bounds, convolutional codes, and the
Viterbi algorithm.

ELEN E6718y Algebraic coding theory
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: SIEO W3658. Elementary concepts
of error control codes. Linear block codes.
Elements of algebra: Galois fields. Cyclic codes:
BCH, Reed Solomon, Goppa codes. Coder, decoder
implementation. Decoding algorithms based on
spectral techniques. Convolutional codes.

ELEN E6761x Computer communications
networks, I
Lect: 3. 3 pts. Professor Maxemchuk.
Prerequisites: SIEO W3658 and CSEE W4119,
or the equivalent, or the instructor’s permission.
Focus on architecture protocols and performance
evaluation of geographically distributed and local
area data networks. Emphasis on layered proto-
cols. Data link layer. Network layer: flow and con-
gestion control routing. Transport layer. Typical
Local and Metropolitan Area Network standards:
Ethernet, DODB, FDDI. Introduction to internett.
Review of relevant aspects of queueing theory to
provide the necessary analytical background.

ELEN E6770-6779x or y Topics in telecommu-
nications networks
Lect: 2. 3 pts. Instructor to be announced.
Further study of areas such as communication
protocols and architectures, flow and congestion
control in data networks, performance evaluation
in integrated networks. Content varies from year
to year, and different topics rotate through the
course numbers 6770 to 6779.

ELEN E6820y Speech and audio processing
and recognition
Lect: 3. 4.5 pts. Professor Ellis.
Prerequisite: ELEN E4810 or the instructor’s per-
mission. Fundamentals of digital processing of
speech and audio signals. Acoustic and perceptual
basis of audio. Short-time Fourier analysis and
filterbank models. Speech and audio coding,
compression, and reconstruction. Acoustic feature
extraction and classification. Recognition tech-
niques for speech and other sounds, including
hidden Markov models.

CSEE E6847y Distributed embedded systems
Lect: 2. 3 pts. Professor Carloni.
Prerequisite: any course numbered in the
COMS4110s, CSEE4800s, or ELEN4300s, or the
instructor’s permission. An interdisciplinary gradu-
ate-level seminar on the design of distributed
embedded systems. Emphasis is put on system
robustness in the presence of highly variable
communication delays and heterogeneous com-
ponent behaviors. The course has a two-fold
structure: the study of the enabling technologies
(VLSI circuits, communication protocols, embed-
ded processors, RTOSs), models of computation,
and design methods is coupled with the analysis
of modern domain-specific applications, including
on-chip micro-networks, multiprocessor systems,
fault-tolerant architectures, and robust deploy-
ment of embedded software. Common research
challenges include design complexity, reliability,
scalability, safety, and security. The course
requires substantial reading, class participation,
and a research project.

ELEN E6850x Visual information systems
Lect: 2. 3 pts. Professor Chang.
Prerequisite: ELEN E4830 or the instructor’s per-
mission. Introduction to critical image technologies
in advanced visual information systems, such as
content-based image databases, video servers,
and desktop video editors. Intended for graduate
students. Topics include visual data representation
and compression, content-based visual indexing
and retrieval, storage system design (data place-
ment, scheduling, and admission control), com-
pressed video editing, and synchronization issues
of stored video/audio signals. Programming proj-
ects and final presentations are required.

ELEN E6860y Advanced digital signal
processing
Lect: 2. 3pts. Instructor to be announced.
Prerequisite: ELEN E4810. This course is
designed as an extension to ELEN E4810, with
emphasis on emerging techniques in the area of
digital signal processing. Topics include multirate
signal processing, multidimensional signal pro-
cessing, short-time Fourier transform, signal
expansion in discrete and continuous time, filter
banks, multiresolution analysis, wavelets, and
their applications to image compression and
understanding. Other topics may be included to
reflect developments in the field.

ELEN E6880–6889x or y Topics in signal
processing
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: ELEN E4810. Advanced topics in
signal processing, such as multidimensional sig-
nal processing, image feature extraction,
image/video editing and indexing, advanced digi-
tal filter design, multirate signal processing, adap-
tive signal processing, and waveform coding of
signals. Topics vary from year to year, and differ-
ent topics rotate through the course numbers
6880-6889.

ELEN E6900–6909x or y Topics in electrical
and computer engineering
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: the instructor’s permission. Selected
topics in electrical and computer engineering.
Content varies from year to year, and different
topics rotate through the course numbers 6900-
6909.

ELEN E6945x or y Device nanofabrication
Lect: 3. 3 pts. Professor Wind.
Prerequisites: ELEN E3106 and E3401, or the
equivalents. Recommended: ELEN E4944. This
course provides an understanding of the methods
used for structuring matter on the nanometer
length: thin-film technology; lithographic pattern-
ing and technologies including photon, electron,
ion and atom, scanning probe, soft lithography, and nanoimprinting; pattern transfer; self-assembly; process integration; and applications.

ELEN E6950x Wireless and mobile networking, I
Lect: 2. Lab: 1. 4.5 pts. Instructor to be announced.
Corequisite: ELEN E6761 or the instructor’s permission. Overview of mobile and wireless networking. Fundamental concepts in mobile wireless systems: propagation and fading, cellular systems, channel assignment, power control, handoff. Examples of second-generation circuits-switched systems and standards. Quantitative homework assignments may require use of a mathematical software package.

ELEN E6951y Wireless and mobile networking, II
Lect: 2. Lab: 1. 3 pts. Instructor to be announced.
Prerequisite: CSEE W4119, ELEN E6761, or the instructor’s permission. Third-generation packet switched systems, wireless LANs, mobile computing and communications. Study of some current research topics. Quantitative homework assignments may require use of a mathematical software package. A project based on readings from the literature will be required. Lab required.

EEEM E6801x Advanced topics in control theory
Lect: 2. 3 pts. Professor Longman.
See entry under “Courses in Mechanical Engineering” for description.

ELEN E9001x and y, and s; E9002x and y, and s Research
0 to 6 pts. Instructor to be announced. Points of credit may be approved by the department.
Prerequisite: submission of an outline of the proposed research for approval by the faculty member who is to supervise the work of the student. The research facilities of the department are available to qualified students interested in advanced study.

ELEN E9011x and y, and s; E9012x and y, and s Doctoral research
0 to 6 pts. Instructor to be announced. Points of credit may be approved by the department. Open only to doctoral students who have passed the qualifying examinations. Prerequisite: submission of an outline of the proposed research for the approval of the faculty member who is to supervise the work of the student.

ELEN E9800x and y, and s Doctoral research instruction
3, 6, 9, or 12 pts. Instructor to be announced. A candidate for the Eng.Sc.D. degree in electrical engineering must register for 12 points of doctoral research instruction. Registration in ELEN E9800 may not be used to satisfy the minimum residence requirement for the degree.

ELEN E9900x and y, and s Doctoral dissertation
0 pts. Instructor to be announced. A candidate for the doctorate may be required to register for this course every term after the student’s course work has been completed, and until the dissertation has been accepted.

Courses in Electrical Engineering
Offered Occasionally

ELEN E3000x Introduction to circuits, systems, and electronics
Lect: 3. Recit: 1. 3.5 pts.
Introductory course in electrical circuits, systems, electronics, and digital information processing for non-electrical engineers.

EEHS E3900y History of telecommunications: from the telegraph to the Internet
Lect. 3. 3 pts.
Historical development of telecommunications from the telegraph of the mid-1800s to the Internet at present. Included are the technologies of telephony, radio, and computer communications. The coverage includes both the technologies themselves and the historical events that shaped, and in turn were shaped by, the technologies. The historical development, both the general context and the particular events concerning communications, is presented chronologically. The social needs that elicited new technologies and the consequences of their adoption are examined. Throughout the course, relevant scientific and engineering principles are explained as needed. These include, among others, the concept and effective use of spectrum, multiplexing to improve capacity, digital coding, and networking principles. There are no prerequisites, and no prior scientific or engineering knowledge is required. SEAS students may not count this course as a technical elective. The course shares lectures with EEHS E4900, but the work requirements differ somewhat.

ELEN E4215y Analog filter synthesis and design
Lect: 3. 3 pts.
Prerequisite: ELEN E3201 and E3801, or the equivalent. Approximation techniques for magnitude, phase, and delay specifications, transfer function realization, sensitivity, passive LC filters, active RC filters, MOSFET-C filters, Gm-C filters, switched-capacitor filters, automatic tuning techniques for integrated filters. Filter noise. A design project is an integral part of the course.

ELEN E4332y VLSI design laboratory
Lect: 3. 3 pts.
CMS integrated circuit. The class may divide up into teams to work on different aspects of a single mixed-signal circuit. The chip(s) is fabricated for testing the following term. Lectures cover use of computer-aided design tools, design issues specific to the project(s), and chip integration issues.

ELEN E4405x Classical nonlinear optics
Lect: 3. 3 pts.

ELEN E4420x Topics in electromagnetics
Lect: 3. 3 pts.
Prerequisite: knowledge of undergraduate electromagnetic theory. Selected topics in the theory and practice of electromagnetics, varying from year to year. Topic for current term will be available in the department office one month before registration. This course may be taken more than once when topics are different. Possible topics: microwave theory and design (generalized waveguides, excitation and coupling of waveguides, junctions, microwave networks, periodic structures, optical fibers); antennas (illuminated antennas, arrays, aperture radiation, system properties, pattern synthesis); electrodynamics (special relativity, radiation by charged particles, relativistic beams, free electron lasers).

ELEN E4720y Networking laboratory
Lab: 3. 3 pts.
Prerequisites: Knowledge of computer programming plus CSEE W4119 or the equivalent. Covers practical experience in network programming and systems. Weekly laboratory sessions on network programming and systems leading to a term project on design, implementation, debugging, and integration of network protocols on IP routers. Emphasis on practical experience with (1) networking equipment, including Intel IXP network processor-based routers, PC-based routers, and commercial routers; and (2) the ns-2 simulator. Laboratory topics include socket programming, setting up a commercial router/PC-routers and wireless networks, setting routing tables, programming network processors, deploying network algorithms, and debugging UDP and TCP protocols.

ELEN E4741x Introduction to biological sensory systems
Lect: 3. 3 pts.
Corequisite: SIEO W3658. Introduction to vision and hearing using engineering principles. Nature
of sound and light; minimum detectable energy for human observers; excitation of the visual and hearing systems; rods, cones, and hair-cell receptors; the experiment of Hecht, Shlaer, and Pirenne; Poisson counting statistics; stimulus-based modeling; detection and false-alarm probabilities; die Vries-Rose square-root law; Weber’s law; relation of sensory and communication systems.

CSEE W4825y Digital systems design
Lect: 3. 3 pts.
Prerequisite: CSEE W3827. Dynamic logic, field programmable gate arrays, logic design languages, multipliers. Special techniques for multilevel NAND and NOR gate circuits. Clocking schemes for one- and two-phase systems. Fault checking: scan method, built-in test. Survey of logic simulation methods. Other topics to be added as appropriate.

EEHS E4900y History of telecommunications: from the telegraph to the Internet
Lect: 3. 3 pts.
Historical development of telecommunications from the telegraphy of the mid-1800s to the Internet at present. Included are the technologies of telephony, radio, and computer communications. The coverage includes both the technologies themselves and the historical events that shaped, and in turn were shaped by, the technologies. The historical development, both the general context and the particular events concerning communications, is presented chronologically. The social needs that elicited new technologies and the consequences of their adoption are examined. Throughout the course, relevant scientific and engineering principles are explained as needed. These include, among others, the concept and effective use of spectrum, multiplexing to improve capacity, digital coding, and networking principles. There are no prerequisites, and no prior scientific or engineering knowledge is required. SEAS students may not include this as a technical elective. This course shares lectures with EEHS E3900, but the work requirements differ somewhat.

ELEN E4944x Principles of device microfabrication
Lect: 3. 3 pts.
Science and technology of conventional and advanced microfabrication techniques for electronics, integrated and discrete components. Topics include diffusion; ion implantation, thin-film growth including oxides and metals, molecular beam and liquid-phase epitaxy; optical and advanced lithography; and plasma and wet etching.

ELEN E6140x Gallium arsenide materials processing
Lect: 3. 3 pts.
Prerequisite: ELEN E4301 or the instructor’s permission. Materials and device aspects of GaAs and compound technologies, electronic properties of GaAs, growth techniques (bulk and epitaxial), surface and etching properties, implantation, MESFETS, transferred electron devices, Impatt diodes, HEMTS, HBTs.

ELEN E6151y Surface physics and analysis of electronic materials
Lect: 2. 3 pts.
Prerequisite: ELEN E6331 and E6316. Basic physical principles of methods of surface analysis, surfaces of electronic materials including structure and optical properties (auger electron spectroscopy, x-ray photoemission, ultraviolet photoelectron spectroscopy, electron energy loss spectroscopy, inverse photoemission, photo stimulated desorption, and low energy electron diffraction), physical principles of each approach.

ELEN E6211x or y Circuit theory
Lect: 3. 3 pts.

ELEN E6261y Computational methods of circuit analysis
Lect: 3. 3 pts.
Prerequisites: ELEN E4331 and APMA E3101. Computational algorithms for DC, transient, and frequency analysis of linear and nonlinear circuits. Formulation of equations: state equations, hybrid equations, sparse tableaux. Solution techniques: iterative methods to solve nonlinear algebraic equations; piecewise linear methods; sparse matrix techniques; numerical integration of stiff, nonlinear differential equations, companion network models; waveform relaxation.

ELEN E6302x or y MOS transistors
Lect: 2. 3 pts.
Prerequisite: ELEN E4306 or the equivalent. Operation and modelling of MOS transistors. MOS two- and three-terminal structures. The MOS transistor as a four-terminal device; general charge-sheet modelling; strong, moderate, and weak inversion models; short-and-narrow-channel effects; ion-implanted devices; scaling considerations in VLSI; charge modelling; large-signal transient and small-signal modeling for quasistatic and nonquasistatic operation.

ELEN E6304x or y Topics in electronic circuits
Lect: 3. 3 pts.
Prerequisite: The instructor’s permission. State-of-the-art techniques in integrated circuits. Topics may change from year to year.

ELEN E6316x or y Analog systems in VLSI
Lect: 3. 3 pts.
Prerequisite: ELEN E6312. Analog-digital interfaces in very large-scale integrated circuits. Precision sampling; A/D and D/A converter architectures; switched capacitor circuits; system considerations.

ELEN E6403y Classical electromagnetic theory
Lect: 3. 4.5 pts.

ELEN E6414y Photonic integrated circuits
Lect: 3. 3 pts.
Photonic integrated circuits are important subsystem components for telecommunications, optically controlled radar, optical signal processing, and photonic local area networks. This course will introduce the student to the devices and the design of these circuits. Principle and modeling of dielectric waveguides (including silica on silicon- and InP-based materials), waveguide devices (simple and star couplers), and surface diffractive elements. Numerical techniques for modelling circuits will be discussed, including beam propagation and finite difference codes. Design of other devices will be discussed: optical isolators, demultiplexers.

EEME E6610x Optimal control theory
Lect: 3. 3 pts.

EEME E6612x or y Control of nonlinear dynamic systems
Lect: 3. 3 pts.
Prerequisites: EEME E6601 or ELEN E6201 and an undergraduate controls course. Fundamental properties of nonlinear systems; qualitative analysis of nonlinear systems; nonlinear controllability and observability; nonlinear stability; zero dynamics and inverse systems; feedback stabilization and linearization; sliding control theory; nonlinear observers; describing functions.

ELEN E6713y Topics in communications
Lect: 3. 3 pts.
Prerequisite: ELEN E6712 or E4707 or E4703, or the equivalent, or the instructor’s permission. Advanced topics in communications, such as turbo codes, LDPC codes, multiuser communications, network coding, cross-layer optimization, cognitive radio. Content may vary from year to year to reflect the latest development in the field.
ELEN E6731y Satellite communication systems  
Lect: 2. 3 pts.  
Prerequisite: ELEN E4702. Introduction to satellite communication, with emphasis on characterization and systems engineering of the transmission channel. Power budgets, antennas, transponders, multiple access, and frequency reuse techniques. Noise, intermodulation, interference, and propagation effects. Modulation methods, earth terminals, and standards. Digital transmission and advanced systems.

ELEN E6762y Computer communications networks, II  
Lect: 2. 3 pts.  
Prerequisite: ELEN E6761. Broadband ISDN—Services and protocols; ATM. Traffic characterization and modeling: Markov-modulated Poisson and Fluid Flow processes; application to voice, video, and images. Traffic management in ATM networks: admission and access control, flow control. ATM switch architectures; input/output queuing. Quality of service (QoS) concepts.

ELEN E6763y Digital circuit switched networks  
Lect: 2. 3 pts.  
Prerequisite: ELEN E6761 or the instructor’s permission. Current topics in digital circuit switching: introduction to circuit switching, comparison with packet switching, elements of telephone traffic engineering, space and time switching, call processing in digital circuit-switched systems, overload control mechanisms, nonhierarchical routing, common channel signaling, introduction to integrated services digital networks. Examples of current systems are introduced throughout. Emphasis on modeling and quantitative performance analysis. Queueing models introduced where possible.

ELEN W6781y Topics in modeling and analysis of random phenomena  
Lect: 3. 3 pts.  
Prerequisite: ELEN E6711. Recommended preparation: a course on real analysis and advanced probability theory. Current methodology in research in stochastic processes applied to communication, control, and signal processing. Topics vary from year to year to reflect student interest and current developments in the field.

CSEE E6831y Sequential logic circuits  
Lect: 3. 3 pts.  

CSEE E6832x Topics in logic design theory  
Lect: 3. 3 pts.  
Prerequisite: CSEE W3827 or any introduction to logic circuits. A list of topics for each offering of the course is available in the department office one month before registration. May be taken more than once if topics are different. Iterative logic circuits applied to pattern recognition. Finite state machines; alternative representations, information loss, linear circuits, structure theory. Reliability and testability of digital systems.

ELEN E6920x or y Topics in VLSI systems design  
Lect: 2. 3 pts.  

ELEN E8701y Point processes in information and dynamical systems  
Lect: 3. 3 pts.  
Prerequisite: ELEN E6711 or the equivalent. Recommended preparation: a course in measure theory or advanced probability theory. Probability and point processes. Random intensity rate, martingales, and the integral representation of point process martingales. Recursive estimation, the theory of innovations, state estimate for queues. Markovian queueing networks. Hypothesis testing, the separation between filtering and detection. Mutual information and capacity for the Poisson-type channel. Stochastic control, dynamic programming for intensity control.

ELEN E9060x or y Seminar in systems biology  
Lect: 2. 3 pts.  
Open to doctoral candidates, and to qualified M.S. candidates with the instructor’s permission. Study of recent developments in the field of systems biology.

EEBM E9070x or y Seminar in computational neuroscience and neuroengineering  
Lect: 2. 3 pts.  
Open to doctoral candidates and qualified M.S. candidates with the instructor’s permission. Study of recent developments in computational neuroscience and neuroengineering.

ELEN E9101y Seminar in physical electronics  
Sem: 2. 3 pts.  
Prerequisite: quantum electronics and ELEN E4944, or the instructor’s permission. Advanced topics in classical and quantum phenomena that are based on ion and electron beams, gas discharges, and related excitation sources. Application to new laser sources and microelectronic fabrication.

ELEN E9201x or y Seminar in circuit theory  
Sem: 2. 3 pts.  
Open to doctoral candidates, and to qualified M.S. candidates with the instructor’s permission. Study of recent developments in linear, nonlinear, and distributed circuit theory and analysis techniques important to the design of very large-scale integrated circuits.

ELEN E9301y Seminar in electronic devices  
Sem: 2. 3 pts.  
Open to doctoral candidates, and to qualified M.S. candidates with the instructor’s permission. Theoretical and experimental studies of semiconductor physics, devices, and technology.

ELEN E9303x or y Seminar in electronic circuits  
Sem: 2. 3 pts.  
Open to doctoral candidates, and to qualified M.S. candidates with the instructor’s permission. Study of recent developments in electronic circuits.

ELEN E9402x and y Seminar in quantum electronics  
Sem: 2. 3 pts.  
Open to doctoral candidates, and to qualified M.S. candidates with the instructor’s permission. Recent experimental and theoretical developments in various areas of quantum electronics research. Examples of topics that may be treated include novel nonlinear optics, lasers, transient phenomena, and detectors.

ELEN E9403x Seminar in photonics  
Sem: 2. 3 pts.  
Prerequisite: ELEN E4411. Open to doctoral candidates, and to qualified M.S. candidates with the instructor’s permission. Recent experimental and theoretical developments in light wave communications research. Examples of topics that may be treated include squeezed-light generation, quantum optics, photon detection, nonlinear optical effects, and ultrafast optics.

ELEN E9404x or y Seminar in light wave communications  
Sem: 2. 3 pts.  
Open to doctoral candidates, and to qualified M.S. candidates with the instructor’s approval. Recent theoretical and experimental developments in light wave communications research. Examples of topics that may be treated include information capacity of light wave channels, photonic switching, novel light wave network architectures, and optical neural networks.

ELEN E9701x Seminar in information and communication theories  
Sem: 2. 3 pts.  
Open to doctoral candidates, and to qualified M.S. candidates with the instructor’s permission. Recent developments in telecommunication networks, information and communication theories, and related topics.

ELEN E9801x or y Seminar in signal processing  
Lect: 2. 3 pts.  
Open to doctoral candidates, and to qualified M.S. candidates with the instructor’s approval. Recent developments in theory and applications of signal processing, machine learning, content analysis, and related topics.
Industrial engineering is the branch of the engineering profession that is concerned with the design, analysis, and control of production and service systems. Originally, an industrial engineer worked in a manufacturing plant and was involved only with the operating efficiency of workers and machines. Today, industrial engineers are more broadly concerned with productivity and all of the technical problems of production management and control. They may be found in every kind of organization: manufacturing, distribution, transportation, mercantile, and service. Their responsibilities range from the design of unit operations to that of controlling complete production and service systems. Their jobs involve the integration of the physical, financial, economic, computer, and human components of such systems to attain specified goals.

Industrial engineering includes activities such as production planning and control; quality control; inventory, equipment, warehouse, and materials management; plant layout; and workstation design.

Operations research is concerned with quantitative decision problems, generally involving the allocation and control of limited resources. Such problems arise, for example, in the operations of industrial firms, financial institutions, health care organizations, transportation systems, and government. The operations research analyst develops and uses mathematical and statistical models to help solve these decision problems. Like engineers, they are problem formulators and solvers. Their work requires the formation of a mathematical model of a system and the analysis and prediction of the consequences of alternate modes of operating the system. The analysis may involve mathematical optimization techniques, probabilistic and statistical methods, experiments, and computer simulations.

Engineering management systems is a multidisciplinary field in industrial engineering, operations research, contemporary technology, business, economics, and management. It provides a foundation for decision making and managing risks in complex systems.

Financial engineering is a multidisciplinary field integrating financial theory with economics, methods of engineering, tools of mathematics, and practice of programming. The field provides training in the application of engineering methodologies and quantitative methods to finance.
Current Research Activities

In industrial engineering, research is conducted in the area of logistics, routing, scheduling, production and supply chain management, inventory control, revenue management, and quality control.

In operations research, new developments are being explored in mathematical programming, combinatorial optimization, stochastic modeling, computational and mathematical finance, queueing theory, reliability, simulation, and both deterministic and stochastic network flows.

In engineering and management systems, research is conducted in the areas of logistics, supply chain optimization, and revenue and risk management.

In financial engineering, research is being carried out in portfolio management; option pricing, including exotic and real options; computational finance, such as Monte Carlo simulation and numerical methods; as well as data mining and risk management.

Projects are sponsored and supported by leading private firms and government agencies. In addition, our students and faculty are involved in the work of two research and educational centers: the Center for Applied Probability (CAP) and the Computational and Optimization Research Center (CORC). Both of these centers are supported principally by grants from the National Science Foundation.

CAP is a cooperative center involving the School of Engineering and Applied Science, several departments in the Graduate School of Arts and Sciences, and the Graduate School of Business.

Its interests are in four applied areas: mathematical and computational finance, stochastic networks, logistics and distribution, and population dynamics.

Computational Optimization Research Center (CORC) at Columbia University is an interdisciplinary group of researchers from a variety of departments on the Columbia campus. Its permanent members are Professors Daniel Bienstock, Don Goldfarb, Garud Iyengar, Jay Sethuraman, and Cliff Stein, from the Industrial Engineering and Operations Research Department, and Professor David Bayer, from the Department of Mathematics at Barnard College.

Researchers at CORC specialize in the design and implementation of state-of-the-art algorithms for the solution of large-scale optimization problems arising from a wide variety of industrial and commercial applications.

UNDEGRADUATE PROGRAMS

Industrial Engineering

The undergraduate program is designed to develop the technical skills and intellectual discipline needed by our graduates to become leaders in industrial engineering and related professions.

The program is distinctive in its emphasis on quantitative, economic, computer-aided approaches to production and service management problems. It is focused on providing an experimental and mathematical problem-formulating and problem-solving framework for industrial engineering work. The curriculum provides a broad foundation in the current ideas, models, and methods of industrial engineering. It also includes a substantial component in the humanities and social sciences to help students understand the societal implications of their work.

The industrial engineering program objectives are:

1. to provide students with the requisite analytical and computational skills to assess practical situations and academic problems, formulate models of the problems represented or embedded therein, design potential solutions, and evaluate their impact;
2. to prepare students for the workplace by fostering their ability to participate in teams, understand and practice interpersonal and organizational behaviors, and communicate their solutions and recommendations effectively through written, oral, and electronic presentations;
3. to familiarize students with the historical development of industrial engineering tools and techniques and with the contemporary state of the art, and to instill the need for lifelong learning within their profession;
4. to instill in our students an understanding of ethical issues and professional and managerial responsibilities.

The program in industrial engineering leading to the B.S. degree is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

SEAS 2008–2009
Operations Research
The operations research program is one of several applied science programs offered at the School. At the undergraduate level, it offers basic courses in probability, statistics, applied mathematics, simulation, and optimization as well as more professionally oriented operations research courses. The curriculum is well suited for students with an aptitude for mathematics applications. It prepares graduates for professional employment as operations research analysts, e.g., with management consultant and financial service organizations, as well as for graduate studies in operations research or business. It is flexible enough to be adapted to the needs of future medical and law students.

Operations Research: Engineering Management Systems
This operations research option is designed to provide students with an understanding of contemporary technology and management. It is for students who are interested in a technical-management background rather than one in a traditional engineering field. It consists of required courses in industrial engineering and operations research, economics, business, and computer science, intended to provide a foundation for dealing with engineering and management systems problems. Elective courses are generally intended to provide a substantive core in at least one technology area and at least one management area.

Due to the flexibility of this option, it can incorporate the varied educational needs of preprofessional students interested in law, medicine, business, and finance. In addition, most students are encouraged to add a minor in economics or computer science to their standard course schedules.

Operations Research: Financial Engineering
In the fall of 2006, the Industrial Engineering and Operations Research Department launched a new concentration in financial engineering. Financial engineering is a multidisciplinary field integrating financial theory with economics, methods of engineering, tools of mathematics, and practice of programming. The concentration is designed to provide training in the application of engineering methodologies and quantitative methods to finance.

Students graduating with this concentration are prepared to enter careers in securities, banking, financial management, and consulting industries, and fill quantitative roles in corporate treasury and finance departments of general manufacturing and service firms.

Students who are interested in pursuing the rigorous concentration in financial engineering must demonstrate proficiency in calculus, computer programming, linear algebra, ordinary differential equations, probability, and statistics. This option is available to the class of 2008 and later. Applications to the concentration will be accepted during the fall semester of the sophomore year, and students will be notified of the departmental decision by the end of that spring semester. The department is seeking students who demonstrate strength and consistency in all the above-mentioned areas. Application to this concentration is available online: www.ieor.columbia.edu/bsfe_application.html.

Undergraduate Advanced Track
The undergraduate advanced track is designed for advanced undergraduate students with the desire to pursue further higher education after graduation. Students with a minimum cumulative GPA of 3.4 and faculty approval have the opportunity to participate. Students are invited to apply to the track upon the completion of their sophomore year. Advanced track students are required to take higher-level IEOR courses, including the following:

IEOR E4004 instead of IEOR E3608
IEOR E4106 instead of IEOR E3106
IEOR E4403 instead of IEOR E4003
and MATH V2500.

Students successfully completing the requirements of the undergraduate advanced track will receive recognition on their academic record.

Minors
A number of minors are available for students wishing to add them to their programs. These minors are described starting on page 186 of this bulletin.

IEOR program students may want to consider minors in economics or computer science. In addition, operations research and engineering and management systems majors may elect to minor in industrial engineering, and industrial engineering majors may elect to minor in operations research.

The department does not offer a minor in engineering management systems or financial engineering.

Major in Economics—Operations Research
Students in Columbia College and the School of General Studies may register for a major in economics and operations research. This degree provides a student with a foundation in economic theory comparable to that provided by the general economics major while at the same time introducing the student to the field of operations research. The program is recommended for students with strong quantitative skills who are contemplating graduate studies in economics, operations research, or business.

For more information on the major in economics and operations research, students should contact the departmental advisers: In Economics, Professor Susan Elmes, 1018 International Affairs Building, 212-854-3680, and in IEOR, Professor Donald Goldfarb, 313 S. W. Mudd, 212-854-8011.

Required courses
This program requires a total of 50.5 points: 23 points in economics, 11 points in mathematics, 13.5 points in industrial engineering and operations research, and 3 points in computer science.

ECONOMICS
W1105: Principles of economics
W3211: Intermediate microeconomics
W3213: Intermediate macroeconomics
W3412: Introduction to econometrics
One seminar and two electives (one must be above the 2000 level). At least one of the electives must have W3211 or W3213 as a prerequisite.

IEOR
E3106: Introduction to operations research: stochastic models
E3600: Introduction to probability and statistics
E3608: Introduction to mathematical programming and

SEAS 2008–2009
one elective in industrial engineering or operations research.

MATHEMATICS: Choose one of three tracks.
1. V1101, V1102, and V1201 (Calculus I, II, and III), V2010 (Linear algebra);
or
2. V1105, V1106, and V1205 (Calculus I, II, and III), V2010 (Linear algebra);
or

COMPUTER SCIENCE
W1004 or W1007: Introduction to computer programming
or another approved computer science course that involves substantial work in programming.

Special note: It is important to take IEOR W3600 and IEOR E3608 as early as feasible; they are prerequisites for most other courses in the program.

GRADUATE PROGRAMS
The Department of Industrial Engineering and Operations Research offers courses and M.S. programs in (1) engineering management systems, (2) financial engineering, (3) industrial engineering, and (4) operations research on either a full- or part-time basis. Graduate programs leading to a Ph.D. or Eng.Sc.D. in industrial engineering or operations research, as well as one leading to the professional degree of Industrial Engineer, are also available. In addition, the department and the Graduate School of Business offer combined M.S./M.B.A. degree programs in industrial engineering, in financial engineering, and in operations research.

All degree program applicants are required to take the Aptitude Tests of the Graduate Record Examination. M.S./M.B.A. candidates are also required to take the Graduate Management Admissions Test.

A minimum grade point average of 3.0 (B) in an undergraduate engineering program is required for admission to the M.S. and professional degree programs. Students are expected, on entry, to have completed courses in ordinary differential equations, in linear algebra, and in a programming language such as C or Java.

Engineering Management Systems
The full-time M.S. program in engineering management systems (EMS) provides students with a curriculum that emphasizes both technology and management perspectives in solving problems, making decisions, and managing risks in complex systems. Students pursuing this degree program are provided with a rigorous exposure to deterministic optimization and stochastic modeling, a basic coverate of applications in the areas of operations engineering and management, and an in-depth coverage of applications in the areas of the selected concentration. Graduates from the program are expected to assume positions as business analysts in logistics, supply chain, revenue management, and consulting firms, and as financial analysts in risk management departments of investment banks, hedge funds, and credit card and insurance firms.

The requirement for the M.S. in engineering management systems degree is ten 3-credit courses (two semesters of full-time study). The program has two concentrations: (1) logistics and supply chain optimization (LSO) and (2) revenue and risk management (RRM).

Financial Engineering
The department offers a full-time M.S. in financial engineering. This program is intended to provide a unique technical background for students interested in pursuing career opportunities in financial analysis and risk management.

In addition to the basic requirements for graduate study, students are expected, on entry, to have attained a high level of mathematical and computer programming skills, particularly in probability, statistics, linear algebra, and the use of a programming language such as C or JAVA. Work experience is desirable but not required.

The program consists of 36 points (twelve courses), which can be taken over a twelve-month period of full-time studies, starting with a Part I six-week summer session (July 7–August 29, 2008) and ending with a Part I six-week summer session (beginning July 3, 2009) the following year. The requirements include seven required core courses and additional elective courses chosen from a variety of departments or schools at Columbia including the Graduate School of Business, International Affairs, Computer Science, Statistics, and Economics. A sample schedule is available in the department office, and on the IEOR Web site: www.ieor.columbia.edu.

The seven required core courses for the financial engineering program are IEOR E4007, IEOR E4701, IEOR E4702, IEOR E4703, IEOR E4706, IEOR E4707, and IEOR E4709.

In addition, students select two semicore courses from a group of specialized offerings in the spring term. Electives are chosen with the approval of an adviser.

Professional Degree in Financial Engineering
The professional degree in financial engineering requires a minimum of 60 points (24 points beyond the M.S. in financial engineering at Columbia). The complete 60-point program includes (1) ten core courses as prescribed in the M.S. in financial engineering and (2) select electives in financial engineering, including advanced graduate and doctoral-level courses.

A minimum of 12 courses, providing 36 points of credit, must be financial engineering courses taken from departmental course offerings or at other institutions where advanced standing is given. A thesis is not required.

Industrial Engineering
The department’s graduate programs in industrial engineering are generally intended to enable students with industrial engineering bachelor’s degrees to enhance their undergraduate training with studies in special fields such as production planning, inventory control, scheduling, and industrial economics. However, the department also offers broader master’s and professional degree programs for engineers whose undergraduate training is not in industrial engineering.

M.S. degree candidates are required to satisfy a core program of graduate courses in production management, probability theory, statistics, simulation, and operations research. Students with B.S. degrees in industrial engineering will usually have satisfied this core in their undergraduate programs. All students must take at least 18 points of graduate work in industrial engineering and at least 30 points of graduate studies at
Columbia. Master’s degree programs may include concentrations in:

- engineering and management systems
- production and operations management
- manufacturing
- industrial regulation studies

Additional details regarding these concentrations are available in the department office. A thesis is not required. Students who plan post-master’s degree studies should give due consideration to the course, examination, and admission requirements of these programs.

M.S. degree programs can be taken on a part-time basis or completed in one year of full-time study.

**Operations Research**
The graduate program in this area is designed to enable students to concentrate their studies in methodological areas such as mathematical programming, stochastic models, and simulation. However, the department also has a broadly based master’s degree program that enables students with engineering or other undergraduate majors that include strong mathematics preparation to complete work in two terms of full-time study.

M.S. degree candidates are required to satisfy a core set of graduate courses in probability, statistics, linear programming, and simulation. All students must complete at least 18 points of operations research courses and at least 30 points of graduate work at Columbia.

The department considers it desirable that students construct balanced programs involving deterministic and

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1. The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.
2. Computer programming should be taken consecutively with data structures.
stochastic models, as well as substantive areas for application.

The M.S. degree program may be constructed to include concentrations in:
• engineering and management systems
• industrial engineering
• production and operations management
• industrial regulation studies

Additional details regarding these concentrations are available in the department office. A thesis is not required. Students who plan to continue their studies beyond the master’s degree level should give due consideration to the course, examination, and grade-point requirements of doctoral programs.

The M.S. degree program can be taken on a part-time basis or completed in one year of full-time study. Students who plan to continue their studies beyond the master’s degree level should give due consideration to the course, examination, and grade-point requirements of doctoral programs.

The Fu Foundation School of Engineering and Applied Science and the Graduate School of Business trains students interested in combining business and engineering careers. This option is available for students in the financial engineering, industrial engineering, and operations research programs.

Admission for the combined program requires filling out separate applications from both schools, meeting the requirements of both schools; admission requirements are the same as those for the regular M.S. programs and for the M.B.A. Students in the program will have advisors assigned from both schools.

For more information, please visit the department or see the departmental Web site at www.ieor.columbia.edu.

**Doctoral Studies**

The requirements for the Ph.D. in industrial engineering and operations research are identical. Both require the student to pass two qualifying examinations—respectively covering stochastic and deterministic models—as well as submit and defend a dissertation based on the candidate’s original research, conducted under the supervision of a faculty member. The dissertation work may be theoretical or computational or both. Doctoral students are also required to select a concentration for their studies and complete a certain amount of course work in one of the following fields: applied probability, mathematical programming, financial engineering, or supply chain management and logistics. Doctoral candidates must obtain a minimum of 60 points of formal course credit beyond the bachelor’s degree. A master’s degree from an accredited institution may be accepted as equivalent to 30 points. A minimum of 30 points beyond the master’s degree must be earned while in residence in the doctoral program. Detailed information regarding the requirements for the doctoral degree may be obtained in the department office or online at www.ieor.columbia.edu.

### COURSES IN INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

For up-to-date course offerings, please visit www.ieor.columbia.edu.
### OPERATIONS RESEARCH: FIRST AND SECOND YEARS

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<th>SEMESTER I</th>
<th>SEMESTER II</th>
<th>SEMESTER III</th>
<th>SEMESTER IV</th>
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<tr>
<td><strong>MATHEMATICS</strong> (three tracks, choose one; track jumping is prohibited)</td>
<td>MATH V1101 (3)</td>
<td>MATH V1102 (3)</td>
<td>MATH V1201 (3)</td>
<td>Linear algebra (3)</td>
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<td>Honors math I</td>
<td>Honors math II</td>
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<td>Honors math I</td>
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<td>Honors math IV</td>
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<tr>
<td><strong>PHYSICS</strong> (three tracks, choose one)</td>
<td>C1401 (3)</td>
<td>C1402 (3)</td>
<td>Chemistry or physics lab:</td>
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<td></td>
<td>C1601 (3.5)</td>
<td>C1602 (3.5)</td>
<td>PHYS C1493 (3) or PHYS W3081 (2)</td>
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<td>C2801 (4.5)</td>
<td>C2802 (4.5)</td>
<td>CHEM C1500 (3) or CHEM C2507 (3)</td>
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<td>C1403 (3) or C1404 (3) or C1604 (3.5) or C3045 (3.5)</td>
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<td>CHEM C3085 (4) or</td>
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<tr>
<td><strong>CHEMISTRY</strong> (choose one course)</td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
<td>HUMA C1001, C0CI C1101,</td>
<td>HUMA C1002, C0CI C1102,</td>
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<td>Z1003 (0)</td>
<td>Z1003 (0)</td>
<td>or Major Cultures (3–4)</td>
<td>or Major Cultures (3–4)</td>
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<td>Z2006 (0)</td>
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<td>HUMA W1121 or W1123 (3)</td>
<td>either semester</td>
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<tr>
<td><strong>ENGLISH COMPOSITION</strong> (three tracks, choose one)</td>
<td>ECON W1105 (4) <strong>and</strong> W1155 recitation (0)</td>
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<td><strong>either semester</strong></td>
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<tr>
<td><strong>REQUIRED NONTECHNICAL ELECTIVES</strong></td>
<td>Professional-level course (3) (see page 12)</td>
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<td>ENGI E2261 (3)</td>
<td>SIEO W3600 (4)</td>
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<tr>
<td><strong>FIRST- AND SECOND- YEAR DEPT. REQUIREMENTS</strong></td>
<td>E1102 (4) either semester</td>
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<tr>
<td><strong>COMPUTER SCIENCE</strong></td>
<td>COMS W1004 (Java) (3) or COMS W1007 (Java) (3)2</td>
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<td>and COMS W3134 (3) or COMS W3137 (4)2</td>
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<tr>
<td><strong>PHYSICAL EDUCATION</strong></td>
<td>C1001 (1)</td>
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<td><strong>GATEWAY LAB</strong></td>
<td>E1102 (4) either semester</td>
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1. The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.
2. Computer programming should be taken consecutively with data structures.

### IEOR E3106x Introduction to operations research: stochastic models
**Lect:** 3. 3 pts. **Professor Whitt.**
For undergraduate students only. Prerequisite: SIEO W3600. Some of the main stochastic models used in engineering and operations research applications: discrete-time Markov chains, Poisson processes, birth and death processes and other continuous Markov chains, renewal reward processes. Applications: queueing, reliability, inventory, and finance.

### IEOR E3402y Production-inventory planning and control
**Lect:** 3. **Rec:** 1. 4 pts. **Professor Sethuraman.**
Prerequisites or corequisites: SIEO W3600 and IEOR E3608. Inventory management and production planning. Continuous and periodic review models: optimal policies and heuristic solutions, deterministic and probabilistic demands. Material requirements planning. Aggregate planning of production, inventory, and work force. Multi-echelon integrated production-inventory systems. Production scheduling. Term project.

### IEOR W3600y Introduction to probability and statistics
**Lect:** 3. **Rec:** 1. 4 pts. **Professor Sigman.**

### IEOR E3608x Introduction to mathematical programming
**Lect:** 3. **Rec:** 1. 4 pts. **Professor Phillips.**
Prerequisite: Linear algebra (MATH V2010 or APMA E3101) and data structures. Introduction to mathematical programming models and computational techniques. Linear programming and the simplex method, dynamic programming, production planning applications.

### IEOR E3658x Probability
**Lect:** 3. 3 pts. **Professor Olvera-Cravioto.**
Prerequisite: a working knowledge of calculus.

**IEOR E3900x, y, and s Undergraduate research or project**
1 to 3 pts. The faculty. 
Prerequisite: approval by a faculty member who agrees to supervise the work. Independent work involving experiments, computer programming, analytical investigation, or engineering design.

**IEOR E4000x Production management**
Lect: 3. 3 pts. The faculty.
Prerequisites or corequisites: SIEO W4105 and IEOR E4004. An introduction to production management for students not having an industrial engineering bachelor’s degree. Topics include deterministic inventory models, aggregate production planning, material requirements planning, forecasting, stochastic inventory models, and supply chain management. Emphasis is on modeling and its implications for managerial decisions.

**IEOR E4001y Design and management of production and service systems**
Lect: 3. 3 pts. Professor Riccio.
Prerequisite: IEOR E4000 or E3402. Design and management problems in production and service systems: process design and capacity management, inventory system design and management, aggregate planning, staff scheduling, and quality control system design.

**IEOR E4003x Industrial economics**
Lect: 3. 3 pts. Professor Kachani.
Prerequisites or corequisites: SIEO W3600 (or W4150) and IEOR E3608 (or E4004). Introduction to the economic evaluation of industrial projects. Economic equivalence and criteria. Deterministic approaches to economic analysis. Multiple projects and constraints. Analysis and choice under risk and uncertainty.

**IEOR E4004x and y Introduction to operations research: deterministic models**
Lect: 3. 3 pts. Professors Goldfarb and Chudnovsky.
Prerequisites: Linear algebra (MATH V2010 or APMA E3101). For students who have not studied linear programming. Some of the main methods used in IEOR applications involving deterministic models: linear programming, the simplex method, nonlinear, integer and dynamic programming.

**IEOR E4007x Optimization models and methods for financial engineering**
Lect: 3. 3 pts. s: Professor Iyengar.
Prerequisite: Linear algebra (MATH V2010 or APMA E3101). Linear, quadratic, nonlinear, dynamic, and stochastic programming. Some discrete optimization techniques will also be introduced. The theory underlying the various optimization methods is covered. The emphasis is on modeling and the choice of appropriate optimization methods. Applications from financial engineering will be discussed.

**IEOR E4106x y Introduction to operations research: stochastic models**
Lect: 3. 3 pts. Professors Yao and White.
For graduate and undergraduate advanced track students only. Prerequisite: SIEO W3600 or W4150. Some of the main stochastic models used in engineering and operations research applications: discrete-time Markov chains, Poisson processes, birth and death processes and other continuous Markov chains, renewal reward processes. Applications: queueing, reliability, inventory, and finance.

**SIEO W4150x Introduction to probability and statistics**
Lect: 3. 3 pts. Professor Gallego.

**IEOR E4201x The engineering of management, I**
Lect: 3. 3 pts. Professors Fordyce and Norden.
Analytical models of the processes of managing and engineering. Application of recent developments in industrial engineering, operations research, and computing to management problems in establishing policies and objectives, patterns of organization, decision processes, and communication and control systems.
### OPERATIONS RESEARCH: ENGINEERING MANAGEMENT SYSTEMS: FIRST AND SECOND YEARS

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<td>C1603 (3)</td>
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<td><strong>CHEMISTRY</strong></td>
<td>C1403 (3)</td>
<td>C1010 (3)</td>
<td>C1103 (3)</td>
<td>HUMA W1121 or W1123 (3)</td>
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<td>(choose one course)</td>
<td>or C1404 (3)</td>
<td>or C1010 (3)</td>
<td>or C1103 (3)</td>
<td>or Major Cultures (3–4)</td>
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<td>or C1604 (3.5)</td>
<td>or C1010 (3)</td>
<td>or C1103 (3)</td>
<td>or Major Cultures (3–4)</td>
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<td>or C3045 (3.5)</td>
<td>or C1010 (3)</td>
<td>or C1103 (3)</td>
<td>or Major Cultures (3–4)</td>
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<tr>
<td><strong>ENGLISH COMPOSITION</strong></td>
<td>C1010 (3)</td>
<td>Z1003 (0)</td>
<td>HUMA C1001, COCI C1101, Major Cultures (3–4)</td>
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<tr>
<td>(three tracks, choose one)</td>
<td>Z0006 (0)</td>
<td>Z1003 (0)</td>
<td>or HUMA C1002, COCI C1102, Major Cultures (3–4)</td>
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<td><strong>REQUIRED</strong></td>
<td>ECON W1105 (4) and W1155 recitation (0)</td>
<td>C1010 (3)</td>
<td>HUMA W1121 or W1123 (3)</td>
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<td>NONTECHNICAL ELECTIVES</td>
<td>either semester</td>
<td>or C1010 (3)</td>
<td>or Major Cultures (3–4)</td>
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<td>Professional-level course (3) (see page 12)</td>
<td>or C1010 (3)</td>
<td>or Major Cultures (3–4)</td>
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<tr>
<td></td>
<td>ENGI E2261 (3)</td>
<td>or C1010 (3)</td>
<td>or Major Cultures (3–4)</td>
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<td><strong>FIRST- AND SECOND-</strong></td>
<td>Professional-level course (3) (see page 12)</td>
<td>ENGI E2261 (3)</td>
<td>SIEO W3600 (4)</td>
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<tr>
<td>YEAR DEPT. REQUIREMENTS</td>
<td>(see page 12)</td>
<td>or SIEO W3600 (4)</td>
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<td>ENGI E2261 (3)</td>
<td>or SIEO W3600 (4)</td>
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<tr>
<td><strong>COMPUTER SCIENCE</strong></td>
<td>ENGI E2261 (3)</td>
<td>or SIEO W3600 (4)</td>
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<td>ENGI E2261 (3)</td>
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<td>COMS W1004 (Java) (3) or COMS W1007 (Java) (3)</td>
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<td>and COMS W3134 (3) or COMS W3137 (4)</td>
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<tr>
<td><strong>PHYSICAL EDUCATION</strong></td>
<td>C1001 (1)</td>
<td>C1002 (1)</td>
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<tr>
<td><strong>GATEWAY LAB</strong></td>
<td>E1102 (4) either semester</td>
<td>E1102 (4) either semester</td>
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</table>

1 The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.
2 Computer programming should be taken consecutively with data structures.

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**IEOR E4202y** The engineering of management, II
Lect: 3 pts. Professors Fordyce and Norden.
Prerequisite: IEOR E4201 or the instructor’s permission. Application of quantitative techniques to problems of organization and management. Integration of optimization, simulation, gaming, knowledge bases, expert systems, sensitivity analyses, and measurement into management information, decision support, and project management and tracking systems. Practical cases and term project.

**IEOR E4207x** Human factors: performance
Lect: 3 pts. Professor Gold.
Open only to IEOR students. Sensory and cognitive (brain) processing considerations in the design, development, and operations of systems, products, and tools. User or operator limits and potential in sensing, perceiving decision making, movement coordination, memory, and motivation. Registration reservation through the IEOR Department. Note: Registration is limited, and a reservation is required through the IEOR Department office.

**IEOR E4208y** Seminar in human factors design
Lect: 3 pts. Professor Gold.
Prerequisite: IEOR E4207 or the instructor’s permission. An in-depth exploration of the application potential of human factor principles for the design of products and processes. Applications to industrial products, tools, layouts, workplaces, and computer displays. Consideration to environmental factors, training and documentation. Term project. Registration reservation through the IEOR Department.
### OPERATIONS RESEARCH: ENGINEERING MANAGEMENT SYSTEMS: THIRD AND FOURTH YEARS

<table>
<thead>
<tr>
<th>SEMESTER V</th>
<th>SEMESTER VI</th>
<th>SEMESTER VII</th>
<th>SEMESTER VIII</th>
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<tr>
<td><strong>REQUIRED COURSES</strong></td>
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<tr>
<td>MATH E1210 (3) Ordinary diff. equations</td>
<td>ECON W3213 (3) Macroeconomics</td>
<td>IEO E4404 (4) Simulation</td>
<td>IEO E4550 Entrepren. bus. creation for engrs. or IEO E4998 Managing technol. innov. &amp; entrepreneurship</td>
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<tr>
<td>IEO E3106 (3) Stochastic models</td>
<td>COMS W4111 (3) Database systems</td>
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<td>ECON W3211 (3) Microeconomics</td>
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<tr>
<th>TECH</th>
<th>MANAGEMENT</th>
<th>NONTECH</th>
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<tbody>
<tr>
<td>Technical and technology electives (12 pts. total)</td>
<td>Management electives (9 pts. total): Please consult lists posted on IEOR Web site: <a href="http://www.ieor.columbia.edu">www.ieor.columbia.edu</a></td>
<td>Complete 27-point requirement; see page 11 or <a href="http://www.engineering.columbia.edu">www.engineering.columbia.edu</a> for details</td>
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1 At least two technical electives must be chosen from IEO; the complete list is available at www.ieor.columbia.edu.

**IEOR E4210y Supply chain management**  
Lect: 3.3 pts. Professor Huh.  
Prerequisite: IEO E3402, E4000, or the instructor’s permission. Major issues in supply chain management, including definition of a supply chain; role of inventory; supply contracts; bullwhip effect and information sharing; vendor-managed inventories and other distribution strategies; third-party logistics providers; managing product variety; information technology and supply chain management; international issues. Emphasis on quantitative models and analysis.

**CSOR W4231x Analysis of algorithms, I**  
Lect: 3.3 pts. Professor Stein.  
Prerequisites: COMS W3137 and W3203. Introduction to the design and analysis of efficient algorithms. Topics covered include models of computation, efficient sorting and searching, algorithms for algebraic problems, graph algorithms, dynamic programming, probabilistic methods, approximation algorithms, and NP-completeness.

**IEOR E4307x Industrial forecasting**  
Lect: 3.3 pts. Professor Dehnad.  
Prerequisite: SIEO W3600. Analytical techniques and forecasting methodologies with application to industrial problems. Evaluation and comparison of techniques as they pertain to industrial applications. Term project.

**IEOR E4308x Industrial budgeting and financial control**  
Lect: 3.3 pts. Professor Riccio.  
Prerequisite: ECON W2261. Management control via the budgeting and financial processes. Topics include the preparation, evaluation, and implementation of operating and capital budgets and review of their performance. Examples from contemporary practice.

**IEEM E4310x The manufacturing enterprise**  
Lect: 3.3 pts. Professor Weing.  
The strategies and technologies of global manufacturing and service enterprises. Connections between the needs of a global enterprise, the technology and methodology needed for manufacturing and product development, and strategic planning as currently practiced in industry.

**IEOR E4403x Advanced engineering and corporate economics**  
Lect: 3.3 pts. Professor Kachani.  
Prerequisites: SIEO W3600 (or W4150) and IEO E3608 (or E4004). Key measures and analytical tools to assess the financial performance of a firm and perform the economic evaluation of industrial projects. Deterministic mathematical programming models for capital budgeting. Concepts in utility theory, game theory, and real options analysis.

**IEOR E4404x and y Simulation**  
Lect: 3. Rec. 1.4 pts. x: Professor Olvera-Cravioto; y: Professor Blanchett.  
Prerequisites: SIEO W3600 or W4150 and knowledge of Java, C, C++, or FORTRAN. Generation of random numbers from given distributions; variance reduction; statistical output analysis; introduction to simulation languages; application to financial, telecommunications, computer, and production systems. Off-campus M.S. students may register for the 3-point lecture only. Undergraduate students must register for 4 points. Note: Students who have taken IEO E4703 may not register for this course.

**IEOR E4405x Facilities location, routing, and network design**  
Lect: 3.3 pts. Professor Luss.  
Prerequisites: SIEO W3600 or W4150 and IEO E3608 or E4004, and a working knowledge of computer programming. Job shop scheduling; parallel machines, machines in series; arbitrary job shops. Algorithms, complexity, and worst-case analysis. Effects of randomness: machine breakdowns, random processing time. Term project.

**IEOR E4406x Facilities location, routing, and network design**  
Lect: 3.3 pts. Professor Luss.  
Prerequisites: IEO E3608 or E4004. Facility location problems in application areas such as telecommunications networks, product distribution systems and emergency services. Emphasis on applications, algorithmic approaches, routing, and network design problems.
IEOR E4407x Game theoretic models of operations  
*Lect.* 3.3 pts. Professor Sethuraman.  
Prerequisites: IEOR E4004 (or E3608), E4106 (or E3106), and familiarity with differential equations and a programming language; or the instructor’s permission. A mathematically rigorous study of game theory and auctions, and their application to operations management. Topics include introductory game theory, private value auction, revenue equivalence, mechanism design, optimal auction, multi-unit auctions, combinatorial auctions, incentives, and supply chain coordination with contracts. No previous knowledge of game theory is required.

IEOR E4412y Quality control and management  
*Lect.* 3.3 pts. Professor Latzko.  
Prerequisite: SIEO W3600 or W4150. Statistical methods for quality control and improvement: graphical methods, introduction to experimental design and reliability engineering, and the relationships between quality and productivity. Contemporary methods for product and process design, production, and delivery of products and services.

IEOR E4416y Capacity planning: models, algorithms and applications  
*Lect.* 3.3 pts. Professor Luss.  
Prerequisite: IEOR E3608 or E4004. Capacity planning problems are of significant importance in capital-intensive service and manufacturing industries, including telecommunications networks, power generation and transport, transportation networks, and heavy process industries. We will explore a large variety of capacity planning models with emphasis on timing, sizing, location, and capacity type decisions. The course will emphasize modeling approaches, key issues, and algorithms.

IEOR E4418y Logistics and transportation management  
*Lect.* 3.3 pts. Professor Kachani.  
Prerequisite: IEOR E3608 or E4004, or the

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**OPERATIONS RESEARCH: FINANCIAL ENGINEERING:**  
**FIRST AND SECOND YEARS**

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<tr>
<th></th>
<th>SEMESTER I</th>
<th>SEMESTER II</th>
<th>SEMESTER III</th>
<th>SEMESTER IV</th>
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</table>
| **MATHEMATICS**       |            |             |              | Linear algebra (3)
| (three tracks, choose one; track jumping is prohibited) |            |             | and ODE (3) | ODE: MATH E1210 (3) |
|                       | MATH V1101 (3) | MATH V1102 (3) | MATH V1201 (3) | Honors math IV |
|                       | Honors math I | Honors math II | Linear algebra (3) |
|                       | Honors math I | Honors math II (3) | Honors math III (4) |
| **PHYSICS**           |            |             |              | ODE (3) |
| (three tracks, choose one) |            |             |              | Honors math IV |
|                       | C1401 (3) | C1402 (3) | Honors math IV |
|                       | C1601 (3.5) | C1602 (3.5) | Honors math IV |
|                       | C2801 (4.5) | C2802 (4.5) | Honors math IV |
| **CHEMISTRY**         |            |             |              | ODE (3) |
| (choose one course)   |            |             |              | Honors math IV |
|                       | C1403 (3.5) or C1404 (3.5) or C1604 (3.5) or C3045 (3.5) |          |              | Honors math IV |
| **ENGLISH COMPOSITION** |              |              |              | Honors math IV |
| (three tracks, choose one) |              |              |              | Honors math IV |
|                       | C1010 (3) | C1010 (3) | Honors math IV |
|                       | Z1003 (0) | Z1003 (0) | Honors math IV |
|                       | Z0006 (0) | Z0006 (0) | Honors math IV |
| **REQUIRED NONTECHNICAL ELECTIVES** |              |              |              | Honors math IV |
|                       | ECON W1105 (4) and W1155 recitation (0) |              |              | Honors math IV |
|                       | either semester |              |              | Honors math IV |
| **FIRST- AND SECOND-YEAR DEPT. REQUIREMENTS** |              |              |              | Honors math IV |
|                       | Professional-level course (3) (see page 12) |              |              | Honors math IV |
| **COMPUTER SCIENCE**  |              |              |              | Honors math IV |
|                       | Professional-level course (3) (see page 12) |              |              | Honors math IV |
| **PHYSICAL EDUCATION** |              |              |              | Honors math IV |
|                       | C1001 (1) | C1002 (1) | Honors math IV |
| **GATEWAY LAB**       |              |              |              | Honors math IV |
|                       | E1102 (4) | E1102 (4) | Honors math IV |

1. The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.
2. Computer programming should be taken consecutively with data structures.
applications program ming for FE
portation planning, investment and operations.
Lect: 2.5.3 pts. Professor Bienstock.
Prerequisites: Programming in Java, C, or C++
and the instructor’s approval. Introduces quantitative
techniques and state-of-the-art practice of opera-
tions research relevant to the design and both the
tactical and strategic management of logistical
and transportation systems. Discusses a wide
variety of passenger and freight systems, includ-
ing air, urban and highway traffic, rail, and mar-
itime systems. Explores the practice of revenue
management and dynamic pricing. Through case
studies, analyzes successes and failures in third-
party logistics, postal, truck and rail pickup and
delivery systems. Investigates large-scale inte-
gated logistics and transportation systems and
studies the underlying principles governing trans-
portation planning, investment and operations.

IEOR E4500x Entrepreneurial business
creation for engineers
Lect: 3. 3 pts. Professor Robbins.
Prerequisites: ECON W1105 and ECON W2261.
Introduces the basic concepts and methodologies
that are used by the nonengineering part of the
world in creating, funding, investing in, relating to,
and operating entrepreneurial ventures. The first
half of the course focuses on the underpinning
principles and skills required in recognizing, ana-
lyzing, evaluating, and nurturing a business idea.
The second half focuses on basic legal knowl-
dge necessary in creating a business entity,
defending your business assets, and promoting
effective interaction with other individuals and
organizations.

IEOR E4600y Applied integer programming
Lect: 3. 3 pts. Professor Bienstock.
Prerequisites: IEOR E3608 and E4004, linear
algebra (MATH V2010 or APMA E3101), and a
working knowledge of computer programming.
Applications of mathematical programming tech-
niques, especially integer programming, with
emphasis on software implementation. Typical
applications: capacity expansion, network design,
and scheduling.

IEOR E4601y Dynamic pricing and revenue
management
Lect: 2.5. 3 pts. Professor Gallego.
Prerequisite: SIEO W4150 and IEOR E4004.
Focus on capacity allocation, dynamic pricing and
revenue management. Perishable and/or limited
product and pricing implications. Applications to
various industries, including service, airlines,
hotel, resource rentals, etc.

IEOR E4602y Quantitative risk management
Lect: 2.5. 3 pts. Professor Blanchet.
Prerequisite: SIEO W4150 and IEOR E4106. Risk
management models and tools; measure risk
using statistical and stochastic methods, hedging,
and diversification. Examples include insurance
risk, financial risk, and operational risk. Topics
covered include VaR, estimating rare events,
extreme value analysis, time series estimation of
extremal events, axioms of risk measures, hedg-
ing using financial options, credit risk modeling,
and various insurance risk models.

IEOR E4620y Applied financial engineering
Lect: 2.5. 3 pts. Professor Dehnad.
Prerequisite: IEOR E4700. Characteristics of
commodities or credit derivatives. Case study
and pricing of structures and products. Topics covered
include swaps, credit derivatives, single tranche
CDO, hedging, convertible arbitrage, FX, leverage
leases, debt markets, and commodities.

IEOR E4630x Pricing models for financial
engineering
Lect: 2.5. 3 pts. Professor Dehnad.
Prerequisite: IEOR E4700. Models for pricing and
hedging equity, fixed-income, credit-derivative
securities, standard tools for hedging and risk
management, models and theoretical foundations
for pricing equity options (standard European,
American equity options, Asian options, standard Black-Scholes model (with multi-asset extension), asset allocation, portfolio optimization, investments over long-time horizons, and pricing of fixed-income derivatives (Ho-Lee, Black-Derman-Toy, Heath-Jarrow-Morton interest-rate model). Note: Students may not take both IEOR E4630 and DRAN B8835.

IEOR E4700x and y Introduction to financial engineering
Lect: 3.3 pts. Professors Stoikov and Gallego.
Prerequisite: IEOR E3106 or IEOR E4106, or the equivalent. Introduction to investment and financial instruments via portfolio theory and derivative securities, using basic operations research/engineering methodology. Portfolio theory, arbitrage; Markowitz model, market equilibrium, and the capital asset pricing model. General models for asset price fluctuations in discrete and continuous time. Elementary introduction to Brownian motion and geometric Brownian motion. Option theory; Black-Scholes equation and call option formula. Computational methods such as Monte Carlo simulation.

IEOR E4701s Stochastic models for financial engineering
Lect: 3. 3 pts. Professor Sigman.
Prerequisite: SIEO W4105 or the equivalent. Review of elements of probability theory, Poisson processes, exponential distribution, renewal theory. Wald’s equation. Introduction to discrete-time Markov chains and applications to queueing theory, inventory models, branching processes.

IEOR E4702s Statistical inference for financial engineering
Lect: 1.5-1.5 pts. The faculty.
The course covers basic tools of statistical inference relevant to financial engineering. The statistical topics covered include point estimation, maximum likelihood estimators, confidence intervals, the delta method, hypothesis testing, and goodness of fit tests. The financial examples include selection bias in finance, estimation of drift and volatility in the geometric Brownian motion model, the leptokurtic feature, and difficulties in estimating the tail distributions of asset returns.

IEOR E4703x Monte Carlo simulation
Lect: 3. 3 pts. Professor Iyengar.
Prerequisite: IEOR E4701 or the equivalent. Multivariate random number generation, bootstrapping, Monte Carlo simulation, efficiency improvement techniques. Simulation output analysis, Markov-chain Monte Carlo. Applications to financial engineering. Introduction to financial engineering simulation software and exposure to modeling with real financial data. Note: Students who have taken IOR E4404 may not register for this course.

IEOR E4705x Studies in operations research
Lect: 3. 3 pts. Professor Riccio.
Prerequisites: IEOR E3608 (or E4004) and E4106 (or E3106). Analysis and critique of current operations research studies. Blood bank inventory, fire departments, police departments, and housing operations research studies are considered.

IEOR E4706x Foundations in financial engineering
Lect: 3. 3 pts. Professors Kou and Tilman. Corequisites: IEOR E4701 and E4702 or their equivalents. Bond mathematics. Introduction to forwards, futures, and other derivative securities. Discrete-time models of equity markets and the term structure. Pricing and dynamic hedging of derivative securities. Option pricing and Black-Scholes, introduction to real options and portfolio optimization.

IEOR E4707x Financial engineering: continuous-time asset pricing

IEOR E4708y Seminar on classical and new papers in financial engineering
Lect: 3. 3 pts. Professor Derman. Corequisites: IEOR E4701 and E4706. Selected topics of special interest to financial engineering M.S. students. If Topics are different, then this course can be taken more than once for credit.

IEOR E4709y Data analysis for financial engineering

IEOR E4710y Term structure models
Lect: 2. 3 pts. The faculty.
Prerequisites: IEOR E4706, E4707, and proficiency in programming. Interest rate models and numerical techniques for pricing and hedging interest rate contracts and fixed income securities.

IEOR E4718y Introduction to the implied volatility smile
Lect: 3. 3 pts. Professor Derman.
Prerequisite: IEOR E4706 or some knowledge of derivatives valuation models. During the past fifteen years the behavior of market options prices have shown systematic deviations from the classic Black-Scholes model. The course will examine the empirical behavior of implied volatilities, in particular the volatility smile that now characterizes most markets, and then discuss the mathematics and intuition behind new models that can account for the smile, and then examine their consequences for hedging and valuation.

IEOR E4720-E4729s and y Topics in quantitative finance
Lect: 2–2.5. 1.5-3 pts. The faculty. Selected topics of interest in the area of quantitative finance. Offerings vary each year; possible topics include asset management, energy derivatives, experimental finance, foreign exchange and related derivative instruments, inflation derivatives, hedge fund management, modeling equity derivatives in Java, mortgage-backed securities, numerical solutions of partial differential equations, quantitative portfolio management, risk management, trading and technology in financial markets.

IEOR E4724y or s Topics in quantitative finance: hedge fund management
Lect: ?. 1.5-3 pts. Professor Metzger.
The course covers the critical managerial aspects and characteristics of hedge funds and the hedge fund industry, including legal regulations, strategies, risk management, performance evaluation, etc.

IEOR E4725y or s Topics in quantitative finance: numerical solutions of partial differential equations
Lect: ?. 1.5-3 pts. Professor Kani.
The course covers derivations and solutions of partial differential equations under a variety of underlying stochastic price processes. Students will gain exposure to applications of partial differential equations to security pricing in different financial markets (i.e., equity derivatives, fixed income securities, and credit derivative markets).

IEOR E4726y or s Topics in quantitative finance: experimental finance
Lect: ?. 3 pts. Professor Stanton.
The course introduces concepts to propose trading schema, organize tests via options/stock databases, and carry out tests efficiently and accurately. It exposes students to the differing strategies between static, thermodynamic/SDE model solutions and real (time-of-flight) pricing. They will become familiar with computational techniques for modeling and testing proposals for trading strategies.

IEOR E4731y Credit derivatives
Lect: 2.5. 3 pts. Professor Cont.
Prerequisites: IEOR E4701 and E4707. Introduction to quantitative modeling of credit risk, with a focus on the pricing of credit derivatives. Focus on the pricing of single-name credit derivatives (credit default swaps) and collateralized debt obligations (CDOs). Detail topics include: default and credit risk, arbitrage pricing, default times, single-name credit derivatives, structured models for single-name credit risk, multi-name default barrier models and multi-name reduced form models.
SIEO W4801x Introduction to property-liability insurance models

SIEO W4802y Introduction to life insurance and aggregate loss models
Prerequisites: IEOR E4007 and E4701, or E4106, or the instructor’s permission. Introduction to actuarial modeling and actuarial and statistical methods useful in modeling life insurance risk and aggregation of insurance risk to the portfolio level. Survival models used in life insurance. Discrete and continuous models. Life insurance and annuity applications. Compound risk models, moments, computation, and approximation. Continuous processes of insurance events and probability of eventual default.

IEOR E4900x, y, and s Master’s research or project
1 to 3 pts. The faculty.
Prerequisite: approval by a faculty member who agrees to supervise the work. Independent work involving experiments, computer programming, analytical investigation, or engineering design.

IEOR E4998x and y Managing technological innovation and entrepreneurship
Lect: 3. 3 pts. Professor McGourty.
This course will focus on the management and consequences of technology-based innovation. The course explores how new industries are created, how existing industries can be transformed by new technologies, the linkages between technological development and the creation of wealth and the management challenges of pursuing strategic innovation.

IEOR E4999x, y, and s Curricular practical training
1 to 2 pts. Professor Derman.
Prerequisite: instructor’s written approval. Only for IEOR graduate students who need relevant work experience as part of their program of study. Final reports required. This course may not be taken for pass/fail credit or audited.

IEOR E6400y Scheduling: deterministic models
Lect: 2. 3 pts. Professor Stein.

IEOR E6403y Routing
Lect: 2. 2 or 3 pts. The faculty.
Prerequisite: IEOR E4004, SIEO W4150, or the instructor’s permission. Vehicle routing in distribution systems. Routing problems in VLSI. Effects of randomness. Students registering for 3 points are required to do a term project.

MSIE W6408y Inventory theory
Lect: 2. 3 pts. The faculty.
Prerequisite: SIEO W4150 and dynamic programming. Construction and analysis of mathematical models used in the design and analysis of inventory systems. Deterministic and stochastic demands and lead times. Optimality of (s, S) policies. Multiproduct and multi-echelon systems. Computational methods.

SIEO W5501x Stochastic processes and applications, I
Lect: 2.5. 3 pts. The faculty.
Prerequisite: SIEO W4105 or the equivalent. Advanced treatment of discrete and continuous-time Markov chains; elements of renewal theory; martingales; Brownian motion, stochastic integrals, Ito’s rule.

SIEO W5502y Stochastic processes and applications, II
Prerequisites: STAT G6104 and SIEO W6501. Recommended corequisite: STAT G6105. With the instructor’s permission, the second term may be taken without the first. Introduction to martingales in continuous time. Brownian motion: construction, basic properties, sample paths. Stochastic integration, Ito’s rule, applications. Introduction to stochastic differential equations and diffusion processes. Applications to financial economics: option pricing, consumption/investment problems.

IEOR E6601y Advanced topics in linear programming
Lect: 2. 3 pts. The faculty.
Prerequisite: IEOR E6613 or the equivalent. Numerical linear algebra for simplex and interior point methods: product-form LU, Cholesky and symmetric indefinite factorizations, sparsity considerations. Steepest-edge pivot rules, column generation, and decomposition approaches. Analysis of interior point methods including path-following, potential reduction, and predictor-corrector methods.

IEOR E6602y Nonlinear programming
Lect: 2. 3 pts. Professor Goldfarb.
Prerequisite: IEOR E6613 or the equivalent. Convex sets and functions, convex duality and optimality conditions. Computational methods: steepest descent, Newton and quasi-Newton methods for unconstrained problems, active set, penalty set, interior point, augmented Lagrangian and sequential quadratic programming methods for constrained problems. Introduction to nondifferentiable optimization and bundle methods.

IEOR E6603x Combinatorial optimization
Prerequisites: IEOR E6613 and E6614. Algorithms for matching problems. Introduction to matroids, polyhedral combinatorics, complexity theory and NP completeness. Perfect graphs and the ellipsoid method.

IEOR E6606y Advanced topics in network flows
Lect: 3. 3 pts. The faculty.
Prerequisite: Knowledge of elementary graph algorithms and computational complexity, equivalent to IEOR E6605, or COMS W4203 and W4231. Analysis of algorithms and their complexity for a variety of network routing problems. Topics: overall minimum cuts, minimum cost network flows, flows with losses and gains, parametric flows, dynamic flows, multicommodity flows and applications.

IEOR E6608x Integer programming
Lect: 2. 3 pts. The faculty.
Prerequisite: IEOR E6613 or the equivalent. Theoretical and algorithmical aspects of integer programming (IP). Theoretical topics: structure of the set of feasible solutions of an IP problem, integral polyhedra, totally unimodular matrices, totally dual integral systems, Lovasz’s lattice reduction method, and Lenstra’s IP algorithm. Algorithmical topics to center on branch and bound algorithms and the “facet” approach to cutting-plane algorithms.

IEOR E6609y Dynamic programming
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: IEOR E4701 or E4106 or the equivalent. General discrete time deterministic, dynamic programming, discrete time-parameter finite branching, Markov decision chains, team decisions, certainty equivalence, continuous time-parameter Markov branching decision processes. Applications include capital budgeting, portfolio selection, inventory control, systems reliability, and maximization of expected utility with constant risk posture.

IEOR E6610x Approximation algorithms
Prerequisites: Basic knowledge of linear programming and analysis of algorithms or combinatorial optimization. The design and analysis of efficient algorithms for providing near-optimal solutions to NP-hard problems. Classic algorithms and recent techniques for approximation algorithms.

IEOR E6611x Semidefinite and second-order cone programming
Lect: 2. 3 pts. Professor Iyengar.
Duality theory for semidefinite programming (SDP) and second-order cone programming (SOCP). Jordan algebras and symmetrical cones. Formulating engineering problems such as robust linear programming, truss design, filter design, and antenna design as SDPs and SOCPs. SDP and SOCP approximations for combinatorial optimization problems.

IEOR E6612 Robust optimization
Lect: 2.3 pts. Professor Iyengar.
Prerequisites: Linear algebra (APMA E3101 or the equivalent) and optimization (IEOR E6613 or the equivalent). Robust convex optimization problems, reformulating robust problems as nominal problems, computational techniques. Adjustably robust optimization. Chance constrained problems and robust chance constrained problems. Applications from portfolio optimization, truss design, inventory theory, revenue management, dynamic programming, etc.

IEOR E6613x Optimization, I
Lect: 3. 4.5 pts. Professor Goldfarb.

IEOR E6614y Optimization, II
Lect: 3. 4.5 pts. Professor Stein.

IEOR E6702x Reliability theory
Prerequisites: IEOR E4701 or E4106, and SIEO W4150. An overview of the techniques available to formulate the reliability structure of a problem, to model the various element probabilities, to estimate parameters of element probability distributions based on data, and to unite these steps to obtain the reliability function of a system.

IEOR E6703x Advanced financial engineering
Lect: 2. 3 pts. Professor Kou.

IEOR E6704y Queueing theory and applications
Lect: 2. 3 pts. Professor Sigman.
Prerequisite: IEOR E4106 or E4701. Introduction to congestion and related stochastic models. Topics include birth and death models, measures of performance, Little's Law, conservation law, PASTA, work in system, service disciplines and priorities, regenerative processes, stability and stationary distributions, approximations and bounds. Examples from telecommunications, production, inventory, and computer science.

IEOR E6706y Queueing networks
Lect: 2. 3 pts. Professor Yao.
Prerequisite: IEOR E4404 or E4701. An introduction to the analysis of queueing networks. Applications to computer and communication systems. The course covers reversibility, local balance, open and closed network models, computational procedures, and other related topics.

IEOR E6707y Advanced topics in queueing theory
Lect: 2. 3 pts. Professor Whitt.
Prerequisite: IEOR E6704 or the instructor's permission. Queueing models with general arrival and service processes, Loynes construction, Harris recurrence, coupling, stability, steady-state moments and tail asymptotics, heavy-traffic and light-traffic approximations. Recent literature and open problems are discussed.

IEOR E6708x Discrete event stochastic systems
Prerequisites: IEOR E4004, E4404, and E4106. Modeling, analysis, control, and optimization of discrete event stochastic systems. Generalized semi-Markov process models; sample path analysis; stochastic optimization optimal control. Applications to manufacturing and communication problems.

IEOR E6710y Markovian decision processes
Lect: 2. 3 pts. Instructor to be announced.
Prerequisite: IEOR E4106 or E4701. Dynamic systems observed periodically and partially controlled by decisions made at each time of observation. Methods of determining optimal decision policies. Applications to inventory, inspection, maintenance, and replacement theories.

IEOR E6711x Stochastic models, I
Lect: 3. 4.5 pts. Professor Whitt.
Prerequisite: SIEO W4105 or the equivalent. Advanced treatment of stochastic modeling in the context of queueing, reliability, manufacturing, insurance risk, financial engineering and other engineering applications. Review of elements of probability theory; exponential distribution; renewal theory; Wald's equation; Poisson processes. Introduction to both discrete and continuous-time Markov chains; introduction to Brownian motion.

IEOR E6712y Stochastic models, II
Lect: 3. 4.5 pts. Professor Yao.
Prerequisite: IEOR E6711 or the equivalent. Continuation of IEOR E6711, covering further topics in stochastic modeling in the context of queueing, reliability, manufacturing, insurance risk, financial engineering, and other engineering applications. Topics from among generalized semi-Markov processes; processes with a nondiscrete state space; point processes; stochastic comparisons; martingales; introduction to stochastic calculus.

IEOR E6801x Monte Carlo methods
Lect: 2. 3 pts. Professor Blanchet.
Prerequisites: IEOR E4106 or E4701, and SIEO 4150, plus a working knowledge of programming. No prior knowledge of simulation is required. Random variate generation, discrete event simulation, Monte Carlo simulation, simulation output analysis, variance reduction, improving simulation efficiency, simulation-based derivative-estimation/sensitivity-analysis, and quasi-Monte Carlo techniques. Application of these techniques to financial engineering and performance analysis/optimization of computer networking, telecommunications, and production systems.

IEOR E8100 Advanced topics in IEOR
Lect: 1–3. 1 to 3 pts. Instructor to be announced. Prerequisite: faculty advisor’s permission. Selected topics of current research interest. May be taken more than once for credit.

IEOR E9101x and y, and s Research
1 to 6 pts. The faculty. A candidate for the Eng.Sc.D. degree in industrial engineering or operations research must register for 12 points of doctoral research instruction. Registration in IEOR E9800 may not be used to satisfy the minimum residence requirement for the Ph.D. degree.

IEOR E9800x and y, and s Doctoral research instruction
3, 6, 9, or 12 pts. The faculty. A candidate for the Eng.Sc.D. degree in industrial engineering or operations research must register for 12 points of doctoral research instruction. Registration in IEOR E9800 may not be used to satisfy the minimum residence requirement for the Ph.D. degree.

IEOR E9901x and y Operations research seminar
Sem: 2. 1 to 3 pts. The faculty. Open to doctoral candidates, and qualified M.S. candidates with the instructor’s permission. This course may be repeated for credit. Selected topics of interest. Topics may vary from year to year.

IEOR E9940x or y Industrial engineering seminar
Sem: 2. 1 to 3 pts. The faculty. Open to doctoral candidates and qualified M.S. candidates with the instructor’s permission. The course may be repeated for credit. Selected topics of interest. Topics may vary from year to year.
MATERIALS SCIENCE AND ENGINEERING PROGRAM

Program in the Department of Applied Physics and Applied Mathematics, sharing teaching and research with the faculty of the Henry Krumb School of Mines.

200 S. W. Mudd, MC 4701, 212-854-4457
www.apam.columbia.edu
www.seas.columbia.edu/matsci

Materials science and engineering (MSE) focuses on understanding, designing, and producing technology-enabling materials by analyzing the relationships among the synthesis and processing of materials, their properties, and their detailed structure. This includes a wide range of materials such as metals, polymers, ceramics, and semiconductors. Solid-state science and engineering focuses on understanding and modifying the properties of solids from the viewpoint of the fundamental physics of the atomic and electronic structure.

Undergraduate and graduate programs in materials science and engineering are coordinated through the Materials Science and Engineering Program in the Department of Applied Physics and Applied Mathematics. This program promotes the interdepartmental nature of the discipline and involves the Departments of Applied Physics and Applied Mathematics, Chemical Engineering and Applied Chemistry, Electrical Engineering, and Earth and Environmental Engineering (EAAE) in the Henry Krumb School of Mines (HKSM) with advisory input from the Departments of Chemistry and Physics.

Students interested in materials science and engineering enroll in the materials science and engineering program in the Department of Applied Physics and Applied Mathematics. Those interested in the solid-state science and engineering specialty enroll in the doctoral program within Applied Physics and Applied Mathematics or Electrical Engineering.

The faculty in the interdepartmental committee constitute but a small fraction of those participating in this program, who include Professors Bailey, Chan, Herman, Im, Neumark, Noyan, O’Brien, Pinczuk, and Stormer from Applied Physics and Applied Mathematics; Brus, Dunning, Flynn, Koberstein, O’Shaughnessy, and Turro from Chemical Engineering; Duby, Somasundaran, and Themelis from EAAE; and Heinz, Osgood, and Wang from Electrical Engineering.

Materials science and engineering uses optical, electron, and scanning probe microscopy and diffraction techniques to reveal details of structure, ranging from the atomic to the macroscopic scale—details essential to understanding properties such as mechanical strength, electrical conductivity, and technical magnetism. These studies also give insight into problems of the deterioration of materials in service, enabling designers to prolong the useful life of their products. Materials science and engineering also focus on new ways to synthesize and process materials, from bulk samples to ultrathin films to epitaxial heterostructures to nanocrystals. This involves techniques such as UHV sputtering; molecular beam epitaxy; plasma etching; laser ablation, chemistry, and recrystallization; and other nonequilibrium processes. The widespread use of new materials and the new uses of existing materials in electronics, communications, and computers have intensified the demand for a systematic approach to the problem of relating properties to structure and necessitates a multidisciplinary approach.

Solid-state science and engineering uses techniques such as transport measurements, X-ray photoelectron...
spectroscopy, inelastic light scattering, luminescence, and nonlinear optics to understand electrical, optical, and magnetic properties on a quantum mechanical level. Such methods are used to investigate exciting new types of structures, such as two-dimensional electron gases in semiconductor heterostructures, superconductors, and semiconductor surfaces and nanocrystals.

Current Research Activities
Current research activities in the materials science and engineering program at Columbia focus on thin films and electronic materials that enable significant advances in information technologies. Specific topics under investigation include interfaces, stresses, and grain boundaries in thin films; lattice defects and electrical properties of semiconductors; laser processing and ultrarapid solidification of thin films; nucleation in condensed systems; optical and electric properties of wide-band semiconductors; synthesis of nanocrystals, carbon nanotubes, and nanotechnology-related materials; deposition, in-situ characterization, electronic testing, and ultrafast spectroscopy of magnetoelectronic ultrathin films and heterostructures. In addition, there is research in surface and colloid chemistry involving both inorganic and organic materials such as surfactants, polymers, and latexes, with emphasis on materials/environment interactions.

The research activities in solid-state science and engineering are described later in this section.

Laboratory Facilities
Facilities and research opportunities also exist within the interdepartmental Materials Research Science and Engineering Center (MRSEC) and Nanoscale Science and Engineering Center (NSEC), which focus on complex films formed from nanoparticles and molecular electronics, respectively. Modern clean room facilities with optical and e-beam lithography, thin film deposition, and surface analytical probes (STM, SPM, XPS) are available. More specialized equipment exists in individual research groups in solid state engineering and materials science and engineering. The research facilities in solid-state science and engineering are listed in the sections for each host department. Facilities, and research opportunities, also exist within the interdepartmental Materials Research Science and Engineering Center, which focuses on complex films composed of nanoparticles.

UNDERGRADUATE PROGRAM IN MATERIALS SCIENCE AND ENGINEERING
This program provides the basis for developing, improving, and understanding materials and processes for electronic, structural, and other applications. It draws from physics, chemistry, and other disciplines to provide a coherent background for immediate application in engineering or for subsequent advanced study. The emphasis is on fundamentals relating atomic- to microscopic-scale phenomena to materials properties and processing, including design and control of industrially important materials processes. Core courses and electives combine rigor with flexibility and provide opportunities for focusing on such areas as electronic materials, polymers, ceramics, biomaterials, structural materials, and metals and mineral processing. There are also opportunities for combining materials science and engineering with interests in areas such as medicine, business, law, or government.

The unifying theme of understanding and interrelating materials synthesis, processing, structure, and properties forms the basis of our MSAE program and is evident in the undergraduate curriculum and in faculty research activities. These activities include work on polycrystalline silicon for flat panel displays; high-temperature superconductors for power transmission and sensors; semiconductors for laser and solar cell applications; magnetic heterostructures for information storage and novel computation architectures; electronic ceramics for batteries, gas sensors, and fuel cells; electrodeposition and corrosion of metals; and the analysis and design of high-temperature reactors. Through involvement with our research groups, students gain valuable hands-on experience and are often engaged in joint projects with industrial and government laboratories.

The materials science and engineering undergraduate curriculum requires sixteen courses in the third and fourth years, of which four are restricted electives. This program allows students to specialize in a subdiscipline of MSAE if they so choose. Students must take twelve required courses and four electives. At least two electives must be in the Type A category, and at most two may be in the Type B category. The Type B electives are listed under different materials subdisciplines for guidance. Still, some courses listed under different categories may appeal to students interested in a given area. For example, CHEE E4252: Introduction to surface and colloid chemistry should also be considered by students interested in biomaterials and environmental materials.

Type A electives are:
CHEE E4530: Corrosion of metals
MSAE E4207: Lattice vibrations and crystal defects
MSAE E4250: Ceramics and composites
ELEN E4944: Principles of device microfabrication

Type B electives are:
BIOMATERIALS
BMEN E4300: Solid biomechanics
BMEN E4301: Structure, mechanics, and adaptation of bone
BMEN E4501: Tissue engineering, I: biological tissue substitutes

ELECTRONIC MATERIALS
APPH E3100: Introduction to quantum mechanics
APPH E3300: Applied electromagnetism
APPH E4100: Quantum physics of matter
APPH E4110: Modern optics
ELEN E4301: Introduction to semiconductor devices
ELEN E4411: Fundamentals of photonics

ENVIRONMENTAL MATERIALS
EAE E4001: Industrial ecology of Earth resources
EAE E4160: Solid and hazardous waste management

MECHANICAL PROPERTIES OF MATERIALS
ENME E3114: Experimental mechanics of solids
ENME E4113: Advanced mechanics of solids
ENME E4114: Mechanics of fracture and fatigue
MECE E4608: Manufacturing processes

SOFT MATERIALS AND SURFACES
CHEE C3443: Organic chemistry (note that C3444 is not allowed)
CHEE E4252: Introduction to surface and colloid chemistry
APMA E4400: Introduction to biophysical modeling

OTHER
MSAE E3900: Undergraduate research in materials science
Alternative courses can be taken as electives with the approval of the undergraduate adviser. Of the 24 points of elective content in the third and fourth years, at least 12 points of restricted electives approved by the adviser must be taken. Of the remaining 12 points of electives allotted, a sufficient number must actually be taken so that no fewer than 64 points of courses are credited to the third and fourth years. Those remaining points of electives are intended primarily as an opportunity to complete the four-year, 27-point nontechnical requirement, but any type of course work can satisfy them.

**GRADUATE PROGRAMS IN MATERIALS SCIENCE AND ENGINEERING**

**Master of Science Degree**
Candidates for the Master of Science degree follow a program of study formulated in consultation with, and approved by, a faculty adviser. A minimum of 30 points of credit must be taken in graduate courses within a specific area of study of primary interest to the candidate. All degree requirements must be completed within five years. A candidate is required to maintain at least a 2.5 grade point average. Applicants for admission are required to take the Graduate Record Examinations. A research report (6 points of credit, MSAE 6273) is required. Special reports (3 points of credit) are acceptable for Columbia Video Network (CVN) students.

**Doctoral Program**
At the end of the first year of graduate study, doctoral candidates are required to take a comprehensive written qualifying examination, which is designed to test the ability of the candidate to apply course work in problem solving and creative thinking. The standard is first-year graduate level. There are two four-hour examinations over a two-day period.

Candidates in the program must take an oral examination within one year of taking the qualifying examination. Within two years of taking the qualifying examination, candidates must submit a written proposal and defend it orally before a Proposal Defense Committee consisting of three members of the faculty, including the adviser. Doctoral candidates must submit a thesis to be defended before a Dissertation Defense Committee consisting of five faculty members, including two professors from outside the doctoral program. Requirements for the Eng.Sc.D. (administered by the School of Engineering and Applied Science) and the Ph.D. (administered by the Graduate School of Arts and Sciences) are listed elsewhere in this bulletin.

**Areas of Research**
Materials science and engineering is concerned with synthesis, processing, structure, and properties of metals, ceramics, polymers, and other materials, with emphasis on understanding and exploiting relationships among structure, properties, and applications requirements. Our graduate research programs encompass projects in areas as diverse as polycrystalline silicon, electronic ceramics, grain boundaries and interfaces, microstructure and stresses in microelectronics, oxides and oxide films for novel sensors and fuel cells, wide-band-gap semiconductors, plasma processing of materials and optical diagnostics of thin-film processing, ceramic nanocomposites, electro-deposition and corrosion processes, and magnetic thin films for giant and colossal magnetoresistance, chemical synthesis of nanoscale materials, nanocrystals, and carbon nanotubes. Application targets for polycrystalline silicon are thin film transistors for active matrix displays and silicon-on-insulator structures for ULSI devices. Wide-band-gap II–VI semiconductors are investigated for laser applications. Novel applications are being developed for oxide thin films, including uncooled IR focal plane arrays and integrated fuel cells for portable equipment. Long-range applications of high-temperature superconductors include efficient power transmission and highly sensitive magnetic field sensors.

Thin film synthesis and processing in this program include evaporation, sputtering, electrodeposition, and plasma and laser processing. For analyzing materials structures and properties, faculty and students employ electron microscopy, scanning probe microscopy, cathodoluminescence and electron beam–induced current imaging, photoluminescence, dielectric and anelastic relaxation techniques, ultrasonic methods, magnetotransport measurements, and X-ray diffraction techniques. Faculty members have research collaborations with Lucent, Exxon, Philips Electronics, IBM, and other New York area research and manufacturing centers, as well as major international research centers. Scientists and engineers from these institutions also serve as adjunct faculty members at Columbia. The National Synchrotron Light Source at Brookhaven National Laboratory is used for high-resolution X-ray diffraction and absorption measurements.

Entering students typically have undergraduate degrees in materials science, metallurgy, physics, chemistry, or other science and engineering disciplines. First-year graduate courses provide a common base of knowledge and technical skills for more advanced courses and for research. In addition to course work, students usually begin an association with a research group, individual laboratory work, and participation in graduate seminars during their first year.

**GRADUATE SPECIALTY IN SOLID-STATE SCIENCE AND ENGINEERING**
Solid-state science and engineering is an interdepartmental graduate specialty that provides coverage of an important area of modern technology that no single department can provide. It encompasses the study of the full range of properties of solid materials, with special emphasis on electrical, magnetic, optical, and thermal properties. The science of solids is concerned with understanding these properties in terms of the atomic and electronic structure of the materials in question. Insulators (dielectrics), semiconductors, ceramics, and metallic materials are all studied from this viewpoint. Quantum and statistical mechanics are key background subjects. The engineering aspects deal with the design of materials to achieve desired properties and the assembling of materials into systems to produce devices of interest to modern technology, e.g., for computers and for energy production and utilization.
Areas of Research

The graduate specialty in solid-state science and engineering includes research programs in the Fractional Quantum Hall Effect and electronic transport (Professor Stormer, Physics/Applied Physics and Applied Mathematics); nonlinear optics of surfaces (Professor Heinz, Electrical Engineering/Physics); semiconductor nanocrystals (Professor Brus, Chemistry/Chemical Engineering); optics of semiconductors, including at high pressure (Professor Herman, Applied Physics and Applied Mathematics); chemical physics of surfaces and photoemission (Professor Osgood, Electrical Engineering/Applied Physics and Applied Mathematics); molecular beam epitaxy leading to semiconductor devices (Professor Wang, Electrical Engineering/Applied Physics and Applied Mathematics); luminescence in heavily doped wide-band-gap semiconductors (Professor Neumark, Henry Krumb School of Mines/Applied Physics and Applied Mathematics); and inelastic light scattering in low-dimensional electron gases within semiconductors (Professor Pinczuk, Applied Physics and Applied Mathematics/Physics); large-area electronics and thin-film transistors (Professor Im, Henry Krumb School of Mines/Applied Physics and Applied Mathematics); structural analysis and high Tc superconductors (Professor Chan, Henry Krumb School of Mines/Applied Physics and Applied Mathematics); x-ray microdiffraction and stresses (Professor Noyan, Henry Krumb School of Mines/Applied Physics and Applied Mathematics); magnetic properties of thin films (Professor Bailey, Henry Krumb School of Mines/Applied Physics and Applied Mathematics); properties of nano materials (Professor O'Brien, Henry Krumb School of Mines/Applied Physics and Applied Mathematics).

Program of Study

The applicant for the graduate specialty must be admitted to one of the participating programs: applied physics and applied mathematics, or electrical engineering. A strong undergraduate background in physics or chemistry and in mathematics is important.

The doctoral student must meet the formal requirements for the Eng.Sc.D. or Ph.D. degree set by the department in which he or she is registered. However, the bulk of the program for the specialty
### MATERIALS SCIENCE AND ENGINEERING: THIRD AND FOURTH YEARS

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<td>MSAE E3111 (3) Thermodynamics, kinetic theory, and statistical mechanics</td>
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\(^1\) Students wishing to have advance preparation for ENME E3113 may take ENME-MECE E3105: Mechanics as an elective in Semester IV.

\(^2\) At least 6 of the 24 points of electives must be Type A. Another 6 points must be from the Type A and Type B elective lists.

\(^3\) Juniors substitute E4132 for E3142 when offered.

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**COURSES IN MATERIALS SCIENCE AND ENGINEERING**

For related courses, see also Applied Physics and Applied Mathematics, Chemical Engineering and Applied Chemistry, Earth and Environmental Engineering, and Electrical Engineering.

**MSAE E1001y Atomic-scale engineering of new materials**

*Lect*: 3.3 pts. *Professor Bailey.*

An introduction to the atomic-scale science and engineering of new materials. The control and manipulation of atomic structure can create new solids with unprecedented properties. Computer hard drives, compact disc players, and liquid crystal displays (LCDs) are explored to understand the role of new materials in enabling technologies. Group problem-solving sessions are used to develop understanding.

**MSAE E3103x Elements of materials science**

*Lect*: 3.3 pts. *Professor Duby.*

Prerequisites: CHEM C1404 and PHYS C1011. Atomic and crystal structures, structural defects, alloying and phase diagrams. The influence of microstructure on the strength and physical properties of metals and alloys, semiconductors, ceramics, glasses, and polymers.

**MSAE E3104y Laboratory in materials science**

*Lect*: 1. Lab: 4.3 pts. *Professor Noyan.*

Corequisite: MSAE E3103. Metallographic specimen preparation, optical microscopy, quantitative metallography, hardness and tensile testing, plastic deformation, annealing, phase diagrams, brittle fracture of glass, temperature and strain rate dependent deformation of polymers. Written and oral reports.

**MSAE E3111x Thermodynamics, kinetic theory, and statistical mechanics**

*Lect*: 3.3 pts. *Professor Bailey.*

An introduction to the basic thermodynamics of systems, including concepts of equilibrium, entropy, thermodynamic functions, and phase changes. Basic kinetic theory and statistical mechanics, including diffusion processes, concept of phase space, classical and quantum statistics, and applications thereof.

**MSAE E3141y Processing of metals and semiconductors**

*Lect*: 3.3 pts. *Professor Bailey.*

Prerequisites: MSAE E3103 or the equivalent. Synthesis and production of metals and semi-conductors with engineered microstructures for desired properties. Includes high-temperature, aqueous, and electrochemical processing; thermal and mechanical processing of metals and alloys; casting and solidification; diffusion, microstructural evolution, and phase transformations; modification and processing of surfaces and interfaces; deposition and removal of thin films. Processing of Si and other materials for elemental and compound semiconductor-based electronic, magnetic, and optical devices.

**MSAE E3142y Processing of ceramics and polymers**

*Lect*: 3.3 pts. *Instructor to be announced.*

Prerequisite: MSAE E3103 or the equivalent. Established and novel methods involved in the processing of polymers and ceramics. The fundamental aspects of the structure and properties of polymers and ceramic materials; strategy in the preparatory, synthesis, and processing methods for obtaining them. Topics include polymer synthesis, elastomers, thermoplastics, thermoset materials, design and molding processes. Ceramics: inorganic glasses and composites, materials production and principle inorganic chemistry.
MSAE E3156x-E3157y Design project
3 pts. Members of the faculty.
Prerequisite: senior standing. May be repeated
with the permission of the undergraduate adviser.
E3156: A design problem in materials science or
metallurgical engineering selected jointly by the
student and a professor in the department. The
project requires research by the student, directed
reading, and regular conferences with the profes-
sor in charge. E3157: Completion of the research,
directed reading, and conferences, culminating in
a written report and an oral presentation to the
department.

MSAE E3900x and y Undergraduate research
in materials science
0 to 4 pts. Members of the faculty.
This course may be repeated for credit, but no
more than 6 points may be counted toward the
satisfaction of the B.S. degree requirements.
Candidates for the B.S. degree may conduct an
investigation in materials science or carry out a
special project under the supervision of the staff.
Credit for the course is contingent upon the sub-
mission of an acceptable thesis or final report.

MSAE E4090x Nanotechnology
Lect. 3. 3 pts. Offered in alternate years.
Prerequisites: APPE E3100 and MSAE E3103 or
their equivalents with instructor’s permission. The
science and engineering of creating materials,
functional structures and devices on the nanometer
element. Carbon nanotubes, nanocrystals, quantum
dots, size-dependent properties, self-assembly,
nanostructured materials. Devices and applications,
nanofabrication. Molecular engineering, bionano-
technology. Imaging and manipulating at the atomic
scale. Nanotechnology in society and industry.

MSAE E4101x Structural analysis of materials
Lect. 3. 3 pts. Professor Chan.
Prerequisite or corequisite: MSAE E3103 or
the instructor’s permission. Geometry of crystals,
basic diffraction theory. X-ray diffraction. Techniques and
theory of electron microscopy. Analysis of crystal
structures and orientations. Microstructure charac-
terization and analysis of crystalline defects.

MSAE E4132y Fundamentals of polymers and
ceramics
Prerequisite: MSAE E3103 or the instructor’s per-
mission. The science and engineering of polymer,
ceramic, and composite inorganic materials.
Fundamental aspects of structure, processing,
and properties. Polymers: classification, synthe-
sis, elastomers, thermoplastics, thermosets.
Ceramics: crystal structure, morphology, classi-
fication, oxides, nitrides, carbides, silicates.
Electrical, mechanical, thermal, and optical prop-
erties. Common and advanced technological
applications, electrical/optical devices, catalytic
and environmental applications.

MSAE E4202y Thermodynamics and reactions
in solids
Lect. 3. 3 pts. Professor im.
Prerequisite: the instructor’s permission. Free
energy of phases, the relationship between phase
diagrams and metastability. Thermodynamics of
surfaces and interfaces, effect of particle size on
phase equilibria, Gibbs adsorption of solute at
interfaces, grain boundaries, surface energy.
Nucleation and growth, spinodal decomposition
of phases. Diffusion in metals, intermetallic com-
pounds and ionic crystals. Diffusion along interfaces.

MSAE E4206x Electronic and magnetic
properties of solids
Lect. 3. 3 pts. Professor Bailey.
Prerequisites: PHYS C1401, C1402, and C1403,
or the equivalent. A survey course on the elec-
tronic and magnetic properties of materials, ori-
ented toward materials for solid-state devices.
Dielectric and magnetic properties, ferroelectrics
and ferromagnets. Conductivity and superconduc-
tivity. Electronic band theory of solids: classifica-
tion of metals, insulators, and semiconductors.
Materials in devices: examples from semiconduc-
tor lasers, cellular telephones, integrated circuits,
and magnetic storage devices. Topics from
physics are introduced as necessary.

MSAE E4207y Lattice vibrations and crystal
defects
Lect. 3. 3 pts. Professor Chan.
An introductory course in topics of solid state
physics other than electronics and magnetic prop-
erties. Elastic waves in solids. Phonons and lat-
tice vibrations. Brillouin zones. Thermal properties
of solids. Defects, such as point defects in metals,
ionic crystals, semiconductors, and ceramics.

MSAE E4215y Mechanical behavior of
materials
Lect. 3. 3 pts. Professor Noyan.
Prerequisite: MSAE E3103. Recommended
preparation: a course in mechanics of materials.
Review of states of stress and strain and their
relations in elastic, plastic, and viscous materials.
Dislocation and plastic deformation concepts introduced
to explain work hardening, various materials-
strengthening mechanisms, ductility, and tough-
ness. Macroscopic and microstructural aspects of
brittle and ductile fracture mechanics, creep and
fatigue phenomena. Case studies used through-
out, including flow and fracture of structural alloys,
polymers, hybrid materials, composite materials,
ceramics, and electronic materials devices. Materials
reliability and fracture prevention emphasized.

MSAE E4250x Ceramics and composites
Lect. 3. 3 pts. Offered in alternate years.
Professor Guha.
Prerequisites or corequisites: MSAE E3142 and
MSAE E3104, or the instructor’s permission.
The science and engineering of ceramic and
composite inorganic materials, including oxides,
nitrides, carbides, silicates, and complex materi-
als. Structure, composition, and classification.
Preparation: synthesis and processing of ceram-
ics; modern techniques; crystal growth and reac-
tion kinetics. The properties of ceramics and
composites: structure-property relations; electric-
al, mechanical, thermal, and optical properties.
Common and advanced technological applica-
tions of ceramics and composites: industrial
utilization, electrical/optical devices, catalytic
and environmental applications.

MSAE E4301x and y Materials science
laboratory
1 to 3 pts. Instructor to be announced.
Prerequisite: the instructor’s permission. Materials
science laboratory work conducted as to fulfill
particular needs of special students.

MSAE E4900x and y Special topics in
materials science and engineering
Lect. 3. 3 pts. Instructors to be announced.
Prerequisite: The instructor’s permission. This
course may be repeated for credit. Topics and
instructors change from year to year. For
advanced undergraduate students and graduate
students in engineering, physical sciences, and
other fields.

MSAE E6020y Electronic ceramics
Lect. 3. 3 pts. Offered in alternate years.
Structure and bonding of ceramics and glasses.
Point defects and diffusion. Electronic and ionic
conduction. Dielectric, ferroelectric, magnetic,
and optical ceramics.

MSAE E6081x Solid state physics, I
Lect. 3. 3 pts. Professor Pinczuk.
Prerequisite: APPE E3100 or the equivalent.
Knowledge of statistical physics on the level of
MSAE E3111 or PHYS G4023 is strongly recom-
pended. Crystal structure; reciprocal lattices;
classification of solids; lattice dynamics; anhar-
monic effects in crystals; stress and strain; classical
electron models of metals; and periodic, nearly
periodic, and more advanced analysis of electron
band structure.

MSAE E6082y Solid state physics, II
Lect. 3. 3 pts. Professor Aleiner.
Prerequisite: MSAE E6081x or the instructor’s
permission. Semiclassical and quantum mechan-
ical electron dynamics and conduction; dielectric
properties of insulators; semiconductors; defects;
magnetism; superconductivity; low-dimensional
structures; and soft matter.

MSAE E6091y Magnetism and magnetic
materials
Lect. 3. 3 pts. Offered in alternate years.
Instructor to be announced.
Prerequisite: MSAE E4206, APPE E6081, or the
equivalent. Types of magnetism. Band theory of
ferromagnetism. Magnetic metals, insulators, and
semiconductors. Magnetic nanostructures: ultra-
thin films, superlattices, and particles. Surface
magnetism and spectroscopies. High-speed
magnetization dynamics. Spin electronics.
MSAE E6120x Grain boundaries and interfaces
Lect: 3.3 pts. Offered in alternate years.
Prerequisite: the instructor’s permission.
Suggested background: basic knowledge of materials science, dislocations, and point defects.
The course gives an overview of the classic approaches in studying grain boundaries. Topics include boundary geometry and structure, boundary interactions with crystal defects, boundaries as short-circuit diffusion paths, applications of boundary concepts to interfaces, and roles of grain boundaries in material properties and in kinetic phenomena in polycrystalline materials.

MSAE E6220x Crystal physics
Lect: 3.3 pts. Offered in alternate years.
Prerequisite: MSAE E4206 or the instructor’s permission.
The course develops the idea of a tensor and applies it to stress and, together with considerations of crystal symmetry, to the study of the physical constants of crystals, such as diamagnetic and paramagnetic susceptibility, dielectric constants, thermal expansivity, piezoelectric constants, and others. The physical properties are also studied against the background material of MSAE E4206.

MSAE E6221x Introduction to dislocation theory
Lect: 3.3 pts. Offered in alternate years.
Prerequisite: MSAE E4215 or a course in theory of elasticity, or the instructor’s permission. Point and line imperfections. Theory of dislocations. Relation between imperfections and structure-sensitive properties.

MSAE E6225y Techniques in x-ray and neutron diffraction
Lect: 3.3 pts. Offered in alternate years.
Prerequisite: MSAE E4101. Crystal symmetry, diffraction, reciprocal space and Ewald sphere construction, radiation sources, analytical representation of diffraction peaks, diffraction line broadening, Fourier analysis of peak shape, texture analysis, diffraction analysis of stress and strain, diffraction analysis of order-disorder thermal diffuse scattering, small angle scattering, instrumentation in diffraction experiments, error analysis.

MSAE E6229x Energy and particle beam processing of materials
Prerequisite: MSAE E4202 or the instructor’s permission. Laser-, electron-, and ion-beam modification of materials to achieve unique microstructures and metastable phases for electronic and structural applications. Fundamentals of energy deposition and heat flow during laser- and electron-beam irradiation. Atomic displacement processes in ion-irradiated materials. Beam-induced microstructural evolution, crystallization, surface alloying, rapid solidification, and metastable phase formation. Review of current industrial applications.

MSAE E6230y Kinetics of phase transformations
Lect: 3.3 pts. Offered in alternate years.
Prerequisite: MSAE E4202 or the instructor’s permission. Principles of nonequilibrium thermodynamics; stochastic equations; nucleation, growth, and coarsening reactions in solids; spinodal decomposition; eutectic and eutectoid transformations.

MSAE E6251y Thin films and layers
Lect: 3.3 pts. Professor Chan.
Vacuum basics, deposition methods, nucleation and growth, conditions for epitaxy, relation between microstructure and deposition conditions, stress, adhesion, interconnects, and electromigration.

MSAE E6273x and y, and s Materials science reports
0 to 6 pts. Members of the faculty.
Formal written reports and conferences with the appropriate member of the faculty on a subject of special interest to the student but not covered in the other course offerings.

MSAE E8235x and y Selected topics in materials science
Lect: 3.3 pts. Instructor to be announced.
This course may be repeated for credit. Selected topics in materials science. Topics and instructors change from year to year. For students in engineering, physical sciences, biological sciences, and related fields.

MSAE E8236y Anelastic relaxations in crystals
Lect: 3.3 pts. Offered in alternate years.
Prerequisite: the instructor’s permission. Formal theory of anelastic relaxation phenomena. Detailed study of the mechanisms of anelasticity and internal friction in crystals, including the role of point defects, dislocations, grain boundaries, electron-phonon interactions, and ferromagnetic domain effects.

MSAE E9000x and y Materials science and engineering colloquium
0 pts. Professor Im.
Speakers from industry are invited to speak on the recent impact of materials science and engineering innovations.

MSAE E9259x-E9260y Research topics in materials science and metallurgical engineering
Lect: 1.1 pt. Members of the faculty.
Discussion of a group of technical papers related to a topic of current research interest.

MSAE E9301x and y, and s Doctoral research instruction
3, 6, 9, or 12 pts. Members of the faculty.
A candidate for the Eng.Sc.D. degree must register for 12 points of doctoral research instruction. Registration in MSAE E9800 may not be used to satisfy the minimum residence requirement for the degree.

MSAE E9900x and y, and s Doctoral dissertation
0 pts. Members of the faculty.
A candidate for the doctorate may be required to register for this course every term after the course work has been completed, and until the dissertation has been accepted.

Courses in other programs relevant to materials science and engineering:
CHEE E4050: Principles of industrial electrochemistry
CHEE E4201: Engineering applications of electrochemistry
CHEE E4252: Introduction to surface and colloid chemistry
CHEE E4530: Corrosion of metals
CHEN E4620: Introduction to polymer science
CHEN E4630: Polymer laboratory
CIEN E4212: Structural assessment
CIEN E4332: Finite element analysis, I
CHEN E3110: Transport phenomena, I: theory and methodology of rate phenomena
EAEE E4011: Industrial ecology of manufacturing
EAEE E4160: Solid and hazardous waste management
EAEE E4900: Applied transport and chemical rate phenomena
EAEE E6228: Theory of flotation
ENME E3113: Mechanics of solids
ENME E5315: Theory of elasticity
Mechanical engineering is a diverse subject that derives its breadth from the need to design and manufacture everything from small individual parts/devices (e.g., micro-scale sensors, inkjet printer nozzles) to large systems (e.g., spacecraft and machine tools). The role of a mechanical engineer is to take a product from an idea to the marketplace. In order to accomplish this, a broad range of skills are needed. The particular skills in which the mechanical engineer acquires deeper knowledge are the ability to understand the forces and the thermal environment that a product, its parts, or its subsystems will encounter; design them for functionality, aesthetics, and the ability to withstand the forces and the thermal environment they will be subjected to; determine the best way to manufacture them and ensure they will operate without failure. Perhaps the one skill that is the mechanical engineer’s exclusive domain is the ability to analyze and design objects and systems with motion.

Since these skills are required for virtually everything that is made, mechanical engineering is perhaps the broadest and most diverse of engineering disciplines. Hence mechanical engineers play a central role in such industries as automotive (from the car chassis to its every subsystem—engine, transmission, sensors); aerospace (airplanes, aircraft engines, control systems for airplanes and spacecraft); biotechnology (implants, prosthetic devices, fluidic systems for pharmaceutical industries); computers and electronics (disk drives, printers, cooling systems, semiconductor tools); microelectromechanical systems, or MEMS (sensors, actuators, micro power generation); energy conversion (gas turbines, wind turbines, solar energy, fuel cells); environmental control (HVAC, air-conditioning, refrigeration, compressors); automation (robots, data/image acquisition, recognition, and control); manufacturing (machining, machine tools, prototyping, microfabrication).

To put it simply, mechanical engineering deals with anything that moves, including the human body, a very complex machine. Mechanical engineers learn about materials, solid and fluid mechanics, thermodynamics, heat transfer, control, instrumentation, design, and manufacturing to realize/understand mechanical systems. Specialized mechanical engineering subjects include biomechanics, cartilage tissue engineering, energy conversion, laser-assisted materials processing, combustion, MEMS, microfluidic devices, fracture mechanics, nanomechanics, mechanisms, micro-power generation, tribology (friction and wear), and vibrations. The American Society of Mechanical Engineers (ASME) currently lists thirty-six technical divisions, from advanced energy systems and aerospace engineering to solid waste engineering and textile engineering.

The breadth of the mechanical engineering discipline allows students a variety of career options beyond some of the industries listed above. Regardless of the particular future path they envision for themselves after they graduate, their education would have provided them with the creative thinking that allows them to design an exciting product or system, the analytical tools to achieve their design goals, the ability to meet several sometimes conflicting con-
straints, and the teamwork needed to design, market, and produce a system. These skills also prove to be valuable in other endeavors and can launch a career in medicine, law, consulting, management, banking, finance, and so on.

For those interested in applied scientific and mathematical aspects of the discipline, graduate study in mechanical engineering can lead to a career of research and teaching.

**Current Research Activities**

Current research activities in the Department of Mechanical Engineering are in the areas of controls and robotics, energy and micropower generation, fluid mechanics, heat/mass transfer, mechanics of materials, manufacturing, material processing, MEMS, nanotechnology, and orthopedic biomechanics.

**Biomechanics and Mechanics of Materials.** Some of the current research in biomechanics is concerned with the application of continuum theories of mixtures to problems of electromechanical behavior of soft biological tissues, contact mechanics, lubrication of diarthrodial joints, and cartilage tissue engineering. (Ateshian)

In the area of the mechanics of materials, research is performed to better understand material constitutive behavior at the micro- and mesoscale levels. This work is experimental, theoretical, and computational in nature. The ultimate goal is to formulate constitutive relationships that are based on physical concepts rather than phenomenology, as in the case of plasticity power-law hardening. In addition, the role that the constitutive relations play in the fracture and failure of materials is emphasized. (Kysar)

**Control, Design, and Manufacturing.** Control research emphasizes iterative learning control (ILC) and repetitive control (RC). ILC creates controllers that learn from previous experience performing a specific command, such as robots on an assembly line, aiming for high-precision mechanical motions. RC learns to cancel repetitive disturbances, such as precision motion through gearing, machining, satellite precision pointing, particle accelerators, etc. Time optimal control of robots is being studied for increased productivity on assembly lines through dynamic motion planning. Research is also being conducted on improved system identification, making mathematical models from input-output data. The results can be the starting point for designing controllers, but they are also studied as a means of assessing damage in civil engineering structures from earthquake data. (Longman)

Robotics and mechanism synthesis research focuses on the analysis of kinematic relationship, optimization, and design of linkages and spatial mechanisms, and the development of novel robotic mechanical architectures. These new robotic architectures include parallel robots, hybrid robots, snakelike robots, and flexible and flexure-based robots. The theoretical aspects of this research include applications of line geometry tools and screw theory for analysis and synthesis of robotic devices, applications of actuation redundancy and kinematic redundancy for stiffness control, and applications of algebraic geometry methods for robot synthesis. The applied aspects of this research include task-based design and construction of new devices/robots for robotic medical assistance in the surgical arena. (Simaan)

In the area of advanced manufacturing processes and systems, current research concentrates on laser materials processing. Investigations are being carried out in laser micromachining; laser forming of sheet metal; microscale laser shock-peening, material processing using improved laser-beam quality. Both numerical and experimental work is conducted using state-of-the-art equipment, instruments, and computing facilities. Close ties with industry have been established for collaborative efforts. (Yao)

**Energy, Fluid Mechanics, and Heat/Mass Transfer.** In the area of energy, one effort addresses the design of flow/mass transport systems for the extraction of carbon dioxide from air. Another effort addresses the development of distributed sensors for use in micrositing and performance evaluation of energy and environmental systems. The design and testing of components and systems for micropower generation is part of the thermofluids effort as well as part of the MEMS effort. (Modi)

In the area of fluid mechanics, study of low-Reynolds-number chaotic flows is being conducted both experimentally and numerically, and the interactions with molecular diffusion and inertia are presently being investigated. Other
areas of investigation include the fluid mechanics of inkjet printing, drop on demand, the suppression of satellite droplets, shock wave propagation, and remediation in high-frequency printing systems. (Attinger, Modi)

In the area of microscale transport phenomena, current research is focused on understanding the transport through interfaces, as well as the dynamics of interfaces. For instance, an oscillating microbubble creates a microflow pattern able to attract biological cells. High-speed visualization is used together with innovative laser measurement techniques to measure the fluid flow and temperature field with a very high resolution. (Attinger)

MEMS and Nanotechnology. In these areas, research activities focus on power generation systems, nanostructures for photonics, fuel cells and photovoltaics, and microfabricated adaptive cooling skin and sensors for flow, shear, and wind speed. Basic research in fluid dynamics and heat/mass transfer phenomena at small scales also support these activities. (Attinger, Hone, Lin, Modi, Wong)

Research in the area of nanotechnology focuses on nanomaterials such as nanotubes and nanowires and their applications, especially in nanoelectromechanical systems (NEMS). A laboratory is available for the synthesis of carbon nanotubes and semiconductor nanowires using chemical vapor deposition (CVD) techniques and to build devices using electron-beam lithography and various etching techniques. This effort will seek to optimize the fabrication, readout, and sensitivity of these devices for numerous applications, such as sensitive detection of mass, charge, and magnetic resonance. (Hone, Wong, Modi)

Research in the area of optical nanotechnology focuses on devices smaller than the wavelength of light, for example, in photonic crystal nanomaterials and NEMS devices. A strong research group with facilities in optical (including ultrafast) characterization, device nanofabrication, and full numerical intensive simulations is available. Current efforts include silicon nanophotonics, quantum dot interactions, negative refraction, dramatically enhanced nonlinearities, and integrated optics. This effort seeks to advance our understanding of nanoscale optical physics, enabled now by our ability to manufacture, design, and engineer precise subwavelength nanostructures, with derived applications in high-sensitivity sensors, high-bandwidth data communications, and biomolecular sciences. Major ongoing collaborations across national laboratories, industrial research centers, and multiuniversities support this research. (Wong)

In the area of microscale power generation, efforts are dedicated to build a micromotor using acoustic energy amplified by a microbubble. (Attinger)

Research in BioMEMS aims to design and create MEMS and micro/nanofluidic systems to control the motion and measure the dynamic behavior of biomolecules in solution. Current efforts involve modeling and understanding the physics of micro/nano devices and systems, exploiting polymer structures to enable micro/nano fluidic manipulation, and integrating MEMS sensors with microfluidics for measuring physical properties of biomolecules. (Lin)

Biological Engineering and Biotechnology. Active areas of research in the musculoskeletal biomechanics laboratory include theoretical and experimental analysis of articular cartilage mechanics; theoretical and experimental analysis of cartilage lubrication, cartilage tissue engineering, and bioreactor design; growth and remodeling of biological tissues; cell mechanics; and mixture theory for biological tissues with experiments and computational analysis (Ateşhian).

The Hone group is involved in a number of projects that employ the tools of micro- and nano-fabrication toward the study of biological systems. With collaborators in biology and applied physics, the group has developed techniques to fabricate metal patterns on the molecular scale (below 10 nanometers) and attach biomolecules to create biofunctionalized nanoarrays. The group is currently using these arrays to study molecular recognition, cell spreading, and protein crystallization. Professor Hone is a co-PI of the NIH-funded Nanotechnology Center for Mechanics in Regenerative Medicine, which seeks to understand and modify at the nanoscale force- and geometry-sensing pathways in health and disease. The Hone group fabricates many of the tools used by the center to measure and apply force on a cellular level (Hone).

Microelectromechanical systems (MEMS) are being exploited to enable and facilitate the characterization and manipulation of biomolecules. MEMS technology allows biomolecules to be studied in well-controlled micro/nanoenvironments of miniaturized, integrated devices, and may enable novel biomedical investigations not attainable by conventional techniques. The research interests center on the development of MEMS devices and systems for label-free manipulation and interrogation of biomolecules. Current research efforts primarily involve microfluidic devices that exploit specific and reversible, stimulus-dependent binding between biomolecules and receptor molecules to enable selective purification, concentration, and label-free detection of nucleic acid, protein, and small molecule analytes; miniaturized instruments for label-free characterization of thermodynamic and other physical properties of biomolecules; and subcutaneously implantable MEMS affinity biosensors for continuous monitoring of glucose and other metabolites (Lin).

The advanced robotics and mechatronics application lab (ARMA) is focused on surgical intervention using novel robotic architectures. Examples of these architectures include flexible snake-like robots, parallel robots, and cooperative robotic systems. The current research activity is focused on providing safer and deeper interaction with the anatomy using minimally invasive approaches, surgery through natural orifices, surgical task planning based on dexterity and performance measures, and manipulation of flexible organs. The ongoing funded research projects include NIH-funded grants on designing next-generation robotic slaves for incisionless surgical intervention (surgery through natural opening); minimally invasive surgery for the throat and upper airways; image-guided insertable robotic platforms for less invasive surgery (surgery that is carried out using a single incision in the abdomen); and robotic assistance for
developed, including Fisher’s linear discriminant preprocessing with neural net, training, multiclass cell detection with customization. Image processing and a support vector machine with improved pattern recognition techniques are employed in which individual cells selected on the basis of optically detectable multiple features at critical time points in dynamic processes can be rapidly and robotically micromanipulated into reaction chambers to permit amplified DNA synthesis and subsequent array analysis. Customized image processing and pattern recognition techniques are developed, including Fisher’s linear discriminant preprocessing with neural net, a support vector machine with improved training, multiclass cell detection with error correcting output coding, and kernel principal component analysis (Yao).

Facilities for Teaching and Research
The undergraduate laboratories, occupying an area of approximately 6,000 square feet of floor space, are the site of experiments ranging in complexity from basic instrumentation and fundamental exercises to advanced experiments in such diverse areas as automatic controls, heat transfer, fluid mechanics, stress analysis, vibrations, microcomputer-based data acquisition, and control of mechanical systems.

Equipment includes microcomputers and microprocessors, analog-to-digital and digital-to-analog converters, lasers and optics for holography and interferometry, a laser-Doppler velocimetry system, a Schlieren system, dynamic strain indicators, a servo-hydraulic material testing machine, a photoelastic testing machine, an internal combustion engine, a dynamometer, subsonic and supersonic wind tunnels, a cryogenic apparatus, computer numerically controlled vertical machine centers (VMC), a coordinate measurement machine (CMM), and a rapid prototyping system. A CNC wire electrical discharge machine (EDM) is also available for the use of specialized projects for students with prior arrangement. The undergraduate laboratory also houses experimental setups for the understanding and performance evaluation of a complete small steam power generation system, a heat exchanger, and a compressor. Part of the undergraduate laboratory is a staffed machine shop with machining tools such as standard vertical milling machines, engine and bench lathes, programmable surface grinder, bandsaw, drill press, tool grinders, and a power hacksaw. The shop also has a Tig welder.

A mechatronics laboratory affords the opportunity for hands-on experience with microcomputer-embedded control of electromechanical systems. Facilities for the construction and testing of analog and digital electronic circuits aid the students in learning the basic components of the microcomputer architecture. The laboratory is divided into work centers for two-person student laboratory teams. Each work center is equipped with several power supplies (for low-power electronics and higher power control), a function generator, a multimeter, a prototype board for building circuits, a microcomputer circuit board (which includes the microcomputer and peripheral components), a microcomputer programmer, and a personal computer that contains a data acquisition board. The data acquisition system serves as an oscilloscope, additional function generator, and spectrum analyzer for the student team. The computer also contains a complete microcomputer software development system, including editor, assembler, simulator, debugger, and C compiler. The laboratory is also equipped with a portable oscilloscope, an EPROM eraser (to erase microcomputer programs from the erasable chips), a logic probe, and an analog filter bank that the student teams share, as well as a stock of analog and digital electronic components.

The department maintains a modern computer-aided design laboratory equipped with fifteen Silicon Graphics workstations and software tools for design, CAD, FEM, and CFD.

The research facilities are located within individual or group research laboratories in the department, and these facilities are being continually upgraded. To view the current research capabilities please visit the various laboratories within the research section of the department Web site (www.me.columbia.edu/pages/research/index.html). The students and staff of the department can, by prior arrangement, use much of the equipment in these research facilities. Through their participation in the NSF-MRSEC center, the faculty also have access to shared instrumentation and the clean room located in the Shapiro Center for Engineering and Physical Science Research. Columbia University’s extensive library system has superb scientific and technical collections (www.columbia.edu/cu/lweb). E-mail and computing services are maintained by Columbia University Information Technology (CUIT) (www.columbia.edu/cuit).

UNDERGRADUATE PROGRAM
The objectives of the undergraduate program in mechanical engineering are as follows:
The Mechanical Engineering Department at Columbia University is dedicated to graduating mechanical engineers who:
1. practice mechanical engineering in a broad range of industries;
2. pursue advanced education, research
and development, and other creative and innovative efforts in science, engineering, and technology, as well as other professional careers;
3. conduct themselves in a responsible, professional, and ethical manner;
4. participate as leaders in their fields of expertise and in activities that support service and economic development nationally and throughout the world.

Highly qualified students are permitted to pursue an honors course consisting of independent study under the guidance of a member of the faculty.

Upon graduation the student may wish to enter employment in industry or government, or continue with graduate study. Alternatively, training in mechanical engineering may be viewed as a basis for a career in business, patent law, medicine, or management. Thus, the department’s undergraduate program provides a sound foundation for a variety of professional endeavors.

The program in mechanical engineering leading to the B.S. degree is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

Of the 21 points of elective content in the third and fourth years, at least 12 points of technical courses, including at least 6 points from the Department of Mechanical Engineering, must be taken. Those remaining points of electives are intended primarily as an opportunity to complete the four-year, 27-point non-technical requirement. Consistent with professional accreditation standards, courses in engineering science and courses in design must have a combined credit of 48 points. Students should see their advisers for details.
Fundamentals of Engineering (FE) Exam

The FE exam is a state licensing exam and the first step toward becoming a Professional Engineer (P.E.). P.E. licensure is important for engineers to obtain—it shows a demonstrated commitment to professionalism and an established record of abilities that will help a job candidate stand out in the field. Ideally, the FE exam should be taken in the senior year while the technical material learned while pursuing the undergraduate degree is still fresh in the student’s mind. In addition to the FE exam, achieving P.E. licensure requires some years of experience and a second examination, which tests knowledge gained in engineering practice. For more information, please see www.columbia.edu/cu/mechanical/misc-pages/FE_Exam.html.

The Mechanical Engineering Department strongly encourages all seniors to take this exam and offers a review course covering material relevant to the exam, including a practice exam to simulate the testing experience. The FE exam is given in the fall and spring of each year. The review course is offered in the spring semester, concluding before the spring exam.

GRADUATE PROGRAMS

Master of Science Degree Program

The program leading to the Master of Science degree in mechanical engineering requires completion of a minimum of 30 points of approved course work consisting of no fewer than ten courses. A thesis based on either experimental, computational, or analytical research is optional and may be counted in lieu of up to 6 points of course work. In general, attainment of the degree requires one academic year of full-time study, although it may also be undertaken on a part-time basis over a correspondingly longer period. A minimum grade point average of 2.5 is required for graduation.

The student’s program of study is developed in consultation with a faculty adviser to reflect the student’s special interests. Typical choices include such subjects as mechanics of solids and fluids, thermodynamics, heat transfer, manufacturing engineering, robotics, kinematics, dynamics and vibrations, controls, and power generation. Nevertheless, the following guidelines must be adhered to:

1. The sequence of courses selected must not be haphazard, but rather show a clearly discernible specialty.
2. All courses must be at the graduate level, i.e., numbered 4000 or higher, with some 6000-level courses included.
3. Every program must contain at least one course in mathematics (APMA or MATH designators) or their equivalent, covering material beyond what the student has taken previously. It should appear early in the sequence in order to serve as a basis for the technical course work.

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### MECHANICAL ENGINEERING: THIRD AND FOURTH YEARS

#### STANDARD TRACK

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<td>MECE E3028 (3) Lab II</td>
<td>MECE E3038 (3) Lab III</td>
<td>MECE E3410 (4) Engineering design</td>
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<td>MECE E3408 (3) Graphics &amp; design</td>
<td>MECE E3409 (3) CAD</td>
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<td>MECE E3601 (3) Classical control sys.</td>
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<td>MECE E4608 (3) Manufacturing proc.</td>
<td>ELEN E1201 (3.5) Intro. elec. eng.</td>
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<td>ENME E3113 (3) Mechanics of solids</td>
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#### TECHNICAL ELECTIVES

- 6 points

#### NONTECH ELECTIVES

- 3 points

#### TOTAL POINTS

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1. Strongly recommended to be taken in Semester III or IV.
2. Students must complete 128 points to graduate.
4. Out-of-department study is encouraged, but at least five courses should be in mechanical engineering.

**Doctoral/Professional Degree Programs**

Students who wish to continue their studies beyond the master’s degree level but are unwilling to embark upon a program of research of the kind required for a doctoral degree may continue in a program leading to the professional degree of Mechanical Engineer (MECE). The course of study consists of a minimum of 30 points of work beyond the master’s degree, combining courses of an analytical nature with those emphasizing the applied aspects of one or more fields in mechanical engineering. For the professional degree, the student must have a grade point average of 3.0 or better.

When a student becomes a prospective candidate for either the Doctor of Engineering Science (Eng.Sc.D.) or Doctor of Philosophy (Ph.D.) degree, a faculty adviser is assigned whose task is to help choose a program of courses, provide general advice on academic matters, and monitor academic performance.

The doctoral candidate is expected to attain a level of mastery in some area of mechanical engineering, and must therefore choose a field and concentrate in it by taking the most advanced courses offered. This choice of specialty is normally made by the time the student has completed 30 points of credit beyond the bachelor’s degree, at which time a complete course program is prepared and submitted to the departmental doctoral committee for approval. The student must maintain a grade point average of 3.2 or better in graduate courses.

The department requires the prospective candidate to pass a qualifying examination. Given once a year, in

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### MECHANICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS

#### EARLY DECISION TRACK

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<td>C1401 (3)</td>
<td>C1402 (3)</td>
<td>C1403 (3)&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>(three tracks, choose one)</td>
<td>C1601 (3.5)</td>
<td>C1602 (3.5)</td>
<td>C2601 (3.5)&lt;sup&gt;3&lt;/sup&gt;</td>
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<tr>
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<td>C2801 (4.5)</td>
<td>C2802 (4.5)</td>
<td></td>
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<tr>
<td><strong>CHEMISTRY</strong></td>
<td>one semester lecture (3–4)</td>
<td>Lab C1500 (3)&lt;sup&gt;2&lt;/sup&gt;</td>
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<td></td>
<td>C1403 or C1404 or C3045 or C1604</td>
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<tr>
<td><strong>ENGLISH COMPOSITION</strong></td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
<td>C1010 (3)</td>
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<tr>
<td>(three tracks, choose one)</td>
<td>Z1003 (0)</td>
<td>Z1003 (0)</td>
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<td>Z2006 (0)</td>
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<tr>
<td><strong>REQUIRED NONTECHNICAL COURSES</strong></td>
<td></td>
<td>HUMA C1001, COCI C1101, or Major Cultures (3–4)</td>
<td>HUMA C1002, COCI C1102, or Major Cultures (3–4)</td>
<td></td>
</tr>
<tr>
<td><strong>REQUIRED TECHNICAL COURSES</strong></td>
<td>(3) Student’s choice, see list of first- and second-year technical electives (professional-level courses; see page 12)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>ENME E3105 (4) Mechanics</td>
<td>ENME E3113 (3) Mechanics of solids</td>
<td>ELEN E1201 (3.5) Intro. elec. eng.</td>
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<td></td>
<td>Computer language: W1003 (3) or W1004 (3) any semester</td>
<td></td>
<td>EME E3408 (3) Graphics &amp; design</td>
<td></td>
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<tr>
<td><strong>COMPUTER SCIENCE</strong></td>
<td>C1001 (1)</td>
<td>C1002 (1)</td>
<td></td>
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<tr>
<td><strong>PHYSICAL EDUCATION</strong></td>
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<tr>
<td><strong>GATEWAY LAB</strong></td>
<td>E1102 (4) either semester</td>
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</tbody>
</table>

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1. ELEN E1201 (see semester IV) satisfies this requirement. However, MECE E1001 is strongly encouraged.

2. May substitute Physics Lab C1493 (3), C1494 (3), or W3081 (2).

3. May substitute BIOL W2001 or higher.
January, it is usually taken after the student has completed 30 points beyond the bachelor's degree. However, it may not be delayed past the next examination given after completion of 45 points. The examination comprises a written test, given in two parts over two days, in which questions may be selected from a broad set in all areas of mechanical engineering and applied mathematics, devised to test the candidate's ability to think creatively. There is also an oral examination based on some research project the student has undertaken. A candidate who fails the examination may be permitted to repeat it once in the following year.

After passing the qualifying examination, the student chooses a faculty member in the pertinent area of specialization who then serves as the research adviser. This adviser helps select a research problem and supervises the research, writing, and defense of the dissertation. Once a specific problem has been identified and a tentative plan for the research prepared, the student submits a research proposal and presents it to a faculty committee. The committee considers whether the proposed problem is suitable for doctoral research, whether the plan of attack is well formulated and appropriate to the problem, and whether the student is adequately prepared. It may approve the plan without reservation, or it may recommend modifications or additions. This is the last formal requirement until the dissertation is submitted for approval.

All doctoral students are required to successfully complete four semesters of the mechanical engineering seminar MECE E9500.

COURSES IN MECHANICAL ENGINEERING

MECE E1001x Mechanical engineering: micromachines to jumbo jets
Lect: 3 pts. Professor Ateshian.
This introductory course explores the role of mechanical engineering in developing many of the fundamental technological advances on which today's society depends. Students will be exposed to several mature and emerging technologies through a series of case studies. Topics include airplanes, automobiles, robots, and modern manufacturing methods, as well as the emerging fields of micro-electro-mechanical machines (MEMS) and nanotechnology. The physical concepts that govern the operation of these technologies will be developed from basic principles and then applied in simple design problems. Students will also be exposed to state-of-the-art innovations in each case study.

MECE E3018 Mechanical engineering laboratory, I
Lect: 1. Lab: 5. 3 pts. Professor Kysar.
Experiments in instrumentation and measurement: optical, pressure, fluid flow, temperature, stress, and electricity; viscometry, cantilever beam, digital data acquisition. Probability theory: distribution, functions of random variables, tests of significance, correlation, ANOVA, linear regression. A lab fee of $50 is collected.

MECE E3018 and y Mechanical engineering laboratory, II
Lect: 1. Lab: 5. 3 pts. Professor Wong.
Selected intermediate experiments in power and energy conversion, heat transfer, and solid and fluid mechanics. A lab fee of $50 is collected.

MECE E3038 y Mechanical engineering laboratory, III
Lect: 1. Lab: 5. 3 pts. Professor Basalo.
Selected advanced experiments in fluid mechanics, heat transfer, and energy conversion. A lab fee of $50 is collected.
MECE E3100x Introduction to mechanics of fluids
Lect: 3. 3 pts. Professor Attinger.

ENME-MECE E3105x and y Mechanics
Lect: 4. 4 pts. Professor Hone.
Prerequisites: PHYS C1401, and MATH V1101-V1102 and V1201. Elements of statics, dynamics of a particle, systems of particles, and rigid bodies.

MECE E3301x Thermodynamics
Lect: 3. 3 pts. Professor Modi.
Classical thermodynamics. Basic properties and concepts, thermodynamic properties of pure substances, equation of state, work, heat, the first and second laws for flow and nonflow processes, energy equations, entropy, and irreversibility. Introduction to power and refrigeration cycles.

MECE E3311y Heat transfer
Lect: 3. 3 pts. Professor Narayanaswamy.

MECE E3401x Mechanics of machines
Lect: 3. 3 pts. Professor Lin.
Prerequisites: ENME E3105 and MECE E3408. Introduction to mechanisms and machines, analytical and graphical synthesis of mechanism, displacement analysis, velocity analysis, acceleration analysis of linkages, dynamics of mechanism, cam design, gear and gear trains, and computer-aided mechanism design.

MECE E3408y Computer graphics and design
Lect: 3. 3 pts. Instructor to be announced.
Introduction to drafting, engineering graphics, computer graphics, solid modeling, and mechanical engineering design. Interactive computer graphics and numerical methods applied to the solution of mechanical engineering design problems. A laboratory fee of $175 is collected.

MECE E3409x Computer-aided design
Lect: 3. 3 pts. Professor Simaan.
Concepts and applications of modern computer-aided design software for formulating and solving mechanical engineering design problems. Problems will be drawn from statics, kinematics, solid modeling, stress analysis, thermal analysis, fluid mechanics, and design optimization.

MECE E3410y Engineering design
Lect: 4. 4 pts. Professor Stolfi.
Prerequisite: senior standing. Elements of the design process: concept formulation, systems synthesis, design analysis optimization. Selection and execution of a project involving the design of an actual engineering device or system. A laboratory fee of $125 is collected. 

MECE E3411y Fundamentals of engineering
Lect: 3. 1 pt. Professor Stolfi.
Prerequisite: Senior Standing. Review of core courses in mechanical engineering, including mechanics, strength of materials, fluid mechanics, thermodynamics, heat transfer, materials and processing, control, and mechanical design and analysis. Review of additional topics, including engineering economics and ethics in engineering. The course culminates with a comprehensive examination, similar to the Fundamentals of Engineering examination.

EEME E3601x Classical control systems
Lect: 3. 3 pts. Professor Longman.
Prerequisite: MATH E1210. Analysis and design of feedback control systems. Transfer functions; block diagrams; proportional, rate, and integral controllers; hardware, implementation. Routh stability criterion, root locus, Bode and Nyquist plots, compensation techniques.

MECE E3900x-E3901y Honors tutorial in engineering
Individual study; may be selected after the first term of the junior year by students maintaining a 3.2 grade-point average. Normally not to be taken in a student’s final semester. Course format may vary from individual tutorial to laboratory work to seminar instruction under faculty supervision. Written application must be made prior to registration outlining proposed study program. Projects requiring machine-shop use must be approved by the laboratory supervisor.

MECE E3996 x and y Projects in mechanical engineering
1 to 3 pts. Professors Ateshian, Attinger, Hone, Kysar, Liao, Lin, Longman, Modi, Narayanaswamy, Simaan, Stolfi, Wong, and Yao. Hours to be arranged by faculty supervising the work.
Prerequisites: Approval by faculty member who agrees to supervise the work. Normally not to be taken in a student’s final semester. Independent project involving theoretical, computational, experimental or engineering design work. May be repeated, but no more than 3 points may be counted toward degree requirements. Projects requiring machine-shop use must be approved by the laboratory supervisor.

MECE E4058x and y Mechatronics and embedded microcomputer control
Lect: 3. 3 pts. Professor Stolfi.
Prerequisite: ELEN E1201. Recommended: ELEN E3000. Enrollment limited to 12 students. Mechatronics is the application of electronics and microcomputers to control mechanical systems. Systems explored include on/off systems, solenoids, stepper motors, dc motors, thermal systems, magnetic levitation. Use of analog and digital electronics and various sensors for control. Programming microcomputers in Assembly and C. Lab required; a lab fee of $75 is collected.

MECE E4100y Mechanics of fluids
Lect: 3. 3 pts. Professor Lin.
Prerequisite: MECE E3100 or the equivalent. Fluid dynamics and analyses for mechanical engineering and aerospace applications: boundary layers and lubrication, stability and turbulence, and compressible flow. Turbomachinery as well as additional selected topics.

MECE E4211y Energy: sources and conversion
Lect: 3. 3 pts. Professor Modi.
Prerequisite: MECE E3301. Energy sources such as oil, gas, coal, gas hydrates, hydrogen, solar, and wind. Energy conversion systems for electrical power generation, automobiles, propulsion, and refrigeration. Engines, steam and gas turbines, wind turbines; devices such as fuel cells, thermoelectric converters, and photovoltaic cells. Specialized topics may include carbon-dioxide sequestration, cogeneration, hybrid vehicles, and energy storage devices.

MECE E4212x Microelectromechanical systems
Lect: 1.5. Lab: 3. 3 pts. Professor Wong.
Enrollment limited to 16 students. MEMS markets and applications; scaling laws; silicon as a mechanical material; sensors and actuators; micromechanical analysis and design; substrate (bulk) and surface micromachining; computer-aided design; packaging; testing and characterization; microfluidics.

MECE E4213y Biomicroelectromechanical systems (BioMEMS): design, fabrication, and analysis
Lect: 3. 3 pts. Professor Lin.
Prerequisites: MECE E3100 and MECE E3311, or a course in transport phenomena, or the instructor’s permission. Silicon and polymer micro/nanofabrication techniques; hydrodynamic microluidic control; electrokinetic microluidic control; microluidic separation and detection; sample preparation; micro bioreactors and temperature control; implantable MEMS including sensors, actuators, and drug delivery devices.

MECE E4302y Advanced thermodynamics
Prerequisite: MECE E3301. Advanced classical thermodynamics. Availability, irreversibility, generalized behavior, equations of state for nonideal gases, mixtures and solutions, phase and chemical behavior, combustion. Thermodynamic properties of ideal gases. Applications to automotive and aircraft engines, refrigeration and air conditioning, and biological systems.
MECE E4304x Turbomachinery  
This course will introduce you to the basics of theory, design, selection, and applications of turbomachinery. Turbomachines are widely used in many engineering applications, such as energy conversion, power plants, air-conditioning, pumping, refrigeration, and vehicle engines, as there are pumps, blowers, compressors, gas turbines, jet engines, wind turbines, etc. Applications are drawn from energy conversion technologies, HVAC, and propulsion. The course will provide you with a basic understanding of the different kinds of turbomachines.

IEME E4310x The manufacturing enterprise  
Lect. 3.3pts. Professor Weinig.  
The strategies and technologies of global manufacturing and service enterprises. Connections between the needs of a global enterprise, the technology and methodology needed for manufacturing and product development, and strategic planning as currently practiced in industry.

MECE E4312y Solar thermal engineering  
Lect: 3.3 pts. Professor Attinger.  

MECE E4314y Energy dynamics of green buildings  
Lect: 3.3 pts. Professors Naraghi and McGough.  

MECE E4400x and y Computer laboratory access  
0 pts. Professor Ateshian.  
Sign up for this class to obtain a computer account and access to the Department of Mechanical Engineering Computer Laboratory. Open to mechanical engineering graduate students only. A laboratory fee of $50 is collected.

MECE E4404x Lubrication theory and design  
Lect: 3.3 pts. Professor Castelli.  

MECE E4431 Space vehicle dynamics and control  
Prerequisite: ENME-CE E3105; ENME E4202 recommended. Space vehicle dynamics and control, rocket equations, satellite orbits, initial trajectory designs from earth to other planets, satellite attitude dynamics, gravity gradient stabilization of satellites, spin-stabilized satellites, dual-spin satellites, satellite attitude control, modeling, dynamics, and control of large flexible spacecraft.

MECE E4501y Geometrical modeling  
Lect: 3.3 pts. Professor Srinivasan.  
Prerequisite: COMS W1005. Relationship between 3-D geometry and CAD/CAM; representations of solids; geometry as the basis of analysis, design, and manufacturing; constructive solid geometry and the CSG tree; octree representation and applications; surface representations and intersections; boundary representation and boundary evaluation; applied computational geometry; analysis of geometrical algorithms and associated data structures; applications of geometrical modeling in vision and robotics.
MECE E4502x Computational geometry for CAD/CAM
Lect: 3. 3 pts. Professor Srinivasan.
Prerequisite: FORTRAN or PASCAL. Analysis of geometric problems and the design of efficient methodologies to obtain solutions to these problems. Algorithms to be studied include geometric searching, convex hulls, triangulations, Voronoi diagrams, intersections, hidden surfaces. Emphasis will be on practical aspects of these algorithms, and on applications of the solutions in computer-aided product design and manufacturing.

EEME E601y Digital control systems
Lect: 3. 3 pts. Professor Longman.
Prerequisite: MECE E3601 or ELEN E3202.

MECE E4602y Introduction to robotics
Lect: 3. 3 pts. Professor Jazar
Overview of robot applications and capabilities. Linear algebra, kinematics, statics, and dynamics of robot manipulators. Survey of sensor technology; force, proximity, vision, compliant manipulators. Motion planning and artificial intelligence; manipulator programming requirements and languages.

MECE E4604x Product design for manufacturability
Lect: 3. 3 pts. Professor Walker.
Prerequisites: Manufacturing process, computer graphics, engineering design, mechanical design. General review of product development process; market analysis and product system design; principles of design for manufacturing; strategy for material selection and manufacturing process choice; component design for machining; casting; molding; sheet metal working and inspection; general assembly processes; product design for manual assembly; design for robotic and automatic assembly; case studies of product design and improvement.

MECE E4608y Manufacturing processes
Lect: 3. 3 pts. Professor Yao.
Prerequisite: ENME E3113 or the equivalent. Processes and materials of manufacture: metal cutting, forming, stamping, forging, welding, powder metallurgy; classification and fabricating characteristics of metals and composites; plastics, adhesives.

MECE E4609y Computer-aided manufacturing
Lect: 3. 3 pts. Professor Walker.
Prerequisites: An introductory course on manufacturing processes, and knowledge of computer-aided design and mechanical design or the instructor’s permission. Computer-aided design, free-form surface modeling, tooling and fixturing, computer numeric control, raid prototyping, process engineering, fixed and programmable automation, industrial robotics.

MECE E4610x Advanced manufacturing processes
Lect: 3. 3 pts. Professor Yao.
Prerequisites: Introductory courses on manufacturing processes and heat transfer, knowledge of engineering materials, or the instructor’s permission. Principles of nontraditional manufacturing, nontraditional transport and media. Emphasis on laser assisted materials processing, laser material interactions with applications to laser material removal, forming, and surface modification. Introduction to electrochemical machining, electrical discharge machining, and abrasive water jet machining.

MEBM E4702x Advanced musculoskeletal biomechanics
Lect: 3. 3 pts. Professor Guo.
Advanced analysis and modeling of the musculoskeletal system. Topics include advanced concepts of 3-D segmental kinematics, musculoskeletal dynamics, experimental measurements of joints kinematics and anatomy, modeling of muscles and locomotion, multibody joint modeling, introduction to musculoskeletal surgical simulations.

MECE E4990x and y Special topics in mechanical engineering
Lect: 3. 3 pts. Instructor to be announced.
Prerequisite: The instructor’s permission. Topics and instructors change from year to year. For advanced undergraduate students and graduate students in engineering, physical sciences, and other fields.

MECE E4999x and y (sect. 001) Curricular practical training
Lect: 3. 3 pts. Professor Yao
Prerequisite: Instructor’s written approval. Only for ME graduate students who need relevant intern or fieldwork experience as part of their program of study as determined by the instructor. Written application must be made prior to registration outlining proposed study program. Final reports required. This course may not be taken for pass/fail credit or audited. International students must also consult with the International Students and Scholars Office.

MECE E6100x Advanced mechanics of fluids
Lect: 3. 3 pts. Professor Panides.
Prerequisites: MATH E1210 and MECE E3100. Eulerian and Lagrangian descriptions of motion. Stress and strain rate tensors, vorticity, integral and differential equations of mass, momentum, and energy conservation. Potential flow.

MECE E6102y Computational heat transfer and fluid flow

MECE E6104y Case studies in computational fluid dynamics
Lect: 3. 3 pts. Professor Panides.
Prerequisites: APMA E4200 and MECE E6100. Corequisites: APMA E4300 and MECE E4400. Hands-on case studies in computational fluid dynamics, including steady and transient flows, heat and mass transfer, turbulence, compressible flow, and multiphase flow. Identifying assumptions, computational domain selection, model creation and setup, boundary conditions, choice of convergence criteria, visualization and interpretation of computed results. Taught in the Mechanical Engineering Computer Laboratory with computational fluid dynamics software.

MECE E6105y Transport phenomena in the presence of interfaces
Lect: 3. 3 pts. Professor Attinger.
Prerequisites: MECE E3301 and MECE E3311; MECE E4100 or the equivalent, or the instructor’s permission; CHEE E4252 or the equivalent, or the instructor’s permission. Surface energy and capillary phenomena. Wetting and spreading of liquids, wetting line pinning and hysteresis, dynamics of wetting. Surfactants. Bubbles: nucleation, stability, dynamics, microstreaming. Jets and drops: generation, dynamics, stability, and impact with surfaces. Measurement of transport phenomena involving interfaces. Interfacial transport phenomena involving thermal, chemical, or electrical gradients. Applications in microfluidic systems.

MECE E6200y Turbulence

MEBM E6310x–E6311y Mixture theories for biological tissues, I and II
Prerequisites: MECE E6422 and APMA E4200, or the equivalent. Development of governing equations for mixtures with solid matrix, interstitial fluid, and ion constituents. Formulation of consti-
tutive models for biological tissues. Linear and nonlinear models of fibrillar and viscoelastic porous matrices. Solutions to special problems, such as confined and unconfined compression, permeation, indentation and contact, and swelling experiments.

**MECE E6313x Advanced heat transfer**

Lect: 3.3 pts. Professor Naraghi.
Prerequisite: MECE E3311. Corequisite: MECE E6100. Application of analytical techniques to the solution of multi-dimensional steady and transient problems in heat conduction and convection. Lumped, integral, and differential formulations. Topics include use of sources and sinks, laminar/turbulent forced convection, and natural convection in internal and external geometries.

**MECE E6400y Advanced machine dynamics**

Prerequisite: MECE E3401. Review of classical dynamics, including Lagrange’s equations. Analysis of dynamic response of high-speed machine elements and systems, including mass-spring systems, cam-follower systems, and gearing; shock isolation; introduction to gyrodynamics.

**MECE E6422x-E6423x or y Introduction to the theory of elasticity, I and II**

Lect: 3.3 pts. E6422x: Professor Lai; E6423y: Instructor to be announced.

**EEME E6601x Introduction to control theory**

Lect: 3.3 pts. Professor Longman.
Prerequisite: MATH E1210. A graduate-level introduction to classical and modern feedback control that does not presume an undergraduate background in control. Scalar and matrix differential equation models and solutions in terms of state transition matrices. Transfer functions and transfer function matrices, block diagram manipulations, closed loop response. Proportional, rate, and integral controllers, and compensators. Design by root locus and frequency response. Controllability and observability. Luenberger observers, pole placement, and linear-quadratic cost controllers.

**EEME E6602y Modern control theory**

Prerequisite: EEME E6601 or EEME 4601 or ELEN E6201, or the instructor’s permission. Singular value decomposition. ARX model and state space model system identification. Recursive least squares filters and Kalman filters. LQR, H∞, linear robust control, predictive control. Learning control, repetitive control, adaptive control. Liapunov and Popov stability. Nonlinear adaptive control, nonlinear robust control, sliding mode control.

**EEME E6610y Optimal control theory**

Lect: 3.3 pts. Professor Longman.
Prerequisite: EEME E6601 or EEME 4601 or the instructor’s permission. Covers topics in calculus of variations, Pontryagin maximum principle, quadratic cost optimal control, predictive control,
dynamic programming for optimal control, Kalman filtering, numerical methods for solution. Some applications discussed include minimum energy subway operation (our solution saved 11 percent in tests on the Flushing Line, and the method was adopted by the Transit Authority, saving many millions of dollars per year), minimum time robot optimal control allowing one to run assembly lines faster for increased productivity.

MECE E6614y Advanced topics in robotics and mechanism synthesis
Lect. 3. 3 pts. Professor Simaan.
Prerequisite: APMA E2101, APMA E3101, MECE E4602, or the instructor’s permission.
Recommended: MECE E3401. Kinematic modeling methods for serial, parallel, redundant, wire-actuated robots and multifingered hands with discussion of open research problems. Introduction to screw theory and line geometry tools for kinematics. Applications of homotopy continuation methods and symbolic-numerical methods for direct kinematics of parallel robots and synthesis of mechanisms. Course uses textbook materials as well as a collection of recent research papers.

EEME E6620x or y Applied signal recognition and classification
Prerequisite: MATH E1210, APMA E3101, knowledge of a programming language, or the instructor’s permission. Applied recognition and classification of signals using a selection of tools borrowed from different disciplines. Applications include human biometrics, imaging, geophysics, machinery, electronics, networking, languages, communications, and finance. Practical algorithms are covered in signal generation; modeling; feature extraction; metrics for comparison and classification; parameter estimation; supervised, unsupervised, and hierarchical clustering and learning; optimization; scaling and alignment; signals as codes emitted from natural sources; information; and extremely large-scale search techniques.

MECE E6700y Carbon nanotube science and technology
Prerequisite: Knowledge of introductory solid state physics (e.g. PHYS G4018, APPH E6081, or MSAE E3103) or the instructor’s permission. Basic science of solid state systems. Crystal structure, electronic and phonon bandstructures of nanotubes. Synthesis of nanotubes and other nanomaterials. Experimental determination of nanotube structures and techniques for nanoscale imaging. Theory and measurement of mechanical, thermal, and electronic properties of nanotubes and nanomaterials. Nanofabrication and nano-electronic devices. Applications of nanotubes.

MEEE E6710x or y Nanofabrication laboratory
Lecture: 1. Lab: 5. 3 pts. Professor Hone.
Prerequisite: ELEN E6945 or the instructor’s permission. Laboratory in techniques for fabrication at the nanometer scale. Electron-beam lithography, Plasma etching and 3D nanofabrication. Thin film deposition. Self-assembly and ‘bottom-up’ nanofabrication. Fabrication of and testing of complete nanodevices. A lab fee of $300 is required.

MECE E8020x-E8021y Master’s thesis
Interpretive research in graduate areas in mechanical engineering and engineering science.

MECE E8100y Advanced topics in fluid mechanics
Prerequisite: MECE E6100. This course may be taken more than once, since its content has minimal overlap between consecutive years. Selected topics from viscous flow, turbulence, compressible flow, rarefied gas dynamics, computational methods, and dynamical systems theory, non-Newtonian fluids, etc.

EEME E8601y Advanced topics in control theory
Prerequisites: EEME E6601 and E4601, or the instructor’s permission. This course may be taken more than once, since the content changes from year to year, electing different topics from control theory such as learning and repetitive control, adaptive control, system identification, Kalman filtering, etc.

MECE E9000x and E9001y, and s Graduate research and study
Theoretical or experimental study or research in graduate areas in mechanical engineering and engineering science.

MECE E9500x or y Graduate seminar
0 pts. Instructor to be announced.
Pass/fail only. All doctoral students are required to successfully complete four semesters of the mechanical engineering seminar MECE 9500.

MECE E9800x and y, and s Doctoral research instruction
A candidate for the Eng.Sc.D. degree in mechanical engineering must register for 12 points of doctoral research instruction. Registration in MECE E9800 may not be used to satisfy the minimum residence requirement for the degree.

MECE E9900x and y Doctoral dissertation
A candidate for the doctorate may be required to register for this course every term after his/her course work has been completed and until the dissertation has been accepted.
Undergraduate Minors
Undergraduate minors are designed to allow engineering and applied science students to study, to a limited extent, a discipline other than their major. Besides engineering minors offered by SEAS departments, new liberal arts minors are available.

A minor requires at least 15 points of credit, and no more than one course can be taken outside of Columbia or met through AP or IB credit. This includes courses taken through study abroad. In SEAS departments with more than one major program, a minor in the second program may be permitted, if approved by the department.

No substitutions or changes of any kind from the approved minors are permitted (see lists below). No appeal for changes will be granted. Please note that the same courses may not be used to satisfy the requirements of more than one minor. No courses taken for pass/fail may be counted for a minor. Minimum GPA for the minor is 2.0. Departments outside SEAS have no responsibility for non-engineering minors offered by SEAS.

For a student to receive credit for a course taken while studying abroad, the department offering the minor must approve the course in writing, ahead of the student’s study abroad.

Students must expect a course load that is heavier than usual. In addition, unforeseen course scheduling changes, problems, and conflicts may occur. The School cannot guarantee a satisfactory completion of the minor.

### Minor in American Studies
Minimum: 18 points.

1. AMST W101: Introduction to American studies 3.0 points
2-6. Five additional courses in American Studies with no distribution or seminar requirements. Students are encouraged to take seminars.

### Minor in Applied Mathematics
Prospective students should consult the first- and second-year requirements for applied mathematics majors to ensure that prerequisites for the applied mathematics minor are satisfied in the first two years.

Course work counting toward the applied mathematics minor may not include advanced placement credits. Any substitutions for the courses listed below require the approval of the applied mathematics program adviser.

1. APMA E3101: Linear algebra 3.0 points
   or
   MATH V2010: Linear algebra 3.0 points
2. APMA E3102: Partial differential equations 3.0 points
   or
   MATH V3028: Partial differential equations 3.0 points
3-5. Any three of the following courses:
   APMA E4300: Introduction to numerical methods 3.0 points
   APMA E4204: Functions of a complex variable 3.0 points
   APMA E4101: Introduction to: dynamical systems 3.0 points
   MATH V2500: Analysis and optimization 3.0 points

SIEO W4105: Probability 3.0 points
STAT W4107: Statistical inference 3.0 points
or any other course designated APMA, MATH, STAT, IEOR, or COMS that is approved by the applied mathematics program adviser.

### Minor in Applied Physics
Prospective students should consult the first- and second-year requirements for applied physics majors to ensure that prerequisites for the applied physics minor are satisfied in the first two years.

Course work counting toward the applied physics minor may not include advanced placement credits.

1. APPH E4901: Seminar: problems in applied physics 1.0 points
2. PHYS W3003: Mechanics 3.0 points
3. APPH E3100: Introduction to quantum mechanics 3.0 points
4. APPH E3300: Applied electromagnetism 3.0 points
5. MSAE E3111: Thermodynamics, kinetic theory, and statistical mechanics 3.0 points
6. Two of the following courses:
   APPH E4010: Introduction to nuclear science 3.0 points
   APPH E4100: Quantum physics of matter 3.0 points
   APPH E4110: Modern optics 3.0 points
   APPH E4112: Laser physics 3.0 points
   APPH E4300: Applied electrodynamics 3.0 points
   APPH E4301: Introduction to plasma physics 3.0 points
MINOR IN ARCHITECTURE

1. Studio course (choose one from the following):
   - ARCH V1020: Introduction to architectural design and visual culture 4.0 points
   - ARCH V3101: Arch representation: abstraction 4.0 points
   - ARCH V3103: Arch representation: perception 4.0 points

2–4. History/theory courses (see Note below)

5. Elective course (must be either an approved second design studio or an additional history/theory course)

Note: A list of the approved history/theory courses is available at the departmental office each semester.

MINOR IN ART HISTORY

1–7. Seven courses in art history, covering four of the following areas: (a) ancient Mediterranean, (b) medieval Europe, (c) Renaissance and baroque, (d) 18th, 19th, and 20th century, and (e) non-Western.

MINOR IN BIOMEDICAL ENGINEERING

The Biomedical Engineering program offers a minor in one of three tracks: (I) cellular engineering, (II) biomechanics, and (III) biomedical imaging. Students who wish to get a minor in biomedical engineering should take the core BME requirements, as well as select courses from one of the three tracks, described below. Participation in the minor is subject to the approval of the major program adviser.

Core BME Requirements

1. BIOL C2005: Introduction to molecular and cellular biology 4.0 points
2. BMEN E4001: Quantitative physiology, I or BMEN E4002: Quantitative physiology, II 3.0 points

I. CELL AND TISSUE ENGINEERING TRACK

3. CHEN E3010: Chemical engineering thermodynamics 4.0 points
4. BMEN E4501: Tissue engineering, I 3.0 points
5. BMEN E4502: Tissue engineering, II 3.0 points
6. One from the following courses:
   - BMEN E3320: Fluid biomechanics 3.0 points
   - BMEN E4570: Science and engineering of body fluids, I 3.0 points
   - BMEN E4580: Science and engineering of body fluids, II 3.0 points
   - ECBM E3060: Introduction to genomic information 3.0 points
   - CHEN E3110: Transport phenomena, I 4.0 points
   - CHEN E4700: Principles of genomic technologies 3.0 points
   - MSAE E3103: Elements of materials science 3.0 points

II. BIOMECHANICS TRACK

3. BMEN E4300: Solid biomechanics 3.0 points
4. BMEN E3320: Fluid biomechanics 3.0 points
5-6. Two from the following course groups:
   - ENME E3113: Mechanics of solids 3.0 points
   - ENME E3161: Fluid mechanics or 4.0 points

III. BIOMEDICAL IMAGING TRACK

3. BMEN E4894: Biomedical imaging 3.0 points
4–5. Two from the following courses:
   - BMEN E4430: Principles of magnetic resonance imaging 3.0 points
   - BMEN E4400: Wavelet applications in biomedical image and signal processing 3.0 points
   - BMEN E4898: Photonics 3.0 points
   - BMEN E4410: Ultrasound in diagnostic imaging 3.0 points
   - BMEN E4420: Biomedical signal processing and signal modeling 3.0 points

6. One from the following courses:
   - ELEN E3801: Signals and systems 3.0 points
   - ELEN E4810: Digital signal processing 3.0 points
   - ELEN E4830: Digital image processing 3.0 points

MINOR IN CHEMICAL ENGINEERING

Of the six courses required, at least three must have the CHEN, CHEE, or CHAP designator:

1. CHEN E3100: Material and energy balances 4.0 points
2. CHEN E3010: Principles of chemical engineering thermodynamics 4.0 points
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4. CHEN E4230:
Reaction kinetics and reactor design 3.0 points

5–6. Two courses from the following:
Any 3000-level or higher BMCH, CHEN, CHAP, or CHEE course

AMPA E3101:
Applied mathematics, I 3.0 points
AMPA E3102:
Applied mathematics, II 3.0 points
BMEN E3320:
Fluid biomechanics 3.0 points
BMEN E4001:
Quantitative physiology, I 3.0 points
BMEN E4002:
Quantitative physiology, II 3.0 points
ELEN E3201:
Circuit analysis 3.5 points
ELEN E3301:
Electronic circuits 3.0 points
SIEO W3600: Introduction to probability and statistics 4.0 points
IEOR W4105: Probability 3.0 points
IEOR W4106:
Stochastic models 3.0 points
MSAE E3103: Elements of materials science 3.0 points
MSAE E3142: Processing of ceramics and polymers 3.0 points

ENME E3161:
Fluid mechanics 4.0 points
ENME E3114: Experimental mechanics of materials 4.0 points
MECE E3414: Advanced strength of materials 3.0 points
CIEN E4332:
Finite element analysis, I 3.0 points
CIEN E3125:
Structural design 3.0 points
CIEN E4241: Geotechnical engineering fundamentals 3.0 points
CIIE E3250:
Hydrostatics engineering 3.0 points
CIIE E4163: Environmental engineering: wastewater 3.0 points
CIEN E3129: Project management for construction 3.0 points
CIEN E4131: Principles of construction techniques 3.0 points

Note: At least three of the courses must be courses that are not required in the student’s major.

MINOR IN COMPUTER SCIENCE
Students who pass the Computer Science Advanced Placement Exam, either A or AB, with a 4 or 5 will receive 3 points and exemption from COMS W1004. An additional elective is to be recommended but not required. Participation in the minor is subject to the approval of the major program adviser. For further information, please see the QuickGuide at www.cs.columbia.edu/education/undergrad/seasguide.

1. COMS W1004: Introduction to computer science and programming in Java 3.0 points
2. COMS W1007: Object-oriented programming and design 3.0 points
   or
   COMS W1009: Introduction to computer science (honors) 3.0 points
3. COMS W3133:
   Data structures in C 3.0 points
   or
   COMS W3134:
   Data structures in Java 3.0 points
   or
   COMS W3137: Data structures and algorithms 4.0 points
   or
   COMS W3139: Data structures and algorithms (honors) 4.0 points
4. COMS W3157:
   Advanced programming 4.0 points
5. COMS W3203:
   Discrete mathematics 3.0 points
6. COMS W3261:
   Computer science theory 3.0 points
7. CSEE W3827: Fundamentals of computer systems 3.0 points
   or
   a 4000-level COMS technical elective

MINOR IN DANCE
The SEAS dance minor consists of five 3-point courses. Please note that no performance/choreography courses below count toward the nontech requirement for SEAS students.

1–2. Two from the following history/criticism courses:
DNCE BC 2565/2566: History of dance, I and/or II
DNCE BC2570: Dance in New York City
DNCE BC 3000: From the page to the dance stage
DNCE BC 3570: Latin American and Caribbean dance: identities in motion
DNCE BC 3577: Performing the political
DNCE BC 3574: Seminar on contemporary choreographers and their works
DNCE BC 3576: Dance criticism
DNCE BC 3578: Traditions of African-American dance

3–4. Two from the following performance/choreography courses:
DNCE BC 2555: Ensemble repertory: modern
DNCE BC 3571: Solo repertory
DNCE BC 2563: Dance composition: form
DNCE BC 2564: Dance composition: content
DNCE BC 3565: Group forms: advanced dance composition
DNCE BC 2567: Music for dance
DNCE BC 2557: Evolution of classic Spanish dance
DNCE BC 2580: Tap as an American art form
DNCE BC 3590: Rehearsal and performance in dance

5. One elective.

MINOR IN ENVIRONMENTAL ENGINEERING
1–3. Three courses from the following:
EAEE E3101: Earth resource production systems 3.0 points
EAEE E3103: Energy, minerals and materials systems 3.0 points

SEAS 2008–2009
MINOR IN EAST ASIAN STUDIES

1-5. Any two of the survey courses on Chinese, Japanese, or Korean civilization (ASCE V2359, V2361, V2363), plus three elective courses dealing with East Asia. The elective courses may be taken in departments outside of East Asian Languages and Cultures. The minor does not include a language requirement. However, one semester of an East Asian language class may be used to fulfill one of the three electives, as long as at least two semesters of that language have been taken. Placement exams may not be used in place of these courses.

MINOR IN ECONOMICS

1. ECON W1105: Principles of economics
2. ECON W3211: Intermediate microeconomics
3. ECON W3213: Intermediate macroeconomics
4. ECON W3412: Introduction to econometrics

Note: W1105 is a prerequisite for W3211, W3213, and W3412. Students must have completed Calculus I before taking W3213, Calculus III before taking W3211, and one of the introductory statistics courses (see list) before taking W3412.

5-6. Two electives from the following:

- ECON W3257: Corporate finance
- ECON W3260: Financial economics
- ECON W3265: Economics of money and banking
- ECON W4020: Economics of uncertainty and information
- ECON W4080: Globalization, incomes and inequality
- ECON W4211: Advanced microeconomics
- ECON W4213: Advanced macroeconomics
- ECON W4228: Urban economics
- ECON W4235: Historical foundations of modern economics
- ECON W4251: Industrial organization
- ECON W4301: Economic growth and development
- ECON W4321: Economic development
- ECON W4329: Economics of sustainable development
- ECON W4345: World economic problems
- ECON W4370: Political economy
- ECON W4400: Labor economics
- ECON W4412: Advanced econometrics
- ECON W4415: Game theory
- ECON W4438: Economics of race in the United States

Note: Electives may be taken only after the completion of both ECON W3211 and W3213, with the exception of ENGI E2261 and ECON W2257, which may be taken after completion of ECON W1105. Some of the elective courses listed above have additional prerequisites. Courses may be taken only after the completion of all prerequisites. Please see the Columbia College bulletin for course descriptions and complete lists of prerequisites.

7. One from the following statistics courses (or sequence of courses):

- STAT W1211: Introduction to statistics
- SIEO W3600: Introduction to probability and statistics
- IEOR W3658: Probability and
- STAT W3659 or W4107: Statistical inference
- SIEO W4150: Introduction to probability and statistics

Notes:

- The statistics course must be finished before taking ECON W3412, and it is recommended that students take ECON W3412 in the semester following the statistics course.
- Generally speaking, course work done as part of the economics minor counts toward fulfilling the School’s nontechnical requirements. However, ECON W3412: Introduction to econometrics and ENGI E2261: Introduction to accounting and finance, which may be used as courses in the minor program, may not be applied toward satisfaction of the nontechnical course requirements; refer to the nontechnical section on pages 10–12 of this bulletin for further details.
- Students with AP credit for economics and an exemption for ECON W1105 may use the credit toward the minor.
• Transfer or study abroad credits may not be applied to fulfill the requirements of the economics minor.

MINOR IN ELECTRICAL ENGINEERING
1. ELEN E1201: Introduction to electrical engineering 3.5 points
   (May be replaced by a similar course or roughly equivalent experience)
2. ELEN E3201: Circuit analysis 3.5 points
3. CSEE W3827: Fundamentals of computer systems 3.0 points
4. ELEN E3081 and ELEN E3082: Electrical engineering labs 2.0 points
5. ELEN E3801: Signals and systems 3.5 points
6. ELEN E3106: Solid-state devices and materials 3.5 points
   or ELEN E3401: Electromagnetics 4.0 points
Note: Not available to computer engineering majors.

MINOR IN ENGINEERING MECHANICS
1. ENME E3105: Mechanics 4.0 points
2. ENME E3113: Mechanics of solids 3.0 points
3. ENME E3161: Fluid mechanics 4.0 points
   or MECE E3100: Mechanics of fluids 3.0 points
4–6. Electives (any two):
   ENME E3106: Dynamics and vibrations 3.0 points
   ENME E3114: Experimental mechanics of materials 4.0 points
   or MECE E3414: Advanced strength of materials 3.0 points
   CIEN E3121: Structural analysis 3.0 points
   ENME E4202: Advanced mechanics 3.0 points
   ENME E4113: Advanced mechanics of solids 3.0 points
   ENME E4114: Mechanics of fracture and fatigue 3.0 points
   ENME E4214: Theory of plates and shells 3.0 points
   ENME E4215: Theory of vibrations 3.0 points
   MECE E3301: Thermodynamics 3.0 points

MINOR IN ENGLISH AND COMPARATIVE LITERATURE
1–5. Any five courses in the English Department with no distribution requirement. No speech courses, only one writing course as above and excluding ENGL C1010, may be taken; total 15 points.

MINOR IN FRENCH
1–2. FREN W3333: Major literary works to 1800 3.0 points
   and FREN W3334: Major literary works since 1800 3.0 points
3–5. Three additional courses in French beyond satisfaction of the language requirement, including one course in French cultural studies.

MINOR IN FRENCH AND FRANCOPHONE STUDIES
Required: 15 points beyond second-year French.
1–2. FREN W3420: Introduction to French and francophone studies, I 3.0 points
   and FREN W3421: Introduction to French and francophone studies, II 3.0 points
3–5. Three additional courses in French beyond satisfaction of the language requirement, including one course in French cultural studies and one in francophone literature.

MINOR IN GREEK OR LATIN
1–4. A minimum of 13 points in the chosen language at the 1200-level or higher.
5. 3 points in ancient history of the appropriate civilization.

MINOR IN HISPANIC STUDIES
1. SPAN W3300: Advanced language through content 3.0 points
2. SPAN W3330: Introduction to Hispanic cultures 3.0 points
3. SPAN W3349: Hispanic cultures, I: Islamic Spain through the colonial period 3.0 points
4. SPAN W3350: Hispanic cultures, II: Enlightenment to the present 3.0 points
5. One additional 3000- or 4000-level elective course in the Department of Spanish and Portuguese
Note: Please see the director of undergraduate studies in the Department of Spanish and Portuguese for more information and to declare the minor.

MINOR IN HISTORY
1–5. Minimum 15 points in the History Department with no distribution or seminar requirements. Transfer or study-abroad credits may not be applied.

MINOR IN INDUSTRIAL ENGINEERING
1. SIEO W3600: Introduction to probability and statistics 4.0 points
2. IEOR E3608: Introduction to mathematical programming 4.0 points
3. IEOR E3402: Production-inventory planning and control 3.0 points
4. IEOR E4003: Industrial economics 3.0 points
5–6. Electives: Two IEOR courses of interest and approved by a faculty adviser.

MINOR IN GERMAN
Required: 15 points beyond second-year German.
1. GERM V3001 or V3002: Advanced German, I or II 3.0 points
2. GERM W3333: Introduction to German literature 3.0 points
3–4. Any two of the period survey courses in German literature and culture, GERM W3442, W3443, W3444, W3445; at least one of these must focus on pre-20th-century culture.
5. One course taken from any 3000/4000 level German or CompLit-German courses taught in German or English.
### MINOR IN MATERIALS SCIENCE AND ENGINEERING

1. MSAE E3103: Elements of materials science 3.0 points

2–3. Two from the following courses:
   - MSAE E3111: Thermodynamics, kinetic theory, and statistical mechanics 3.0 points
   - MSAE E3141: Processing of metals and semiconductors 3.0 points
   - MSAE E3142: Processing of ceramics and polymers 3.0 points
   - MSAE E4090: Nanotechnology 3.0 points
   - MSAE E4101: Structural analysis of materials 3.0 points
   - MSAE E4206: Electronic and magnetic properties of solids 3.0 points
   - MSAE E4215: Mechanical behavior of materials 3.0 points
   - MSAE E4250: Ceramics and composites 3.0 points

4–6. Three from the following courses (other materials-related courses may be acceptable):
   - APPH E4100: Quantum physics of matter 3.0 points
   - CHEE E4050: Industrial and environmental electrochemistry 3.0 points
   - CHEE E4252: Introduction to surface and colloid chemistry 3.0 points
   - CHEE E4530: Corrosion of metals 3.0 points
   - CHEE E4620: Introduction to polymer science 3.0 points
   - CHEN E4630: Polymer laboratory 3.0 points
   - CHEM C3443-C3444: Organic chemistry 3.5 points
   - ELEN E4111: Fundamentals of photonics 3.0 points
   - ELEN E4301: Introduction to semiconductor devices 3.0 points
   - ELEN E4944: Principles of device microfabrication 3.0 points
   - ENME E4113: Advanced mechanics of solids 3.0 points
   - ENME E4114: Mechanics of fracture and fatigue 3.0 points
   - MECE E4608: Manufacturing processes 3.0 points
   - MECE E4701: Introductory biomechanics 3.0 points
   - MECE E3100: Introduction to mechanics of fluids 3.0 points
   - or one of the following:
     - ENME E3161: Fluid mechanics 4.0 points
     - CHEN E3110: Transport phenomena, I 4.0 points
     - EAE E4900: Applied transport and chemical rate phenomena 3.0 points
   - ENME E3105: Mechanics 4.0 points
   - MECE E3301: Thermodynamics 3.0 points
   - or one from the following:
     - CHEN E3010: Principles of chemical engineering thermodynamics 4.0 points
     - MSAE E3111: Thermodynamics, kinetic theory, and statistical mechanics 3.0 points
   - ENME E3113: Mechanics of solids 3.0 points
   - MECE E3408: Computer graphics and design 3.0 points
   - MECE E4311: Heat transfer 3.0 points
   - MECE E4608: Manufacturing processes 3.0 points
   - MECE E3409: Computer-aided design 3.0 points
   - EEME E3601: Classical control systems 3.0 points

5–6. Electives: Two additional mechanical engineering courses from either the above list or the following (not all courses in this list are given every year):
   - MECE E3401: Mechanics of machines 3.0 points
   - MECE E4058: Mechatronics and embedded microcomputer control 3.0 points
   - MECE E4100: Mechanics of fluids 3.0 points
   - MECE E4111: Energy: sources and conversion 3.0 points
   - MECE E4212: Microelectromechanical systems 3.0 points
   - MECE E4302: Advanced thermodynamics 3.0 points
   - MECE E4404: Lubrication theory and design 3.0 points
   - MECE E4501: Geometrical modeling 3.0 points
   - MECE E4502: Computational geometry for CAD/CAM 3.0 points
   - EEE E4601: Digital control systems 3.0 points
   - MECE E4602: Introduction to robotics 3.0 points
   - MECE E4604: Product design for manufacturability 3.0 points
   - MECE E4609: Computer-aided manufacturing 3.0 points
   - MECE E4610: Advanced manufacturing processes 3.0 points

### MINOR IN MECHANICAL ENGINEERING

1–4. Any four courses from the following (equivalent substitution courses require the approval of the mechanical engineering program adviser):
   - SICE E3106: Stochastic models 3.0 points
   - SIEO E3600: Introduction to probability and statistics 4.0 points
   - SIEO E3608: Introduction to mathematical programming 4.0 points
   - SIEO E4404: Simulation 3.0 points

5–6. Electives: Two SIEO courses of interest and approved by a faculty adviser. SIEO E3402: Production-inventory planning and control (3.0 points) is strongly recommended.

Notes:
- Students must successfully place out of MUSI V1002: Fundamentals of Western music (3.0 points).
- Steps 4 and 5 must be completed to fulfill the nontechnical elective requirement for graduation.
- Students are strongly encouraged to take HUMA W1123: Masterpieces of Western music (3.0 points) from the list of nontechnical electives.
MINOR IN PHILOSOPHY
1–5. Any five courses in the Philosophy Department with no distribution requirement; total 15 points. See also the list of exceptions on page 17.

MINOR IN POLITICAL SCIENCE
1–2. Two from the following courses:
   W1201: Introduction to American government and politics 3.0 points
   W1501: Comparative politics: an introduction 3.0 points
   W1601: Introduction to international politics 3.0 points

3–5. Any three courses in the Political Science Department with no distribution requirement; total 9 points.

MINOR IN PSYCHOLOGY
Five courses required, including PSYC W1001 and courses in at least two of the three groups listed below (for example, you could select two courses from Group I and two from Group III along with the required W1001); total 15 points (minimum).
1. PSYC W1001: The science of psychology
2–5. Any four courses from, at a minimum, two of the three groups below:
   I. PERCEPTION AND COGNITION
      Courses numbered in the 2200s, 3200s, or 4200s. Also PSYC W1420, W1480, or W1490.
   II. PSYCHOBIOLOGY AND NEUROSCIENCE
      PSYC W1010: Mind, brain, and behavior 3.0 points
      Courses numbered in the 2400s, 3400s, or 4400s. Also PSYC W1440.
   III. SOCIAL, PERSONALITY, AND ABNORMAL
      Courses numbered in the 2600s, 3600s, or 4600s. Also PSYC W1450 or W1455.

MINOR IN RELIGION
1–5. Five courses (total 15 points), one of which must be at the 2000 level.

MINOR IN SOCIOLOGY
1. SOCI V1202: Sociological imagination 3.0 points
2. SOCI V1205: Evaluation of evidence 3.0 points
3. SOCI V3100: Classical social theory 3.0 points
4–5. Any two 3000- or 4000-level courses offered by the Department of Sociology; total 6 points.

Note: The year’s array of elective courses can be found online in the Columbia College or General Studies bulletin.

MINOR IN STATISTICS
1. STAT W1111 or W1211: Introduction to statistics 3.0 points
2. STAT W2110: Introduction to applied statistics 3.0 points
3. STAT W3105: Introduction to probability or STAT W4105: Probability 3.0 points
4. STAT W3107 or STAT W4107 3.0 points
5. STAT W4315: Linear regression models 3.0 points
6. One of any other 4000-level STAT courses, excluding STAT W4105, W4107, and W3109.

Note: Well-prepared students may substitute W4201 (to be taken after W4315) for W1111 (or W1211) and W2110.

MINOR IN TECHNOLOGICAL ENTREPRENEURSHIP
Minimum: 15 points
1–3. Required courses:
   ENGI E2261: Introduction to accounting and finance 3.0 points
   BUSI W3020: Introduction of marketing and marketing management 3.0 points
   I EOR E4998: Managing technological innovation and entrepreneurship 3.0 points

4–5. Electives (either two courses from list A or one course from list A and one from list B):
   A. Engineering electives (at least one)
      CHEN E4020: Protection of industrial and business property 3.0 points
      CIEN E4136: Entrepreneurship in civil engineering and construction 3.0 points
      COMS W4444: Programming and problem solving 3.0 points
      BMEN E3998: Projects in biomedical engineering (or equivalent) 3.0 points
      IEOR E4550: Entrepreneurial business creation for engineers 3.0 points
      ISME E4310: The manufacturing enterprise 3.0 points
      Either SCNC W3010: Science, technology, and society or URBS V3310: Science and technology in urban environments (but not both) 3.0 points
   B: Other electives (no more than one)
      ECON W4280: Corporate finance 3.0 points
      BUSI W3010: Managing human behavior in the organization 3.0 points
      IEOR W4308: Industrial budgeting and finance control 3.0 points
Interdisciplinary Courses and Courses in Other Divisions of the University
The following courses are designated Engineering because they are not offered by a specific department of the School. Some may be requirements for degree programs, and others may be taken as electives. See your departmental program of study or consult with an adviser for more information.

**ENGI E1102x and y Design fundamentals using advanced computer technologies**
Lect: 4.4 pts. Professor McGourty.
Core requirement for all entering SEAS students. Students learn the basics of engineering design from problem definition to detailed conceptual design. Computer technologies such as advanced three-dimensional graphical and computational applications are applied in the service of authentic community-based design projects, using the state-of-the-art design facility, the Botwinick Multimedia Learning Laboratory. Aligned with the technical components of the design, students develop collaboration, communication, problem solving, and project management skills, as well as a life-long orientation of social responsibility and community service. Lab fee: $225.

**ENGI E2261x Introduction to accounting and finance**
Lect: 3.3 pts. Professor Webster.
Prerequisite: ECON W1105. The concepts and methods underlying the financial statements of business corporations. Attention to problems of asset valuation, income determination, cash flows, and cost and profit behavior in response to changes in the level of business activity. Analysis of selected corporate financial statements, capital structure, and leverage. Strategies and analytical methods for the evaluation of capital projects.

**SCNC W3010x and y Science, technology and society**
Lect: 3.3 pts. Professor McGourty.
Prerequisite: students must have declared their concentration/major. By investigating the scientific and technical evolution and subsequent diffusion of contemporary technological innovations, students learn how science and technology fit into the bigger picture; i.e. how technologies technically develop from concept to diffusion into society, how they work, and how they are bi-directionally related to social forces, cultural values, economic trends, environmental factors, and political influences. An essential part of the course work is participation in a community-based learning project, working with local nonprofit organizations.

**EEHS E3900y History of telecommunications: from the telegraph to the Internet**
Lect: 3.3 pts. Professors Schwartz and Nebeker.
Historical development of telecommunications from the telegraphy of the mid-1800s to the Internet at present. Included are the technologies of telephony, radio, and computer communications. The coverage includes both the technologies themselves and the historical events that shaped, and in turn were shaped by, the technologies. The historical development, both the general context and the particular events concerning communications, is presented chronologically. The social needs that elicited new technologies and the consequences of their adoption are examined. Throughout the course, relevant scientific and engineering principles are explained as needed. These include, among others, the concept and effective use of spectrum, multiplexing to improve capacity, digital coding, and networking principles. There are no prerequisites, and no prior scientific or engineering knowledge is required. SEAS students may not count this course as a technical elective.

**ENGI/CHEN E4020x Safeguarding intellectual and business property**
Lect: 3.3 pts. Professor Pearlman.
Designed for both University engineering students and engineers in industry to provide a broad background in those aspects of the law that are most frequently encountered in a professional engineering career. Topics include patents, protection of know-how, contracts, employer-employee rights, confidential relationships, unfair competition, trademarks, and the like. Principles of law are illustrated by case studies.

**URBS V3310x Science and technology in urban environments**
Lect: 3.3 pts. Professors Cross and McGourty.
Prerequisite: students must have declared their concentration/major. The course examines the role of science and technology in urban settings, using examples from modern cities. It explores how technology shapes towns and cities, and how urban environments—including politics, economics, culture, and the natural environment—have influenced the development, acceptance, and application of technology. An essential part of the course work is participation in a community-based learning project, working with local nonprofit organizations.
This listing of courses has been selected with specific engineering program requirements in mind. For information on these courses and additional courses offered by these departments, please consult the bulletins of Columbia College, the School of Continuing Education, the School of General Studies, and the Graduate School of Arts and Sciences.

**BIOLOGICAL SCIENCES**

**BIOL C2005x Introduction to molecular and cellular biology, I**
Prerequisite: one year of college chemistry, or a strong high school chemistry background. Recommended introductory biology course for biology and related majors and for premed students. Fundamental principles of biochemistry, molecular biology, and genetics.

**BIOL C2006y Introduction to molecular and cellular biology, II**
Prerequisite: ENVB W2001 or BIOL C2005 or the instructor's permission. Recommended second term of biology for biology and related majors and for premed students. Fundamental principles of biochemistry, molecular biology, and genetics.

**BIOL W2501x or y Contemporary biology laboratory**
Lab: 4. 3 pts. C. Hazen.
Each section limited to twenty-four students. Early registration is advised. Students must come to the first day of class to secure their place. Strongly recommended prerequisite or required corequisite: BIOL C2005 or F2401. Laboratory fee: $150.

**BIOC C3501 Biochemistry: structure and metabolism**
Prerequisites: one year of college-level biology and one year of organic chemistry, or the instructor's permission. Biochemistry, organic chemistry, and structural biology. Structure and function of both proteins and small molecules in biological systems. The first half of the course covers protein structure and enzyme kinetics. The second half of the course will focus on the organic chemistry involved in metabolic pathways.

**BUSINESS**

School of Continuing Education
Contact: Lucas Rubin,
303 Lewisohn, 212-854-3771,
lr2008@columbia.edu
Academic adviser: Charissa Asbury,
312 Uris, 212-854-5564,
cda3@columbia.edu

The Graduate School of Business offers several undergraduate courses in business. These courses are offered in cooperation with the School of Continuing Education. A limited number of seats are reserved for IEOR students with approval from the IEOR departmental office. Students planning their programs should know that BUSI W3001 and BUSI W3003 are normally also offered during the summer session.

For current information on course availability and registration procedures, please refer to: www.ce.columbia.edu/bci/courseAvailability.cfm.

**BUSI W3001x and y Introductory finance**
3 pts. R. Mesznik.
Prerequisites: an introductory course in economics and a firm grasp of high school algebra. Prerequisite or corequisite: an introductory accounting course such as ECON W2261. Those without such a background should first take ECON 1105 plus one of the following: MATH 1003, or STAT W1001 or W1111. Mathematics proficiency must be demonstrated through the Mathematics Placement Examination administered during registration. (For information concerning the exam, call 212-854-4097.) How assets are priced in financial markets, where assets are viewed, most generally, as claims to future income streams. Applications to stocks, bonds, entire companies, etc. Notions of the present value of a cash flow, systematic risk, capital structure, and Miller-Modigliani Theory are emphasized. Consideration of leveraged buyouts, mergers, stock repurchases. Introduction to options and futures. Lectures, problems.

**BUSI W3003x and y Corporate finance**
3 pts. C. Asbury.
Prerequisites: one accounting course (ENGI E2261 or the equivalent) and one course in finance (BUSI W3001 or the equivalent). Students with substantial and relevant professional experience in financial institutions may be able to meet the demands of this course without a previous finance course. An exploration of the central concepts of corporate finance for those who already have some basic knowledge of finance and accounting. This case-based course considers project valuation; cost of capital; capital structure; firm valuation; the interplay between financial decisions, strategic consideration, and economic analyses; and the provision and acquisition of funds. These concepts are analyzed in relation to agency problems: market domination, risk profile, and risk resolution; and market efficiency or the lack thereof. The validity of analytic tools is tested on issues such as highly leveraged transactions, hybrid securities, volatility in initial public offerings, mergers and acquisitions, divestitures,
acquisition and control premiums, corporate restructurings, sustainable and unsustainable market inefficiencies, etc.

**BUSI W3008y Options and futures**
3 pts. C. Giannikos.
The evaluation of derivative securities—securities whose value is fundamentally dependent upon the value of some underlying asset. About 80 percent of the course focuses on options, with the remainder focused on futures and forward contracts. For each of these instruments, the goal is to understand how the instrument is priced in a competitive securities market and how it is used to manage portfolio risk and/or to facilitate the execution of complex corporate transactions. These uses are in part illustrated in the context of three case discussions/presentations.

**BUSI W3010x and y Managing human behavior in the organization**
3 pts. R. Kopelman.
An introduction to and overview of major concepts of management and organization theory concentrating on understanding human behavior in organizational contexts, with heavy emphasis on the application of concepts to solve managerial problems. Behavioral issues at the individual, group, and systems levels. Lectures, discussions, case studies, simulations, and small group exercises.

**CHEM C1403x-C1404y General chemistry**
Lect: 3.5 pts. and a 1-hour recitation section. G. Flynn, G. Parkin, S. Brydges, and N. Turro. No special registration through the Chemistry Department is required; only students with scheduling conflicts need report to 318 Havemeyer during registration. Preparation equivalent to one year of high school chemistry is assumed. Students lacking such preparation should plan independent study of chemistry over the summer or take CHEM F0001 before taking C1403. Corequisite: MATH V1101 or the equivalent. Topics include stoichiometry, states of matter, chemical equilibria, acids and bases, chemical thermodynamics, nuclear properties, electronic structures of atoms, periodic properties, chemical bonding, molecular geometry, chemical reactivity, nuclear properties, chemical bonding, molecular geometry, chemical reactivity, nuclear properties, chemical bonding, molecular geometry, chemical reactivity, nuclear properties, chemical bonding, molecular geometry, chemical reactivity. Although C1403 and C1404 are separate courses, students are expected to take the two terms sequentially. The order of presentation of the topics may vary.

**CHEM C1500x or y General chemistry laboratory**
Lab: 3 pts. Instructor to be announced. Prerequisite or corequisite: CHEM C1403. Fee $125. An introduction to basic techniques and practices of modern experimental chemistry, including qualitative procedures and chemical analysis.

**CHEM C1604x Second semester general chemistry**
Lect: 3.5 pts. G. Flynn
Prerequisite: grade of B or better in CHEM C1403 or F1403 or acceptable performance on the Chemistry Advanced Placement exam and/or department placement exam. Corequisite: MATH V1102. Topics include gases (kinetic theory of gases); binary collision model for chemical reactions; chemical kinetics; acid-base equilibria; thermodynamics (thermodynamics I); atomic and molecular structures, chemical kinetics, coordination chemistry, and electrochemistry. Although C1403 and C1404 are separate courses, students are expected to take the two terms sequentially. The order of presentation of the topics may vary.

**CHEM C1500x-C1501y Intensive organic chemistry for first-year students (lecture)**
Lect: 3.5 pts. and a 1-hour recitation section. N. Breslow and J. Leighton.
Prerequisite: grade of 5 on the Advanced Placement Examination given during first-year orientation. Not open to students who have taken other courses in chemistry in college. Premedical students may take CHEM C3045x, C3046y, and C3543 to meet the minimum requirements for admission to medical school. This course covers the same material as CHEM C3443-C3444 but is intended for students who have learned the principles of general chemistry in high school. The level of instruction will be appropriate for those who have not had a college course in general chemistry. Students enrolled in CHEM C3045-C3046 are encouraged to enroll concurrently in CHEM C2507, the intensive general chemistry laboratory course.

**CHEM C3071y Introduction to inorganic chemistry**
Lect: 3 pts. B. Gibney.
Prerequisite: CHEM C3444 (or F3444) or C3046. Principles governing the structure and reactivity of inorganic compounds surveyed from experimental and theoretical viewpoints. Topics include inorganic solids, aqueous and nonaqueous solutions, the chemistry of selected main group elements, transition metal chemistry, metal clusters, metal carbonyls, and organometallic chemistry.

**CHEM C3085x-C3086y Physical and analytical chemistry laboratory**
Lab: 4 pts. L. Avila.
Prerequisite or corequisite: CHEM C3079-C3080. C3085 is prerequisite to C3086. Fee: $105 per term. Techniques of experimental physical chemistry and instrumental analysis, including infrared and ultraviolet spectrophotometry, magnetic resonance, electroanalytical methods, calorimetry, reaction kinetics, hydrodynamic methods, and applications of digital computers to the analysis of experimental data.
Undergraduates in the four-year course of study in the School of Engineering and Applied Science may take courses numbered to 4999 but may enter courses of higher numbers only if:

1. the course is expressly included in the prescribed curriculum or
2. special permission is obtained from the Department of Earth and Environmental Sciences.

CHEM C3086x and y Senior chemistry laboratory
Lab: 4 to 6 pts. The staff.
Prerequisite: the permission of the professor in charge for entrance, and the permission of the departmental representative for aggregate points in excess of 12 or less than 4. Limited registration. Fee: $105 per term. This course may be repeated for credit (see major and concentration requirements). Individual research under the supervision of a member of the staff. Research areas include organic, physical, inorganic, analytical, and biological chemistry.

CHEM C3443x-C3444y Organic chemistry (lecture)
Lect: 3.5 pts. V. Cornish, C. Nuckolls, and D. Sames.
Prerequisite: CHEM C1404 or C1500 or their equivalents. Premedical students may take CHEM C3443, C3444, and C3543 to meet the minimum requirements for admission to medical school. The principles of organic chemistry. The structure and reactivity of organic molecules are examined from the standpoint of modern theories of chemistry. Topics include stereochemistry, reactions of organic molecules, mechanisms of organic reactions, syntheses and degradations of organic molecules, and spectroscopic techniques of structure determination.

CHEM C3543x and y Organic chemistry (laboratory)
Lab: 3 pts. L. Fine.
Prerequisite or corequisite: CHEM C3443-C3444. Limited registration. Students planning to take a full year of laboratory should enroll in CHEM C3543 and C3544. Fee: $105. Techniques of experimental organic chemistry, with emphasis on understanding fundamental principles underlying the experiments and methodology of solving laboratory problems involving organic molecules.

CHEM C3546y Advanced organic chemistry (laboratory)
Lab: 3 pts. L. Fine.
Prerequisite: CHEM C3543 or C3545. Limited registration. Corequisite: C3444. Fee: $105. A project laboratory with emphasis on complex synthesis and advanced techniques including qualitative organic analysis and instrumentation.

EARTH AND ENVIRONMENTAL SCIENCES

Undergraduates in the four-year course of study in the School of Engineering and Applied Science may take courses numbered to 4999 but may enter courses of higher numbers only if:

1. the course is expressly included in the prescribed curriculum or
2. special permission is obtained from the Department of Earth and Environmental Sciences.

EESC V1011x Introduction to Earth sciences
Lect: 3. Lab: 3.4 pts. Professors Mutter and Nettles. Students who wish to take only the lectures should register for EESC V1411. What is the nature of our planet and how did it form? From geochemical and geophysical perspectives we explore Earth’s internal structure, its dynamical character expressed in plate tectonics, and ask if its future behavior can be known.

EESC V1030x Oceanography
3 pts. Professor Hoenisch.
Explore the geography of the sea floor, understand what drives ocean currents and how ocean ecosystems operate. Case studies and discussions centered on ocean-related issues facing society.

EESC V1201y Environmental risks and disasters
3 pts. Professor Ekstrom.
Prerequisites: High-school science and mathematics. An introduction to risks and hazards in the environment. Different types of hazards are analyzed and compared: natural disasters, such as tornados, earthquakes, and meteorite impacts; acute and chronic health effects caused by exposure to radiation and toxic substances such as radon, asbestos, and arsenic; long-term societal effects due to environmental change, such as sea level rise and global warming. Emphasizes the basic physical principles controlling the hazardous phenomena and develops simple quantitative methods for making scientifically reasoned assessments of the threats (to health and wealth) posed by various events, processes, and exposures. Discusses methods of risk mitigation and sociological, psychological, and economic aspects of risk control and management.

EESC W3018y Weapons of mass destruction
3 pts. Professors Richards and Miller.
Prerequisite: one semester of a lab science or permission of the instructor. A review of the history and environmental consequences of nuclear, chemical, and biological weapons of mass destruction (WMD); of how these weapons work, what they cost, how they have spread, how they might be used, how they are currently controlled by international treaties and domestic legislation, and what issues of policy and technology arise in current debates on WMD. What aspects of the manufacture of WMD are easily addressed, and what aspects are technically challenging? It may be expected that current events/headlines will be discussed in class.

EESC W4008x Introduction to atmospheric science
Lect: 3. 3 pts. Professor Del Genio.
Prerequisite: advanced calculus and general physics, or the instructor’s permission. Basic physical processes controlling atmospheric structure: thermodynamics; radiation physics and radiative transfer; principles of atmospheric dynamics; cloud processes; applications to Earth’s atmospheric general circulation, climatic variations, and the atmospheres of the other planets.

EESC W409x. Chemical geology
4 pts. Offered in alternate years. Professor Walker.
Prerequisites: physical chemistry or the instructor’s permission. Thermodynamics as applied to earth systems.

EESC W4050x Global assessment and monitoring using remote sensing
3 pts. Offered in alternate years. Professor Small.
Prerequisite: permission of the instructors. Recommended preparation: some college-level physics or math. Enrollment limited to 24 students. General introduction to fundamentals of remote sensing and image processing. Example applications in the Earth and environmental sciences are explored through the analysis of remote sensing imagery in a state-of-the-art visualization laboratory. Lab required.

EESC W4076y Geologic mapping
3 pts. Professors Walker and Anders.
Field work on weekends in April and for two weeks in mid-May, immediately following the end of examinations. Estimated expenses: $250. The principles and practice of deciphering geologic history by observing rocks in the field, making geological maps, constructing geological cross-sections, and writing short reports.

EESC W4085x Geodynamics
3 pts. Offered in alternate years. Professor Buck.
Prerequisites: calculus, differential equations, introductory physics. Physical processes that control plate tectonics and the evolution of planetary interiors and surfaces; analytical descriptions of these processes; weekly physical model demonstrations.

EESC W4113x Introduction to mineralogy
3. Lab: 3. 4 pts. Offered in alternate years. Professor Walker.
Prerequisites: introductory geology or the equivalent and elementary college physics and chemistry, or the instructor’s permission. Elementary crystallography and crystal structures, optical properties of minerals, mineral associations and phase equilibria, economic minerals. Laboratory: identification of minerals in hand specimens, chemical and physical tests, and use of the petrographic microscope.
EESC W4230y Crustal deformation
3 pts. Professors Anders and Scholz.
Prerequisites: Introductory geology and one year of calculus. Recommended preparation: higher levels of mathematics. Introduction to the deformation processes in the Earth's crust. Fundamental theories of stress and strain; rock behavior in both brittle and ductile fields; earth-quake processes; ductile deformation; large-scale crustal contractional and extensional events.

EESC W4300x The Earth's deep interior
3 pts. Professor Ekstrom.
Prerequisites: Calculus, differential equations, one year of college physics, and EESC W4950 or its equivalent. An introduction to properties of the Earth's mantle, fluid outer core, and solid inner core. Current knowledge of these features is explored, using observations of seismology, heat flow, gravity, and geomagnetism, plus information on the Earth's bulk composition.

EESC W4701y. Introduction to igneous petrology
4 pts. Offered in alternate years.
Prerequisites: EESC V1011-V1012 or the equivalent. Recommended preparation: EESC W4113 and knowledge of chemistry. Fee: $15. Students not enrolled in terrestrial geology may elect to write a substantial term paper in lieu of the laboratory course. Compositional characteristics of igneous and metamorphic rocks and how they can be used as tools to investigate earth processes. Development of igneous and metamorphic rocks in a plate-tectonic framework.

EESC W4865y The chemistry of continental waters
3 pts. Offered in alternate years. Instructors to be announced.
Recommended preparation: a solid background in basic chemistry. Introduction to geochemical cycles involving the atmosphere, land, and biosphere; chemistry of precipitation, weathering reactions, rivers, lakes, estuaries, and groundwaters; stable isotopes and radioactive tracers of transport processes in continental waters.

EESC W4924y Introduction to atmospheric chemistry
3 pts. Offered in alternate years. Professor Shindell.
A survey of trace gas photochemistry important in the Earth's atmosphere. Major topics are composition, including biogenic and anthropogenic inputs, and chemical processes, including reaction kinetics and photochemistry. Specific applications to tropospheric air quality, including smog, acid rain, and stratospheric ozone, including the Antarctic ozone hole, are covered, with an emphasis on the response to anthropogenic pollutants and climate change.

EESC W4925x Principles of physical oceanography
3 pts. Professor Gordon.
Recommended preparation: a solid background in mathematics, physics, and chemistry. Physical properties of seawater, water masses and their distribution, sea-air interaction influence on the ocean structure, basic ocean circulation pattern, relation of diffusion and advection with respect to distribution of ocean properties, and introduction to ocean dynamics.

EESC W4926y. Principles of chemical oceanography
3 pts. Offered in alternate years. Professors Anderson and Hoenisch.
Recommended preparation: a solid background in mathematics, physics, and chemistry. Given in alternate years. Factors controlling the concentration and distribution of dissolved chemical species within the sea. Application of tracer and natural radiotracer methods to large-scale mixing of the ocean, the geological record preserved in marine sediments, the role of ocean processes in the global carbon cycle, and biogeochemical processes influencing the distribution and fate of elements in the ocean.

EESC W4930y Earth's oceans and atmosphere
3 pts. Professor Gordon.
Recommended preparation: a good background in the physical sciences. Physical properties of water and air. Overview of the stratification and circulation of Earth's oceans and atmosphere and their governing processes; ocean-atmosphere interaction; resultant climate system; natural and anthropogenic forced climate change.

EESC W4941y Principles of geophysics
3 pts. Offered in alternate years. Instructor to be announced.
Prerequisite: calculus through MATH V1202 and physics through PHYS C1007. The structure and properties of the Earth as inferred from geophysical investigations: gravity, isostasy, earthquakes, seismic exploration, geomagnetism, marine geophysics, satellite observations, tides. Recommended for nongeophysics majors or those with little previous geophysics background.

EESC W4947y Plate tectonics
3 pts. Professors Abern and Planck.
Prerequisites: physical geology. Prepares students for research and oral exams. Evolution of the interiors and surfaces of Earth, Venus, Mars and the moons of Jupiter. Planetary accretion, tidal heating, convection, magma oceans, formation of continents, mantle plumes, sea-floor spreading, kinematics of triple junctions, surface repaving, subduction, sedimentation, catastrophic impacts and floods, and the building of mountain chains.

HUMANITIES AND SOCIAL SCIENCES
For listings of additional courses of interest to engineering students, consult the bulletins of Columbia College; the School of General Studies; the Graduate School of Architecture, Planning, and Preservation; the Graduate School of Business; and the Graduate School of Arts and Sciences.

ASCE V2002x or y Introduction to major topics in Asian civilizations: East Asia
4 pts.
An interdisciplinary and topical approach to the major issues and phases in the development of Asian civilizations and their role in the contemporary world.

ASCM V2001x Introduction to major topics in the civilizations of the Middle East and India
4 pts.
An interdisciplinary and topical approach to the major issues and phases in the development of Asian civilizations and their role in the contemporary world.

COCI C1101x-C1102y Introduction to contemporary civilization in the West
4 pts.
Popularity known as “CC,” this course, which covers texts from Plato to the present, introduces students to a range of issues concerning the kinds of communities—political, social, moral, and religious—that human beings construct for themselves. Students are expected to complete fifteen pages of written work, take two examinations, and participate actively in class discussions.

ECON W1105x or y Principles of economics
4 pts. Recitation section required (W1155).
How a market economy determines the relative prices of goods, factors of production, and the allocation of resources, and the circumstances under which it does so efficiently. Why such an economy has fluctuations and how they may be controlled.

ENGL C1010x or y University writing
3 pts. The staff.
Teaches general techniques and strategies for academic reading and writing. Students read and discuss a range of published essays, complete regular reading and writing exercises, write several longer essays, and undertake a collaborative research and writing project designed by the class. Students placed in C1010 whose names fall in the first part of the alphabet must take the course in the fall. Students whose names fall in the second part of the alphabet take the course in the spring. The alphabet will be split somewhere between K and O. The exact place for the split will be posted before fall registration.
HUMA C1001x-C1002y Masterpieces of Western literature and philosophy
4 pts.
Popularly known as “Literature Humanities,” or “LitHu m,” this course considers works by over twenty authors, ranging in time, theme, and genre from Homer to Virginia Woolf. Students are expected to complete fifteen pages of written work, take two examinations, and participate actively in class discussions.

HUMA W1121x or y Masterpieces of Western art
3 pts.
Popularly known as “Art Hum,” this course teaches students how to look at, think about, and engage in critical discussion of the visual arts. Not a historical survey, but an analytical study of a limited number of monuments and artists ranging from early Athens to the present, the course focuses on the formal structure of works of architecture, sculpture, painting, and other media, as well as the historical contexts in which these works were made and understood.

HUMA W1123x or y Masterpieces of Western music
3 pts.
Popularly known as “Music Hum,” this course aims to instill in students a basic comprehension of the many forms of the Western musical imagination. The course involves students actively in the process of critical listening, both in the classroom and in concerts. Although not a history of Western music, the course is taught in chronological format and includes masterpieces by Josquin des Prez, Monteverdi, Bach, Handel, Mozart, Haydn, Beethoven, Verdi, Wagner, Schoenberg, Stravinsky, Louis Armstrong, and Duke Ellington, among others.

MATHEMATICS
Courses for First-Year Students
Depending on the program, completion of Calculus III or IV satisfies the basic mathematics requirement. Normally students who have taken an AP Calculus course begin with either Calculus II or Calculus III. Refer to the AP guidelines on page 14 for placement information. The sequence ends with MATH E1210: Ordinary differential equations.

Students who wish to transfer from one calculus course to another are allowed to do so beyond the date specified on the Academic Calendar. They are considered to be adjusting their level, not changing their program. They must, however, obtain the approval of the new instructor and the Center for Student Advising before reporting to the Registrar.

MATH V1101 Calculus I
Lect: 3 pts.
Functions, limits, derivatives, introduction to integrals.

MATH V1102 Calculus II
Lect. 3 pts.
Prerequisite: Calculus I or the equivalent.
Methods of integration, applications of integrals, series, including Taylor’s series.

MATH V1201 Calculus III
Lect. 3 pts.
Prerequisite: Calculus II or the equivalent. Vector algebra, complex numbers and exponential, vector differential calculus.

MATH V1202 Calculus IV
Lect. 3 pts.
Prerequisite: Calculus II and III. Multiple integrals, line and surface integrals, calculus of vector fields, Fourier series.

MATH V1207x-V1208y Honors math A-B
Lect. and recit. 4 pts. M. Thaddeus.
Prerequisite: Score of 5 on the Advanced Placement BC calculus exam. The second term of this course may not be taken without the first. Multivariable calculus and linear algebra from a rigorous point of view.

MATH E1210x or y Ordinary differential equations
Lect. 3 pts. T. Perutz.
Prerequisite: MATH V1201 or the equivalent. Special differential equations of order one. Linear differential equations with constant and variable coefficients. Systems of such equations. Transform and series solution techniques. Emphasis on applications.

MATH V2010 x and y Linear algebra
Lect. 3 pts.
Prerequisite: MATH V1201 or the equivalent. Vector spaces, linear transformations, matrices, quadratic and hermitian forms, reduction to canonical forms.

MATH V2500y Analysis and optimization
Lect. 3 pts. H. Pinkham.

MATH V3007y Complex variables
Prerequisite: MATH V1202. An elementary course in functions of a complex variable. Fundamental properties of the complex numbers, differentiability, Cauchy-Riemann equations, Cauchy integral theorem, Taylor and Laurent series, poles, and essential singularities. Residue theorem and conformal mapping.

MATH V3027x Ordinary differential equations
Lect. 3 pts. P. Daskalopoulos.
Prerequisite: MATH V1201 or the equivalent. Equations of order one, linear equations, series solutions at regular and singular points, boundary value problems. Selected applications.

MATH V3028y Partial differential equations
Lect. 3 pts. P. Daskalopoulos.
Prerequisite: MATH V3027 or the equivalent. Introduction to partial differential equations. First-order equations. Linear second-order equations, separation of variables, solution by series expansions. Boundary value problems.

MATH W4032x Fourier analysis
Lect. 3 pts. M. Lipyanskiy.
Prerequisite: MATH V1201 and linear algebra, or MATH V1202. Fourier series and integrals, discrete analogues, inversion and Poisson summation, formulae, convolution, Heisenberg uncertainty principle. Emphasis on the application of Fourier analysis to a wide range of disciplines.

MATH W4041x-W4042y Introduction to modern algebra
Lect. 3 pts. P. Gallagher.
The second term of this course may not be taken without the first. Prerequisite: MATH V1202 and V2010 or the equivalent. Groups, homomorphisms, rings, ideals, fields, polynomials, and field extensions. Galois theory.

MATH W4061x-W4062y Introduction to modern analysis
Lect. 3 pts. D. De Silva.
The second term of this course may not be taken without the first. Prerequisite: MATH V1202 or the equivalent. Real numbers, metric spaces, elements of general topology. Continuous and differentiable functions. Implicit functions. Integration, change of variables. Function spaces. Further topics chosen by the instructor.

MATH W4065x Honors complex variables
Lect. 3 pts. K. Tignor.
Prerequisite: MATH V1207, V1208, or W4061. A theoretical introduction to analytic functions. Holomorphic functions, harmonic functions, power series, Cauchy-Riemann equations, Cauchy’s integral formula, poles, Laurent series, residue theorem. Other topics as time permits: elliptic functions, the gamma and zeta functions, the Riemann mapping theorem, Riemann surfaces, Nevanlinna theory.
PHYS 1401x Introduction to mechanics and thermodynamics
Lect: 3 pts. Professors Dodd and Tuck. Corequisite: MATH V1101 or the equivalent. This course introduces the fundamental laws of mechanics, kinematics and dynamics, work and energy, rotational dynamics, oscillations, gravitation, fluids, temperature and heat, gas laws, the first and second laws of thermodynamics.

PHYS 1401y Introduction to electricity, magnetism, and optics
Lect: 3 pts. Professors Dodd and Hughes. Prerequisite: PHYS C1401. Corequisite: MATH V1102 or the equivalent. This course covers electric fields, direct currents, magnetic fields, alternating currents, electromagnetic waves, polarization, geometrical optics, interference and diffraction.

PHYS 1402x Introduction to classical and quantum waves
Lect: 3.5 pts. Professor Brooijmans. Prerequisite: PHYS C1402. Corequisite: MATH V1201 or the equivalent. This course introduces classical waves and the wave equation, Fourier series and integrals, normal modes, wave-particle duality, the uncertainty principle, basic principles of quantum mechanics, energy levels, reflection and transmission coefficients, applications to atomic and nuclear physics.

PHYS 1402y Introduction to experimental physics
Lab and lecture: 3 pts. Lect: 1 hour weekly to be arranged. Lab: 3 hours weekly to be arranged. Instructor to be announced. Prerequisites: PHYS C1401 and C1402. Laboratory work associated with the two prerequisite lecture courses. Experiments in mechanics, thermodynamics, electricity, magnetism, optics, and wave motion. (Students cannot receive credit for both PHYS C1493 and C1494.)

PHYS 1493x Introduction to experimental physics
Lab and lecture: 3 pts. Lect: 1 hour weekly to be arranged. Lab: 3 hours weekly to be arranged. Instructor to be announced. Prerequisites: PHYS C1401 and C1402. Laboratory work associated with the three prerequisite lecture courses. Experiments in mechanics, thermodynamics, electricity, magnetism, optics, wave motion, atomic and nuclear physics. (Students cannot receive credit for both PHYS C1493 and C1494.)

PHYS 1403x Introduction to classical and quantum physics
Lect: 3.5 pts. Rec: 1 hour weekly to be arranged. Professor Zagic. Corequisite: MATH V1102 or the equivalent. This course introduces fundamental laws of mechanics, kinematics and dynamics, work and energy, rotational dynamics, oscillations, gravitation, fluids, temperature and heat, gas laws, the first and second laws of thermodynamics. The course is preparatory for advanced work in physics and related fields.

PHYS 1404y Introduction to mechanics and relativity
Lect: 3.5 pts. Rec: 1 hour weekly to be arranged. Professor Zagic. Corequisite: MATH V1102 or the equivalent. This course introduces fundamental laws of mechanics, kinematics and dynamics, work and energy, rotational dynamics, oscillations, gravitation, fluids, temperature and heat, gas laws, the first and second laws of thermodynamics. The course is preparatory for advanced work in physics and related fields.

PHYS 1601x Physics I: mechanics and relativity
Lect: 3.5 pts. Rec: 1 hour weekly to be arranged. Professor Zagic. Corequisite: MATH V1102 or the equivalent. This course introduces fundamental laws of mechanics, kinematics and dynamics, work and energy, rotational dynamics, oscillations, gravitation, fluids, temperature and heat, gas laws, the first and second laws of thermodynamics. The course is preparatory for advanced work in physics and related fields.

PHYS 1602y Physics II: thermodynamics, electricity, and magnetism
Lect: 3.5 pts. Rec: 1 hour weekly to be arranged. Professor Zagic. Corequisite: PHYS C1601. Corequisite: MATH V1201 or the equivalent. This course introduces the fundamental laws of thermodynamics, kinetic theory of gases, electric fields, direct currents, magnetic fields, alternating currents, electromagnetic waves. The course is preparatory for advanced work in physics and related fields.

PHYS 2601x Physics III: classical and quantum waves
Lect: 3.5 pts. Rec: 1 hour weekly to be arranged. Professor Zagic. Corequisite: PHYS C1602 or C1402. Corequisite: MATH V1202 or the equivalent. This course introduces classical waves and the wave equation, geometrical optics, interference and diffraction, Fourier series and integrals, normal modes, wave-particle duality, the uncertainty principle, basic principles of quantum mechanics, energy levels, reflection and transmission coefficients, the harmonic oscillator. The course is preparatory for advanced work in physics and related fields.

PHYS 2602y Physics IV: quantum mechanics
Lect: 3.5 pts. Rec: 1 hour weekly to be arranged. Professor Zagic. Corequisite: PHYS C1601. Corequisite: MATH V1201 or the equivalent. This course introduces classical waves and the wave equation, geometrical optics, interference and diffraction, Fourier series and integrals, normal modes, wave-particle duality, the uncertainty principle, basic principles of quantum mechanics, energy levels, reflection and transmission coefficients, the harmonic oscillator. The course is preparatory for advanced work in physics and related fields.

PHYS 2603y Electromagnetic waves and optics
Lect: 3 pts. Professor Blaer. Prerequisite: PHYS C1403. This course reinforces basic ideas of modern physics through applications to nuclear physics, high energy physics, astrophysics, and cosmology. The ongoing Columbia research programs in these fields are used as practical examples. The course is preparatory for advanced work in physics and related fields.

PHYS 2604y Intermediate laboratory work
Lab: 2 pts. Professors May, Aprile, and Uemura. Primarily for junior and senior physics majors. Other majors require the instructor’s permission. May be repeated for credit by performing different experiments. The laboratory has 13 individual experiments available, of which two are required per 2 points. Each experiment is chosen by the student in consultation with the instructor. Each section meets one afternoon per week, with registration in each section limited by the laboratory capacity. Experiments (classical and modern) cover topics in electricity, magnetism, optics, atomic physics, and nuclear physics.
PHYS G4003y Advanced mechanics  
Lect: 3 pts. Professor Pontón.  
Prerequisite: differential and integral calculus, differential equations, and PHYS W3003 or the equivalent. Lagrange’s formulation of mechanics, calculus of variations and the Action Principle, Hamilton’s formulation of mechanics, rigid body motion, Euler angles, continuum mechanics, introduction to chaotic dynamics.

PHYS G4018y Solid-state physics  
Lect: 3 pts. Professor Uemura.  
Prerequisite: PHYS G4021, G4022, G4023 or the equivalent. Introduction to solid-state physics: crystal structures, properties of periodic lattices, electrons in metals, band structure, transport properties, semiconductors, magnetism, and superconductivity.

PHYS G4019x Mathematical methods of physics  
Lect: 3 pts. Professor Aleiner.  
Prerequisite: differential and integral calculus. Highlights of complex analysis, differential equations, integral equations, Green’s functions, special functions, Fourier and other transforms, approximation methods, group theory and representations, differential geometry and manifolds. Emphasis is placed on applications to physical problems.

PHYS G4021x–G4022y Quantum mechanics, I and II  
Lect: 3 pts. Professor Mueller.  
Prerequisite: PHYS C2601 or C2802, or the equivalent. The formulation of quantum mechanics in terms of state vectors and linear operators, three-dimensional spherically symmetric potentials, the theory of angular momentum and spin, time-independent and time-dependent perturbation theory, scattering theory, identical particles. Selected phenomena from atomic physics, nuclear physics, and elementary particle physics are described and then interpreted using quantum mechanical models.

PHYS G4023x Thermal and statistical physics  
Lect: 3 pts. Professor Heinz.  
Prerequisite: PHYS G4021 or the equivalent. Thermodynamics, kinetic theory, and methods of statistical mechanics; energy and entropy; Boltzmann, Fermi, and Bose distributions; ideal and real gases; blackbody radiation; chemical equilibrium; phase transitions; ferromagnetism.

PHYS G4040x General relativity  
Lect: 3 pts. Professor Beloborodov.  
Prerequisites: PHYS G4003 and W3007. Tensor algebra, tensor analysis, introduction to Riemann geometry. Motion of particles, fluid, and fields in curved spacetime. Einstein equation. Schwarzschild solution; test-particle orbits and light bending. Introduction to black holes, gravitational waves, and cosmological models.

STATISTICS

For a description of the following course offered jointly by the Departments of Statistics and Industrial Engineering and Operations Research, see “Industrial Engineering and Operations Research”:  
SIEO W4150: Introduction to probability and statistics

STAT W3105x Introduction to probability  
3 pts. Instructor to be announced.  
Prerequisites: MATH V1101 and V1102 or the equivalent. This course is an introduction to probability specially designed for sophomore and junior students. Emphasis is on conceptual understanding and problem solving. Students require slightly less mathematical background than required for STAT W4105. A quick review of multivariate calculus is provided. This course satisfies the prerequisite for STAT W3659/W4107. Topics covered include random variables, conditional probability, expectation, independence, Bayes’ rule, important distributions, joint distributions, moment generating functions, central limit theorem, laws of large numbers, and Markov’s inequality.

STAT W3107 y Introduction to statistical inference  
3 pts. Instructor to be announced.  

STAT W3659y Statistical inference  
3 pts. Instructor to be announced.  
Prerequisite: STAT W3000 or W4105, or the equivalent. Useful distributions, law of large numbers and central limit theorem, point estimation, hypothesis testing, confidence intervals, maximum likelihood, likelihood ratio tests, nonparametric procedures, theory of least squares, and analysis of variance. General Education Requirement: Quantitative and Deductive Reasoning (QUA).

STAT W4201 x and y Advanced data analysis  
3 pts. D. Alemayehu and instructor to be announced.  
Prerequisite: A one-term introductory statistics course. This is a course on getting the most out of data. The emphasis will be on hands-on experience, involving case studies with real data and using common statistical packages. The course covers, at a very high level, exploratory data analysis, model formulation, goodness-of-fit testing, and other standard and nonstandard statistical procedures, including linear regression, analysis of variance, nonlinear regression, generalized linear models, survival analysis, time series analysis, and modern regression methods. Students will be expected to propose a data set of their choice for use as case study material.

STAT W4109x Probability and statistical inference  
6 pts. Instructor to be announced.  
Combines STAT W4105 and W4107.

STAT W4290 y Statistical methods in finance  
3 pts. Instructor to be announced.  
Prerequisites: STAT W4105 and W4107. This is a master-level course introducing statistical methodologies in quantitative finance. Financial applications and statistical methodologies are intertwined in all lectures, with several research topics being introduced through problems in a term project. Lecture notes by the instructor will be distributed. The course will cover linear regression with applications to single and multifactor pricing models, multivariate analysis and their applications in Markowitz’s portfolio management, estimation and modeling of volatilities, calculation of value-at-risk, nonparametric methods with applications to option pricing and interest rate markets.

STAT W4315x and y Linear regression models  
3 pts. Instructor to be announced.  
Prerequisites: STAT W3000 or the equivalent and STAT W3659 or the equivalent. Corequisites: MATH V1101, V1102, and V2110. Simple and multiple regression, including testing, estimation and confidence procedures, modeling, regression diagnostics and plots, polynomial regression, fixed effects ANOVA and ANCOVA models, non-linear regression, multiple comparisons, co-linearity and confounding, model selection. Emphasis on geometric approach to the theory and computer use to analyze data.
STAT W4335x Sample surveys
3 pts. Instructor to be announced.
Introductory course on the design and analysis of sample surveys. How sample surveys are conducted, why the designs are used, how to analyze survey results, and how to derive from first principles the standard results and their generalizations. Discussions include detail surveys from areas including public health, social work, opinion polling, and other topics of interest. General Education Requirement: Quantitative and Deductive Reasoning (QUA).

STAT W4413x Nonparametric statistics
3 pts. Instructor to be announced.

STAT W4437x and y Time series analysis
3 pts. Instructor to be announced.
Prerequisite: STAT W4315 or the equivalent. Least-squares smoothing and prediction, linear systems, Fourier analysis and spectral estimation. Impulse response and transfer function. Fourier series, the fast Fourier transform algorithm, autocorrelation function, and spectral density. Univariate Box-Jenkins modeling and forecasting. Emphasis on practical applications in examples from the physical sciences, social sciences, and business. Computing is an integral part of the lectures.

STAT W4543y Survival analysis
3 pts. Instructor to be announced.
Prerequisite: STAT W3659/W4107 or the equivalent. Survival distributions, types of censored data, estimation for various survival models, non-parametric estimation of survival distributions, the proportional hazard and accelerated lifetime models for covariate data, regression analysis with lifetime data. Extensive use of the computer to analyze data. Applications in clinical trials and actuarial science.

STAT W4606x and y Elementary stochastic processes
3 pts. M. Brown and instructor to be announced.
Prerequisite: STAT W4105 or the equivalent. Review of elements of probability theory. Poisson processes. Exponential distribution. Renewal theory. Wald’s equation. Introduction to discrete time Markov chains and applications to queueing theory, inventory models, branching processes.

STAT W4840x Theory of interest
3 pts. N. Rajah.
No prerequisite. Introduction to the mathematical theory of interest as well as the elements of economic and financial theory of interest. Topics include rates of interest and discount; simple, compound, real, nominal, effective, dollar (time)-weighted; present, current, future value; discount function; annuities; stocks and other financial instruments; definitions of key terms of modern financial analysis; yield curves; spot (forward) rates; duration; immunization; and short sales. The course will cover determining equivalent measures of interest; discounting, accumulating, determining yield rates, and amortization.

STAT W6501x Stochastic processes and application, I
3 pts. J. Vecer.
Prerequisite: STAT W4105 or the equivalent. Discrete and continuous-time Markov chains; elements of renewal theory; Martingales and their basic properties. Brownian motion: construction, basic properties, sample paths. Stochastic integration, Ito’s rule, applications. Introduction to stochastic differential equations and diffusion processes.
The Fu Foundation School of Engineering and Applied Science attracts and admits an exceptionally interesting, diverse, and multicultural group of students, and it takes steps to provide a campus environment that promotes the continued expansion of each student’s ideas and perspectives. Starting with the residence halls, in which nearly all first-year undergraduate students live, the University assigns rooms to both Engineering and Columbia College undergraduate students, ensuring that all students will live either with or near a student attending the other program.

Once students have moved into their new campus home they will find themselves part of a residential system that offers undergraduates a network of social and academic support. Designed to make students aware of the vast number of social and academic opportunities available to them at the University, these networks provide an umbrella of comprehensive advising to help students articulate and realize their goals while at Columbia. More information about the residence halls can be found in the chapter “Housing and Residence Life” in this bulletin.

**DIVISION OF STUDENT AFFAIRS OFFICE**

Undergraduate life is not confined to the classroom. A blend of academic, educational, social, and cocurricular activities contributes to the Columbia experience. While The Fu Foundation School of Engineering and Applied Science is large enough to support a wide variety of programs, it is also small enough to promote the close interaction among students, faculty, and administration that has created a strong sense of community on campus.

With its mission of providing a wide range of services designed to enhance the student experience from the time of admission through graduation, the Division of Student Affairs Office is the hub of undergraduate student life. Admissions, Financial Aid and Educational Financing, Center for Student Advising, Residential Programs, Office of Multicultural Affairs, Parent and Family Programs, Office of Judicial Affairs, Events and Communications, Student Development and Activities, and Office of Student Group Advising are integral components of the Office, and the integrated effort of these units assures that individual students receive support in both their academic and cocurricular pursuits. The Division of Student Affairs Office is responsible for assisting students in all matters beyond actual course instruction and helping to create a special spirit and sense of community for students.

**CENTER FOR STUDENT ADVISING**

The Center for Student Advising reflects the mission of the University in striving to support and challenge the intellectual and personal growth of its students and by creating a developmental, diverse, and open learning environment. Individually and collaboratively, each center:

- provides individual and group academic advisement, exploration, and counseling
- provides information on preprofessional studies, study abroad, and major declaration and completion, as well as various leadership, career, graduate school, and research opportunities; refers to additional campus resources
- designs and facilitates programming to meet the unique developmental needs of each class and to enhance community among students, faculty, and administrators
- interprets and disseminates information regarding University policies, procedures, resources, and programs
- educates and empowers students to take responsibility in making informed decisions

Each student is assigned to an advising dean who will work with him or her during the undergraduate years. When a student declares a major, a faculty member is appointed to guide him or her for the next two years. Advising deans regularly refer students to their academic departments to receive coordinated expert advice in their engineering course selections.
Preprofessional Advising

The Office of Preprofessional Advising works closely with the Center for Student Advising and with the Center for Career Education to provide information for students who plan a career in law or the health professions. The Office advises and assists students throughout their four years, but works most closely with students during their application year and with alumni who apply for admission after graduation. Information sheets, forms, and helpful resources are available in the Office of Preprofessional Advising. Students will work with their advising deans as primary preprofessional advisers; these advisers will be instrumental in writing committee evaluations for some professional schools.

COMMUNITY DEVELOPMENT

The Community Development team works to foster a vibrant and welcoming undergraduate community through organizational advising, leadership development, advocacy, diversity education, civic engagement, and community programming. The team includes the Office of Student Development and Activities, the Office of Multicultural Affairs, the Office of Student Group Advising, and the Office of Residential Programs. Knowing that students’ learning continues beyond the classroom, Columbia University strongly encourages students to become involved in programs and activities to enhance their educational experience and personal growth. A wide array of student organizations addresses both student interests and professional concerns, including the arts, politics, identity, culture, and religion. Joining such groups offers an exciting and dynamic opportunity to develop leadership skills that will serve students well throughout their lives.

Student Organizations

Programs and activities at Columbia are shaped primarily by students who assume leadership and volunteer positions in hundreds of organizations across the campus. The Engineering Student Council and its associated class councils are the elected representative body of undergraduates with The Fu Foundation School of Engineering and Applied Science. Its members represent student interests on committees and projects addressing a wide range of issues facing the Columbia community and help shape the quality of life for Columbia students.

Working in conjunction with the Student Council, the Activities Board at Columbia (ABC), Student Governing Board (SGB), Inter-Greek Council (IGC), Community Impact (CI), Club Sports, and InterSchool Governing Board (IGB) oversee the management and funding of over 300 student organizations.

The ABC provides governance for over 160 recognized student organizations, including cultural organizations, performance-based and theatrical groups, media and publications groups, competition and special interests groups and preprofessional organizations and societies. The preprofessional organizations and societies are of special interest to engineering students. These societies reflect the range of academic disciplines and interests to be found among students and include the Asian-American Society of Engineers, National Society of Black Engineers, the Society of Women Engineers, the American Institute of Aeronautics and Astronautics, and the Biomedical Engineering Society, just to name a few.

The SGB provides governance for approximately 100 recognized student organizations that are faith-based, spiritual, political, activist, and humanitarian and that encourage open interreligious and political dialogue at Columbia University’s Morningside Campus. The InterSchool Governing Board recognizes student organizations whose membership is open and spans among the various undergraduate and graduate schools.

For more information on IGC see Residential Programs, below. For more information on Club Sports see Intercollegiate Athletics Program (page 208), and for more information on Community Impact see Office of the University Chaplain (page 207). All the governing groups provide networking and leadership and professional development for students.

Columbia University graduate students can participate in and enjoy hundreds of diverse, University-affiliated social, religious, cultural, academic, athletic, political, literary, professional, public service, and other organizations. At SEAS, graduate students are encouraged to become active members of the Engineering Graduate Student Council (EGSC). The EGSC is a recognized group that consists of representatives
from each of the nine academic departments at SEAS. The objectives of the EGSC are to foster interaction among graduate engineering students, to serve as a voice for graduate engineering students, and to sponsor social and educational events of interest to the graduate engineering community.

**Office of Student Development and Activities**

The Office of Student Development and Activities (SDA) provides programs and services designed to support a wide range of co-curricular activities that help build a sense of community, support responsible student governance and student group management, and further students’ leadership development and personal growth.

Student Development and Activities staff members advise all student organizations recognized through the Activities Board of Columbia (ABC), as well as the student governments of The Fu Foundation School of Engineering and Applied Science and Columbia College. SDA serves as resources for event planning, organizational leadership, and budgeting. The Office of Student Development and Activities offers leadership training workshops and helps networking among student leaders and administrative offices. In addition, the SDA administers the Urban New York Program, the New Student Orientation Program, the Columbia Urban Experience Program, and the Columbia Outdoor Orientation Program.

**Orientation**

All new students are required to participate in an orientation program that is designed to acquaint them with the University and its traditions, the administration and faculty of The Fu Foundation School of Engineering and Applied Science, upperclass students, and New York City. The New Student Orientation Program (NSOP) for new undergraduate students begins the week prior to the start of the fall semester. NSOP is intended to assist all new students with the transition to college life.

Orientation is busy, exciting, and a lot of fun, but it is also a week in which important academic decisions are made. Scheduled into the program are information sessions and opportunities to meet with academic advisers. Through large group programs and small group activities, student will be introduced to faculty members, deans, resident advisers, and other students. NSOP includes walking tours of New York City, social events, and information sessions on University services and co-curricular opportunities. During NSOP, new students have the campus to themselves. This provides students with a unique opportunity to make friends and settle into life at Columbia before classes begin.

Undergraduate students may e-mail nsop@columbia.edu or call 212-854-5808 for additional information on NSOP.

Orientation for graduate students is scheduled during the week prior to the beginning of each semester. For more information on orientation for graduate students, contact the Office of Graduate Student Services.

**Office of Student Group Advising**

The Office of Student Group Advising (OSGA) is committed to supporting the programming of our faith-based, spiritual, political, activist, and humanitarian student organizations. In reaching to fulfill this commitment, OSGA provides programming in leadership skills, program development, and organizational management to all undergraduate student organizations recognized by the Student Governing Board (SGB) and organizations recognized by the Interschool Governing Board (IGB). OSGA assists students in their development as individuals, community members, and leaders.

Issues of social responsibility and civic engagement are central to the mission of OSGA and the student organizations that OSGA supports. OSGA strives to encourage open dialogue at Columbia University’s Morningside Campus and seeks to find connections among student groups. The Office of Student Group Advising works to enhance the undergraduate educational experience by fostering a dynamic and enriching University community, supporting responsible student governance and co-curricular activities. Through advising, the office encourages critical thinking and the free exchange of ideas by all of the student organizations it supports.

**Office of Multicultural Affairs**

The Office of Multicultural Affairs is devoted to promoting a just society and exploring issues of interculturalism and diversity within and beyond the Columbia University community. By promoting forums that address diversity issues, self-discovery takes place along with a greater awareness and appreciation of cultural history within and between communities on campus. We endeavor to empower students, faculty, and staff with the tools to be able to successfully navigate their environments and thus be able to positively change and impact the community at large.

Programs and services provided by Multicultural Affairs include Student and Alumni Mentoring Programs; Respecting Ourselves and Others Through Education (ROOTED), a peer diversity facilitation program; Dessert and Discussion, the signature lecture series; and the Intercultural House (ICH), a unique residential experience that is supportive of Multicultural Affairs’ goals.

**Residential Programs**

The Residential Programs staff, supervised by the Assistant Dean/Director of Residential Programs and consisting of professional staff and graduates students as well as selected undergraduates, contributes to the growth, well-being, and personal and intellectual development of students. The Residential Programs staff strives to enhance the quality of residential life by cultivating an atmosphere conducive to educational pursuits and the development of community within the student body. These contributions form an integral part of a Columbia education by stimulating mutual understanding and by fostering an atmosphere based on the appreciation of the differences and similarities characterizing such a diverse cultural community.

The undergraduate student staff, resident advisers (RAs), and community program assistants (CPAs) serve as role models for their residents. They facilitate discussions about community standards, provide community building programs,
and serve as a resource for the residents of their floors and buildings. They are available to assist and respond to the variety of issues and incidents that emerge in a residential community. Additionally, RAs/CPAs serve as the front line of a layered on-call system. As back-up, they have graduate assistants (GAs), associate directors (ADs), and a dean-on-duty.

The well-known and highly successful program of Faculty-in-Residence allows students, alumni, and faculty to meet formally and informally throughout the year for conversations, guest speakers, and other activities. These faculty members live in several of the residence halls throughout the year, establishing mentorships with residents that often endure long after graduation. Resident professors invite students to dine in their apartments; organize special programs around issues of interest; provide opportunities for academic growth and challenges within the residence halls; and help students establish links with major cultural, political, and professional institutions in New York City.

Begun in fall 2006, the Gateway Residential Initiative allows SEAS freshmen, sophomores, juniors, and seniors to live together clustered in the Hartley and Wallach Living Learning Center (LLC). This initiative seeks to bridge the academic and co-curricular experience for SEAS students. Mentorship between students, connection among the class years, and alumni interaction are the foundations for the success of the program.

Fraternities and Sororities
Columbia has a diverse Greek system that includes fourteen men's fraternities, one coed society, and four National Pan-Hellenic conference sororities. Many of the organizations have brownstones near the campus and most of the organizations without brownstones have a suite within the residence halls. There is a full-time Assistant Director for Greek Life and Leadership.

OFFICE OF JUDICIAL AFFAIRS
The Office of Judicial Affairs partners with various offices on campus to create programs designed to educate students regarding the potential impact of their actions on both their individual lives and the community at large. In addition, the Office of Judicial Affairs works with student groups to facilitate the development of skills and processes students can use to hold each other accountable when they encounter inappropriate behavior. The Office of Judicial Affairs also holds students accountable for inappropriate behavior through the Dean's Discipline process when necessary.

OFFICE OF THE UNIVERSITY CHAPLAIN
The Office of the University Chaplain is located in the Earl Hall Center and includes the United Campus Ministries, the Common Meal Program, and “Music at St. Paul’s.” The mission of the Center is to build community within the University and with its neighbors while providing students with an opportunity to explore the relationship between faith and learning. The Center is as diverse as the university it serves. United Campus Ministries, which includes denominations of Christian, Jewish, Islamic, and Eastern practices, provides students with individual counseling, religious and nonreligious group support, referrals, and personal assistance.

The University Chaplain is the director of the Earl Hall Center. As University Chaplain, Jewelnel Davis supports the coherence and unity that connects the University. She focuses on a nexus of issues including religion, spirituality, race, ethnicity, sexual identity, gender, social justice, and community service.

One point of focus for Chaplain Davis is accessibility to students. Students often e-mail her, make appointments with her individually or in groups, or speak with the chaplain associates or program coordinators—student liaisons who work directly with Chaplain Davis on student programming initiatives. The Common Meal Program is a weekly gathering to which student leaders from Columbia College, Barnard, SEAS, General Studies, and the graduate schools are invited along with faculty and senior administrators to discuss ideas and opinions about Columbia’s past, present, and future.

In addition to student programming, community service is also a main function of the Center. As a center for all undergraduate, graduate, and professional schools at Columbia, the Earl Hall Center offers any student a number of great opportunities. Columbia University’s largest community service program, Community Impact, which is located in the Earl Hall Center, involves more than 900 student and neighborhood volunteers in twenty-six programs, including GED, Earth Coalition, Peace Games, a soup kitchen, and student help for the aging.

Besides Earl Hall, the Center includes St. Paul’s Chapel. One of Columbia’s oldest and most beautiful buildings, the Chapel not only hosts weddings and various religious services, but also features many speakers and performances. The Postcrypt Coffeehouse at St. Paul’s Chapel is a favorite spot for artists to play music, read poetry, or exhibit artwork.

The administrative offices for the Center are open during regular business hours, but the buildings have more extensive hours—as late as 11:00 p.m. on weekends. For more information, please call the Earl Hall Center at 212-854-1474 or 212-854-6242.

LEARNER HALL
Columbia’s new student center, Lerner Hall, officially opened in the fall of 1999. Located on the southwest corner of campus, this 225,000-square-foot student center was designed by Bernard Tschumi, the former Dean of Columbia’s Graduate School of Architecture, Planning and Preservation. Architectural features of Lerner Hall, such as the glass facade and ramps, allow the campus to clearly view the activities within the building, and offer those within Lerner scenic views of the campus.

Undergraduate students are likely to visit Lerner to check the mail from the 7,000 student mailboxes located along the ramps. Students may check their e-mail in Lerner’s computer center or by plugging in their laptop computers at one of Lerner’s Ethernet-outfitted lounges. Students will also visit Lerner to interact with one another in various ways. They may strategize and plan events with
their student organizations in one of the student club offices, or in the meeting rooms designated for student club usage. Students may also meet friends in one of Lerner’s two dining locations, for an event in the auditorium, in various lounges, or in one of the building’s multipurpose spaces that are ideal for exercise classes.

In addition to providing spaces for student interaction, Lerner is home to the Columbia University Bookstore. Lerner also features retail services, including a travel agency, a copy center, and an electronic banking center. Included in the building are orchestra/band rehearsal and art exhibition spaces, and various administrative offices (Student Affairs, Student Services, Residential Programs, Judicial Affairs, Multicultural Affairs, Center for Student Advising, Financial Aid, and Educational Financing). These offices also include Student Development and Activities, the Double Discovery Center, Columbia TV, WKCR, Disability Services, Counseling and Psychological Services, and Columbia’s Alice! The Health Education Program.

OFFICE OF GRADUATE STUDENT SERVICES
The Office of Graduate Student Services at The Fu Foundation School of Engineering and Applied Science is integral to the School’s teaching, research, and service mission, and works to enhance the educational opportunities available to students. This Office provides leadership for the integration of educational programs and services that enhance recruitment, retention, and quality of campus life for graduate students at SEAS. It strives to demonstrate sensitivity and concern in addressing the needs of the School’s population. The Office is dedicated to providing service to prospective, new, and continuing students pursuing a graduate education in engineering or applied science.

INTERCOLLEGIATE ATHLETICS PROGRAM
Columbia has a long tradition of success in intercollegiate athletics, and The Fu Foundation School of Engineering and Applied Science has always been an active participant in these programs. While Columbia’s intercollegiate athletic program is governed by Ivy League regulations, Columbia is also a member of the Eastern College Athletic Conference and the National Collegiate Athletic Association. Columbia sponsors men’s varsity teams in baseball, basketball, cross-country, fencing, football, golf, rowing (heavy-weight and lightweight), soccer, swimming and diving, tennis, track and field (indoor and outdoor), and wrestling.

Women in all undergraduate divisions of Columbia and in Barnard College compete together as members of University-wide athletic teams. The arrangement, called a consortium under NCAA rules, is one of only three in the nation and the only one on a Division I level. Currently, there are women’s varsity teams in archery, basketball, cross-country, fencing, field hockey, golf, lacrosse, rowing, soccer, softball, swimming and diving, tennis, track and field (indoor and outdoor), and volleyball.

Columbia’s commitment to success in intercollegiate sporting competition has been matched by the determination
of alumni and administrators to upgrade the University’s sports facilities. The Baker Field Athletic Center, a few miles up the Hudson River on the northern tip of Manhattan, has been completely rebuilt and expanded. The Center features a precast concrete football stadium capable of seating 17,000 spectators; an Olympic-quality synthetic track; a 3,500-seat soccer stadium; softball and baseball fields; and an Astroturf field hockey field. At the Columbia Tennis Center near the Baker Field Athletic Center, Columbia maintains six hard tennis courts, which are covered by an air dome for winter use. The 1929 Boathouse includes a three-bay shell house, complete with an upper level that includes an erg and weight room.

Columbia’s Dodge Physical Fitness Center draws thousands of students each day for recreation, physical education classes, intramural play, club competition, and varsity sport contests and practices. The Dodge Center houses most indoor sports and is available to all registered students. Major athletic facilities on campus include two full-size gymnasiums for basketball, volleyball, and badminton; eight squash and handball courts; the eight-lane Uris pool with three diving boards; a fully equipped three-level exercise and weight room facility; two aerobic dance/martial arts rooms; a fencing room; a wrestling room; an indoor running track; and two fully equipped saunas.

Eligibility for Intercollegiate Athletics
Any student in the Engineering School who is pursuing the undergraduate program or an approved combined program toward a first degree is eligible for intercollegiate athletics. To be eligible for athletic activities, the student must:
- be a candidate for a bachelor’s degree
- be registered for at least 12 points of credit
- make appropriate progress toward the degree as defined by the NCAA, the Ivy League, and Columbia University. These criteria are monitored by the Director of Compliance and certified by the Office of the Registrar.
- have attended the University for not more than eight terms
- not have completed the requirements for the bachelor’s degree

Questions about athletic eligibility should be referred to the appropriate academic adviser or the Director of Compliance in the Department of Intercollegiate Athletics and Physical Education.

Recreational Programs
In addition to the activity courses (see page 13), the Physical Education Department offers a comprehensive Intramural and Club Sports Program. Through intramurals, the student has the opportunity to participate in both individual and team sports. Individual activities function through tournaments, while the team activities feature both league and play-off competition. Club sports are designed to allow groups of individuals who share a common athletic interest to organize and collectively pursue this activity. Clubs are organized on recreational, instructional, and competitive levels, and their activities range from informal play to regular practice or instruction and intercollegiate and tournament competition. A list of the intramural activities and sports clubs as well as all information regarding the program can be obtained in the Intramural Office, 331 Dodge Fitness Center or on the Web site, www.gocolumbiaions.com.

CAMPUS SAFETY AND SECURITY
At Columbia University, the safety and well-being of our students, faculty, and staff is a priority. Columbia’s campuses and their environs are safe and have a very low crime rate for an urban university.

The University is required by federal law to publish an annual security report containing information with respect to campus security policies and statistics on the incidence of certain crimes on and around our campuses. This information is available at the Web site for the United States Department of Education (ope.ed.gov/Security/search.asp); by requesting a copy of the report from: Campus Crime Report, Department of Public Safety, Columbia University, 111 Low Library, Mail Code 4301, 535 West 116th Street, New York, NY 10027 (Attn: Mr. Rocco Osso); or at the Web site for Public Safety (www.columbia.edu/cu/publicsafety).
UNIVERSITY HOUSING

Undergraduate Housing
The residence halls are an important focus for campus life outside the classroom, with the University housing over 95 percent of the undergraduate population in residence halls on or near the campus. A trained Residential Programs staff lives with the students in the halls. They work to create an atmosphere conducive to educational pursuits and the development of community among the diverse student body. Throughout the year the Residential Programs staff presents programs in the residence halls and off campus that are both social and educational.

Columbia guarantees housing for all undergraduate students (except transfers) who have filed their intent to reside on campus by the stated deadline and who have continuously registered as full-time students. Each spring, continuing students participate in a room-selection process to select their accommodations for the next academic year. Students who take an unauthorized leave of absence are placed on the nonguaranteed wait list upon their return and are on the wait list for each subsequent year.

A variety of residence hall accommodations are available to Columbia students. Carman, John Jay, Wien, Furnald, McBain, Schapiro, and Broadway Residence Hall are traditional corridor-style residence halls, and all but Wien, John Jay, and Carman have kitchens on each floor. East Campus, 47 Claremont, Hartley-Wallach Living Learning Center, Hogan, River, Ruggles, 600 West 113th Street, Watt, and Woodbridge offer suite-style living, and all have kitchens. All residence hall rooms are either single or double. Single and double rooms are available in all halls except Carman, which has only doubles, and Hogan, which is all singles.

The residence halls are also home to a variety of Special Interest Communities. These communities provide an opportunity for students with a common interest to live together and develop programs in their area of interest. The themes may vary from year to year. The current communities include Casa Latina, Metta House, Pan African House, Community Health House, The Symposium House, and others. First-year students are not eligible to live in Special Interest Communities but are welcome to attend events.

Upper-class Columbia students also have the option of living in certain Barnard College halls. Rooms in Barnard and Columbia halls are chosen by a room selection process, which takes place each spring.

For more information, please visit the housing Web site at www.columbia.edu/cu/housing.

Graduate Housing
Graduate students have a number of housing opportunities in the Morningside Heights neighborhood. The three main sources are University Apartment Housing (UAH), International House, and off-campus listings. UAH operates Columbia-owned apartments and dormitory-style suites in the Morningside area within walking distance of the campus. For further information, see UAH’s Web site at www.columbia.edu/ire.

International House, a privately owned student residence near the campus, has accommodations for about five hundred graduate students, both international and American, who attend various area colleges and universities. It provides a supportive and cross-cultural environment with many activities and resources, and it is conveniently located two blocks from the Engineering building. For more information, write or call: International House, 500 Riverside Drive, New York, NY 10027; 212-316-8400; or check their Web site at www.ihouse-nyc.org.

There are also a number of off-campus housing opportunities. The University operates Off-Campus Housing Assistance (OCHA), which lists rooms and apartments in rental properties not owned or operated by the University. Only students with a valid ID or admission acceptance letter are permitted to use the facility. OCHA is open throughout the winter and summer vacation periods except academic holidays. Students should call 212-854-2773 for office hours. OCHA also operates a Web page at www.columbia.edu/cu/ire/ocha. There is also a list of alternative housing opportunities maintained by the Office of Graduate Student Services in 524 S. W. Mudd. Students are sent the Alternative Housing flyer in their orientation packets.

UAH applications are sent along with acceptance packets from the Office of Graduate Student Services. They are also available in the Office of Graduate Student Services and the UAH Office. You can also seek additional information on the Columbia Students Page: www.columbia.edu/cu/students. Graduate housing through UAH is processed for the fall and spring terms only. Summer sublets are also available through individual referrals. The UAH
Office maintains an active listing for those interested. Due to the growing demand for housing, graduate housing is no longer guaranteed, but every effort is made to accommodate you. It is critical that you submit your housing application as soon as possible and that you follow the instructions in your acceptance packet. Housing applications received after the set date are not guaranteed housing. The order of priority for selection is: graduate fellowship recipients, Zone 1 students (those who live further than 250 miles from campus), and then Zone 2 students (those who live between fifty and 250 miles from campus). All continuing students and applications from Zone 3 areas (within fifty miles) are automatically placed on a waiting list.

**DINING SERVICES**

**First-Year Students**

All first-year students in residence are required to enroll in one of four dining plans, ranging from 210 meals and 150 Columbia Dining Dollars per term to 115 meals and 500 Dining Dollars per term. The dining plans are transacted through Columbia’s ID Card, called the Columbia Card, which serves as a convenient way to enjoy dining all over campus without carrying cash.

**Meals**

The meals portion of your dining plan enables you to help yourself to unlimited servings of food served buffet-style in John Jay Dining Hall. Brunch and dinner are served Monday through Sunday, while breakfast is served Monday through Thursday from 7:30 a.m. to 9:30 a.m.

**Dining Dollars**

In addition to meals, Dining Dollars comprise the other portion of your first-year dining plan. Each Dining Dollar is equal to one dollar and operates as a declining balance account, much like a debit card. Columbia Dining Services maintains fourteen dining facilities conveniently located on campus. Each of the locations, except Uris Deli, accepts Dining Dollars, an alternative to cash payment that is accessed by your Columbia Card (your student ID card).

With Dining Dollars, you will enjoy the ease and flexibility of cashless transactions. You will also enjoy the savings of sales tax on all food purchases each time you dine. Dining Dollars will roll over from year to year until you graduate.

**Upperclass and Graduate Students**

Many upperclass and graduate students who dine on campus open a Dining Dollars account; however, some choose to enroll in an upperclass/graduate student dining plan.

Dining Services offers four plans—150 meals per term, 75 meals per term, 45 meals per term, or 30 meals per term. All plans are accessed by the Columbia Card and can be used for meals in John Jay Dining Hall for brunch and dinner.

**Kosher Dining Plan**

All students who participate in a dining plan, including first year, upperclass, General Studies, or graduate students are eligible for the Columbia Kosher Dining Plan. Signing up for this dining plan allows access to a restricted kosher area within John Jay Dining Hall as well as Express Meals to go. CU kosher meals can also be exchanged for a kosher meal at Barnard's Hewitt Hall (kosher to kosher only). To sign up, select a plan from either the First Year Dining Plan or the Upperclass Dining Plan options, according to your student status, then elect to enroll in the Kosher Dining Plan. The addition of the Kosher Dining Plan adds another 10 percent to the cost of the selected plan. Visit the H&D Customer Service Center in 118 Hartley Hall (enrollment allowed at any point throughout the term) to sign up.

**Locations/Menus/Hours**

Locations, menus, and hours of all campus dining facilities can be found at www.columbia.edu/cu/dining.

**HEALTH SERVICES AND INSURANCE**

Health Services at Columbia provides integrated and accessible services and programs that support the well-being of the campus community and the personal and academic development of students. We offer a variety of programs and services specifically designed to meet stu-
Students’ health needs. We are comprised of more than 100 individuals: medical providers, nutritionists, disability specialists, health educators, therapists, psychiatrists, peer counselors, student personnel, support staff, and administrative professionals. Our programs are arranged in five departments.

Primary Care Medical Services (PCMS) provides comprehensive care for routine, urgent, and chronic medical needs of students. We also provide sexual health, reproductive, and gynecological services, travel medicine, LGBTQ health care, confidential HIV testing, immunizations, and specialist referrals. Through our Open Communicator function, students can make appointments online and view their primary care provider information (bios and photos are available online). When Primary Care is closed, a clinician-on-call can provide telephone advice about urgent medical conditions. John Jay Hall, 3rd and 4th floors.

Counseling and Psychological Services (CPS) offers short-term individual and couples counseling for students and their partners, student life support groups, medication consultation, training, and emergency consultation. Students are encouraged to make appointments and to select a CPS clinician (bios and photos are available online). When CPS is closed, a clinician-on-call can provide telephone advice about urgent mental health concerns. Alfred Lerner Hall, 8th floor.

Alice! Health Promotion Program seeks to help students achieve their personal and academic goals by disseminating useful, current health information in a straightforward and accessible manner, connecting students to appropriate resources, cultivating healthy attitudes and behaviors that encourage students to make informed decisions about their health, and fostering a culture that values and supports a healthy community. Alice! provides workshops and programs for students, and runs Go Ask Alice!, a health question-and-answer Web site. Alfred Lerner Hall, 7th floor.

Office of Disability Services (ODS) coordinates reasonable accommodations and support services for eligible students, including assistive technology, networking groups, academic skills workshops, and consultation with a learning specialist. Students seeking reasonable accommodations or support services from ODS are required to register with the office and provide disability documentation before receiving services. Registration and documentation guidelines are available online. Alfred Lerner Hall, Room 801.

Sexual Violence Prevention and Response Program (SVPRP) provides comprehensive and integrated education, support, and advocacy about sexual and relationship violence. Through innovative programming and community collaboration, SVPRP empowers students to heal from sexual violence, make informed decisions, and take action to end sexual and relationship violence. Alfred Lerner Hall, Room 301.

All Health Services programs adhere to strict standards of confidentiality in compliance with state and federal laws.

Contact Health Services at Columbia
www.health.columbia.edu
212-854-2284

On-Campus Emergency Resources
CAVA (Ambulance): 212-854-5555
Rape Crisis/Anti-Violence Support Center: 212-854-HELP, 212-854-WALK
Public Safety: 212-854-5555

Off-Campus Emergency Resources
St. Luke’s-Roosevelt Hospital Emergency Room 212-523-3335
Psychiatric Emergency 212-523-3347

Your Health at Columbia
Columbia students have access to comprehensive health care through a network of on- and off-campus services. On-campus medical and counseling appointments are covered through the Health Service Program. Off-campus medical services, such as emergency room visits or prescriptions, are covered through a student’s insurance plan. Columbia requires all full-time and residential students to enroll in both the Health Service Program and a mandatory insurance plan. To meet the insurance requirement, students may enroll in the Columbia Student Medical Insurance Plan or provide proof of comparable insurance coverage.

Health Service Program covers on-campus services, including routine and urgent medical appointments, short-term mental health counseling, disability services, educational programs, and sexual violence services. The Health Service Program also provides supplemental coverage for emergency health care, outpatient chemical dependency treatment, and outpatient mental health care. The Health Service Program is mandatory for all full-time students, and the fee automatically appears on students’ bills. Students pay no additional charge for accessing on-campus services, except for immunizations and travel assessments.

Columbia Student Medical Insurance Plan covers off-campus medical services. The plan has two levels: Comprehensive and Basic. All full-time students are automatically enrolled and billed for the Basic insurance plan, but may upgrade to the Comprehensive plan online. Students may submit a request to waive the insurance requirement online by providing proof of comparable insurance coverage (alternate plans must meet Columbia’s criteria for comparable coverage, available online). The Columbia Plan includes local, national, and worldwide health coverage, and discounts on dental and vision care.

Part-time students are encouraged to enroll in the Columbia Plan. Enrolling in the Columbia Plan will automatically enroll students in the Health Service Program, as the two plans are meant to work together to provide comprehensive medical care.

Immunization Requirements All students must fulfill two New York State public health immunization requirements before registering for classes. Students must document immunity to measles, mumps, and rubella (MMR) and make an informed decision about receiving the meningitis vaccine. The Columbia MMR documentation form is available online—complete the form, then mail, fax, or bring it to the Immunization Office. Students record their meningitis decision online. Directions for completing each requirement are available at our Web site.

Insurance and Immunization Questions
www.health.columbia.edu
E-mail: hs-enrollment@columbia.edu
Scholarships, Fellowships, Awards, and Prizes
FELLOWSHIPS

H. Dean Baker Fellowship (1982)
Awarded to support deserving graduate students in mechanical engineering.

Boris A. Bakhmeteff Research Fellowship in Fluid Mechanics
Provides a stipend for the academic year, with tuition exemption to be arranged by the recipient’s department, to a candidate for a doctoral degree in any department at Columbia University whose research is in fluid mechanics.

Quincy Ward Boese Fellowships
Predoctoral fellowships awarded annually to students studying under the Faculty of Engineering and Applied Science.

Roy S. Bonsib Memorial Fellowship (1957)
Awarded to worthy students for advanced study or research in engineering.

Arthur Brant Fellowship (1997)
Gift of Arthur Brant. Awarded to graduate students of the Henry Krumb School of Mines in the field of applied geophysics.

Samuel Willard Bridgham-William Petit Trowbridge Fellowship
A combined fellowship awarded annually for research.

Robert A.W. and Christine S. Carleton Fellowships in Civil Engineering
Fellowships awarded to graduate students in the Department of Civil Engineering and Engineering Mechanics.

Chiang Chen Fellowship (2004)
Chiang Chen Industrial Charity Foundation. Awarded to students in mechanical engineering.

Professor Bergen Davis Fellowship
Gift of Dr. Samuel Ruben. To be awarded to a student in chemical engineering and applied chemistry upon the recommendation of the senior professor in chemical engineering active in electrochemistry research.

George W. Ellis Fellowships
Awarded annually for graduate study in any division of the University. Open to graduate students who are residents of the state of Vermont or who have been graduated from a Vermont college or university.

Michael Frydman Endowed Fellowship (2000)
To support a fellowship to a deserving master’s student in the financial engineering program of the Department of Industrial Engineering and Operations Research.

Robert F. Gartland Fellowship
Awarded annually for graduate study in the Department of Industrial Engineering and Operations Research. Preference is given to students who are native-born U.S. citizens and who intend to pursue a career in business or finance.

GEM Fellowship
The GEM fellowship provides African-Americans, Hispanic Americans, and Native Americans access to graduate education. The fellowship includes tuition, fees, a stipend, and a paid summer internship. Applicants for this fellowship must be engineering or applied science majors.

Governor’s Committee on Scholarship Achievement
One year awards based on financial need. Renewal is based on academic progress, financial need, and availability of funds. The student applies directly to the GCSA; the awards are matched by the School and are not in supplement to initial School awards.

Carl Gryte Fellowship (2007)
Gift from friends of Professor Carl Campbell Gryte. Awarded to needy and deserving graduate students.

Daniel and Florence Guggenheim Fellowships
Two fellowships for the study of engineering mechanics in the Institute of Flight Structures.

M. D. Hassialis Memorial Fellowship (2002)
Gift of former students of the late Krumb Professor Emeritus Hassialis. Awarded to graduate students of the Henry Krumb School of Mines in the field of Earth resources economics and management.

Higgins Fellowships
Fellowships awarded annually to first-year graduate students.
Leta Stetter Hollingworth Fellowship
Awarded annually to women who are graduates of the University of Nebraska, with preference given to those who were born in Nebraska or received their earlier education there. Holders are eligible to apply for reappointment for one year. A gift of Harry L. Hollingworth in memory of his wife.

Edward J. Ignall Research Fellowship
Awarded annually to encourage and help support the research activities of a graduate student in the Department of Industrial Engineering and Operations Research who is selected by the department chair. Gift of family, friends, and former students in memory of Professor Edward J. Ignall.

George M. Jaffin Fellowship
Awarded for graduate study and research leading to the Ph.D. degree in orthopedic biomechanics by the Department of Bioengineering of the Hospital for Joint Diseases, Orthopedic Institute, and the Department of Mechanical Engineering. It carries tuition exemption and a twelve-month stipend of up to $10,000.

Herbert H. Kellogg Fellowship (1988)
Funded by former students and friends of Professor Emeritus H. H. Kellogg and the generous contribution of Professor Kellogg. Awarded to graduate students of the Henry Krumb School of Mines in the field of mineral engineering and chemical metallurgy.

Otto Kress Fellowship (1990)
Bequest of Mrs. Florence T. Kress in memory of her husband, Otto Kress. Awarded to postgraduate students.

Henry Krumb Fellowships
Annual fellowships in mining engineering, metallurgy, and ore dressing.

John F. T. Kuo Fellowship (1992)
Established by Dr. I. J. Won and other students of Professor Emeritus Kuo for the support of graduate students in applied geophysics.

Charles and Sarah Lapple Fellowship (2004)
Bequest of Charles (1936, 1937) and Sarah Lapple. Awarded to support deserving students in the Department of Chemical Engineering.

Kuo and Grace Li Memorial Fellowship (1993)
Gift from the Li Foundation Inc. Awarded to deserving graduate students interested in mining, mineral resources, metallurgy, and materials science.

Ralph H. McKee Fellowship (1979)
Bequest of Ralph H. McKee. Income to be used for fellowships and/or scholarships in the fields of mathematics or chemical engineering.

Benjamin Miller Memorial Fellowship
Awarded to a graduate student in the Department of Industrial Engineering and Operations Research. Preference will be given to students concerned with work in government-industry regulatory policy, procurement procedures and trade regulations.

Nicholas Fellowship
Designated for male students of Greek extraction or born in Greece and graduated from any Greek college or university. Recipients will be eligible to receive benefits for not more than two years.

Anthony Pesco Fellowship (2006)

Piyasombatkul Fellowship (2007)
Gift from Mr. and Mrs. Chatchai Piyasombatkul. Preference for students from Southeast Asia or Presidential Fellow candidates.

Presidential Distinguished Fellowships
These fellowships are awarded annually to selected incoming Ph.D., Eng.Sc.D., and master’s/Ph.D. students. Fellowships include tuition plus an annual stipend of $24,000 for up to four years, including three months of summer research. All applications for admission are considered for these new fellowships.

Queneau Fellowship Fund
Donated by Bernard R. Queneau. Awarded to a deserving graduate student in the Department of Earth and Environmental Engineering.

David M. Rickey Endowed Fellowship (2000)
Lydia C. Roberts Graduate Fellowships
Awarded annually. Open to persons born in Iowa who have been graduated from an Iowa college or university. In addition to the stipend, the fellow is reimbursed the cost of traveling once from Iowa to New York City and back. Special provisions: holders may not concentrate their studies in law, medicine, dentistry, veterinary medicine, or theology, and each holder must, when accepting the award, state that it is his or her purpose to return to Iowa for at least two years after completing studies at Columbia; holders are eligible for reappointment.

Leo Rubinstein Endowed Fellowship (2005)
Bequest of Leo Rubinstein (1963) and gift of Frederick Rubinstein. Awarded to deserving students studying applied mathematics or industrial design.

Frank E. Stinchfield Fellowship in Orthopedic Biomechanics
Awarded for graduate study and research in the Department of Mechanical Engineering through the Orthopedic Research Laboratory of the Department of Orthopedic Surgery, College of Physicians and Surgeons, it carries tuition exemption and a twelve-month stipend of up to $15,000.

Nickolas and Liliana Themelis Fellowship in Earth and Environmental Engineering (2000)
Gift of Nickolas and Liliana Themelis.

Theodore and Jennifer Tsung Fellowship

Christian R. Viros Fellowship
All French citizens and French nationals are eligible to apply. This fellowship is made possible by the generosity of Mr. Viros, a 1975 graduate of SEAS. The fellowship will include tuition and an annual stipend of $10,000.

Erwin S. and Rose F. Wolfson Memorial Engineering Fellowship (1979)
Gift of Erwin S. and Rose F. Wolfson.

ENDOWED SCHOLARSHIPS AND GRANTS

Cvi Abel Memorial Scholarship (2003)
Gift of Jack Abel.

Walter H. Aldridge (1936)
Gift of Walter H. Aldridge.

Alvey-Ferguson Company Scholarship (1948)
Gift of the Alvey-Ferguson Company.

Erwin H. Amick Memorial Scholarship (1970)
Gift of various donors for students in chemical engineering and applied chemistry.

Nathanial Arbitrue Scholarship (1985)
Gift of various donors in honor of Professor Nathanial Arbitrue for graduate and undergraduate students in the Henry Krumb School of Mines in the following specializations in order of preference: mineral beneficiation, mines, and physical metallurgy.

Attardo Scholarship (1999)

Gift of Michael M. Au (1990) to support undergraduate scholarships at The Fu Foundation School of Engineering and Applied Science, with a preference to be given to needy and deserving students who have graduated from Stuyvesant High School in New York City.

Frank and Harriet Ayer Scholarship (1977)
Bequest of Frank A. Ayer. Graduates of Deerfield Academy are given first preference.

Cesare Barbieri Scholarship (1953)
Gift of Cesare Barbieri Fund.

William S. Barstow Scholarship (1935)
Gift of William S. Barstow.

Edwin D. Becker Scholarship Fund (1993)
Gift of Edwin D. Becker (1956). Preference is given to students from the Rocky Mountain states.

John E. Bertram Memorial Scholarship (1990)
Gift of Mrs. Lucy Bertram and friends in honor of John E. Bertram. Awarded to students in electrical engineering or computer science.

Jerry and Evelyn Bishop Scholarship (1984)
Gift of Jerry (1942) and Evelyn Bishop for students in the Combined Plan Program. Preference is given to students in the program who attended Columbia College.

Paul H. Blaustein Scholarship (1994)
Gift of Barbara Blaustein, Stacey Blaustein Divack and Joshua Divack.

Philip P. Bonanno Scholarship (1999)
Donated by Philip P. Bonanno (1955), Fidelity Investments Charitable Gift Fund. Awarded to a deserving undergraduate.

Cornelius A. Boyle Scholarship (1962)
Bequest of Cornelius A. Boyle.

Lauren Breakiron Fund (1999)

Edwin W. and Mary Elizabeth Bright Scholarship in Mechanical Engineering (1985)
Gift of Edwin W. (1942) and Mary Elizabeth Bright. Awarded to a deserving mechanical engineering student who is a native-born U.S. citizen.

Lewis G. Burnell Memorial Scholarship (2001)
Gift of Roger W. Burnell in memory of his father, Lewis G. Burnell. Income to award an annual scholarship to a needy and deserving undergraduate student in The Fu Foundation School of Engineering and Applied Science.

Gifts from various donors in memory of Arthur J. Fiehn (1946).

Byron Fellowship (1980)
Bequest of Verna and Oscar Byron (1914).
Samuel J. Clarke Scholarship (1960)
Bequest of Agnes Robertson Clarke.

Class of 1885 (1910)
Gift of the Class of 1885 School of Mines in commemoration of the twenty-fifth anniversary of their graduation.

Class of 1889 (1939)
Gift of the Class of 1889 College and Engineering.

Class of 1900 (1940)
Gift of the Class of 1900 College and Engineering.

Class of 1902 (1952)
Gift of the Class of 1902 College and Engineering.

Class of 1906 (1940)
Gift of the Class of 1906 in honor of Frank D. Fackenthal (1906).

Class of 1907 (1937)
Gift of the Class of 1907. Preference is given to sons and descendants of class members.

Class of 1909 (1959)
Gift of the Class of 1909 in honor of John J. Ryan.

Class of 1913 (1963)
Gift of the Class of 1913 in commemoration of the fiftieth anniversary of their graduation.

Class of 1914 (1937)
Gift of the Class of 1914 College and Engineering for a pre-engineering or prearchitecture student.

Class of 1950 Endowed Scholarship (2000)
Gift of members of the Class of 1950 in commemoration of the fiftieth anniversary of their graduation. Awarded to a deserving undergraduate.

Class of 1951 Endowed Scholarship (2001)
Gift of members of the Class of 1951 in commemoration of the fiftieth anniversary of their graduation. Awarded to a deserving undergraduate.

Class of 1952 Endowed Scholarship (2002)
Established by Alexander Feiner to be awarded to a deserving undergraduate.

Hugo Cohn Scholarship (1984)
Awarded annually with preference given to electrical engineering students. Gift of Hugo Cohn (1909).

Herbert J. Cooper Scholarship (1999)
Gift of Mrs. Deborah Cooper and the Estate of Herbert J. Cooper (1946). Awarded to a deserving undergraduate.

Milton L. Cornell Scholarship (1958)
Gift of various donors in memory of Milton L. Cornell.

Paul and Lillian Costallat Scholarship (1972)
Gift of Paul and Lillian Costallat.

Frederick Van Dyke Cruser Scholarship (1980)
Bequest of Maude Adelaide Cruser. For students in chemical engineering with financial need.

Cytryn Family Endowed Scholarship (2002)
Gift of the Cytryn Family Fund to provide financial aid to deserving undergraduates.

Frank W. Demuth Scholarship (1965)
Bequest of Frank W. Demuth (1914).

Freda Imber Dicker Endowed Scholarship Fund (2000)
Gift of Dr. Stanley Dicker (1961) in honor of the hundredth anniversary of his mother’s birth (March 5, 1900).

Gift of Dr. Stanley Dicker (1961) in honor of his father, to support a deserving junior or senior in the Department of Biomedical Engineering.

James and Donna Down Scholarship (1997)
Gift of James (1973) and Donna Down to be awarded annually to a deserving minority undergraduate who has demonstrated academic achievement.

Stancliffe Bazen Downes Scholarship (1945)
Bequest of Bezena Treat Downes Merriman in honor of her brother, for a student in civil engineering.

Brooke Lynn Elzweig Scholarship (2002)
Gift of Gary Elzweig (1977). Income to support an annual scholarship for a deserving undergraduate student with high financial need.

Jack B. Freeman Scholarship (1994)
Supports an undergraduate at SEAS who also plays varsity baseball. Gift of Jack B. Freeman (1955).

Pier-Luigi Focardi Scholarship (1964)
Bequest of Clara G. Focardi.

Ford/EEOC Scholarship
Designated for minorities and women. Preference is given to Ford employees, their spouses, or children.

Z. Y. Fu Scholarship (1993)
Gift of The Fu Foundation for undergraduate scholarship support for the School of Engineering and Applied Science.

General Motors Scholarship
Designated for minorities and women. Preference is given to General Motors employees, their spouses, or children.

Ben and Ethelyn Geschwind Endowed Scholarship (2004)

Alger C. Gildersleeve Scholarship (1955)
Bequest of Josephine M. Gildersleeve, in honor of Alger G. Gildersleeve (1889).

Frederick A. Goetze Scholarship (1960)
Gift of William A. Baum, in honor of the former Dean of the School of Engineering.

Sarah E. Grant Memorial Scholarship (1997)
Gift of Geoffrey T. (1982) and Annette M. Grant in memory of their daughter,
Sarah, to be awarded annually to a deserving undergraduate who has demonstrated academic achievement.

Adam R. Greenbaum Memorial Scholarship Fund
Established in memory of Adam R. Greenbaum by his parents, relatives, and friends following his death in February 2001, when he was a sophomore. The scholarship is given to a SEAS sophomore who was named to the Dean's List as a first-year, as Adam was, with a preference to students from New Jersey and New York.

Luther E. Gregory Scholarship (1963)
Bequest of Luther E. Gregory (1893).

Gifts of friends of Robert Gross. For an applied physics student.

Gift of Wallace Grubman (1950) and the Grubman Graham Foundation to support an undergraduate student in chemical engineering.

Lawrence A. Gussman Scholarship (1987)
Gift of Lawrence Gussman (1938). Awarded annually to students studying computer science.


Ralph W. Haines Scholarship (2002)
Gift of Ralph W. Haines (1969) for needy and deserving students in The Fu Foundation School of Engineering and Applied Science.

A. A. Halden Scholarship (1962)
Established by bequests from Dorothy C. Halden and Barbara Schwartz in memory of Alfred A. Halden.

The Hamann Scholarship (1970)
Bequest of Adolf M. Hamann (1910).

Alfred M. and Cornelia H. Haring Scholarship (1965)
Gift of the Aeroflex Foundation for an annual scholarship in the School of Mines.

H. Field Haviland Scholarship Fund (1988)
Scholarships to be awarded equally between The Fu Foundation School of Engineering and Applied Science and Columbia College. Bequest of Henry F. Haviland (1902).

Harold T. Helmer Scholarship (1965)
Bequest of Harold T. Helmer.

David Bendel Hertz College/Engineering Interschool Scholarship (1989)
Gift of David B. Hertz (1939). Awarded in alternate years to the College and to the Engineering School to a student electing to receive a B.A. from Columbia College and a B.S. from The Fu Foundation School of Engineering and Applied Science.

Edward Gurnee Hewitt Scholarship (1980)
Bequest of Mary Louise Cromwell.

Prentice Hiam Memorial Scholarship (2007)

James T. Horn Scholarship (1938)
Gift of Sarah L. and Mary T. Horn, in memory of their brother, James T. Horn (1884).

Richard and Janet Hunter Scholarship (2000)
Gift of Richard (1967) and Janet Hunter. Scholarship awarded to 3-2 program participants entering the School of Engineering and Applied Science, with preferences given to graduates from Whitman College.

Jonathan Lewis Isaacs Memorial Scholarship (2001)
This scholarship was endowed in 2001 by Gary F. Jonas '66 and Jonathan L. Isaacs '66 as the Future Entrepreneurs Scholarship to acknowledge the thirty-fifth anniversary of their graduation from Columbia School of Engineering and Applied Science. On April 30, 2003, Mr. Isaacs died at the young age of fifty-seven, and the scholarship was then renamed in his memory by Gary F. Jonas, with the support of Jon's wife, Charlotte Isaacs.

Sheldon E. Isakoff Endowed Scholarship Fund (2000)
Gift of Sheldon E. (1945) and Anita Isakoff. Awarded to a deserving chemical engineering undergraduate.

Alfred L. Jaros Memorial Scholarship (1967)
Gift of various donors, in memory of Alfred L. Jaros (1911).

Cavalier Hargrave Jouet Scholarship (1941)

Alfred E. Kadell Scholarship (1995)
Bequest of the Estate of Alfred E. Kadell (1921).

Wayne Kao Scholarship (1988)
Awarded annually to undergraduate students. Gift of Mabel C. Kao in memory of Wayne Kao (1949).

Stanley A. and Minna Kroll Scholarship for Engineering and Computer Science (1987)
Gift of Stanley A. Kroll (1928). For undergraduates who are studying electrical engineering or computer science.

Henry Krumb Scholarship (1945)
Gift of Henry Krumb for annual scholarships in mining engineering, metallurgy, and ore dressing.

Jacob Kurtz Memorial Scholarship (1982)
Gift of Kulite Semiconductor Products, Inc., and Kulite Tungsten, for undergraduates, preferably studying in the fields of metallurgy or solid-state physics. In memory of Jacob Kurtz (1917).

Ronald A. Kurtz Scholarship Fund (1990)
Gift of Kulite Tungsten.
Lahey Scholarship (1932)
Bequest of Richard Lahey.

Charles and Sarah Lapple Scholarship (2004)
Bequest from the Estate of Charles E. Lapple and Sarah V. Lapple to be used to provide scholarships to deserving undergraduate students in The Fu Foundation School of Engineering and Applied Science. The students receiving the scholarship shall be designated Lapple Scholars.

Frank H. Lee Memorial Scholarship for Combined Plan Students (1986)
Awarded annually to a student in the Combined Plan Program in honor of Professor Frank H. Lee.

Leung Endowed Scholarship (2006)
Gift of Lawrence Leung. Awarded annually to a deserving undergraduate.

James F. Levens Scholarship (1973)
Bequest of Ola Levens Poole for students in chemical engineering and applied chemistry.

George J. Lewin Scholarship (1965)
Gift of George J. Lewin (1917) and friends. Preference given to hearing-impaired students.

Alvin and Richard H. Lewis Scholarship
Gift of Alvin and Helen S. Lewis in memory of their son, Richard Lewis (1963).

James M. and Elizabeth S. Li Endowed Scholarship (2006)
Gift of James (1968, 1970, 1976) and Elizabeth Li. Awarded to students majoring in industrial engineering and operations.

Robert D. Lilley Memorial Scholarship and Fellowship (1988)
For students who are in their final year of the 3-2 Combined Plan Program and who have a commitment to community service.

Bruce and Doris Lister Endowed Scholarship (2000)
Gift of Bruce A. Lister (1943, 1947) to support a needy and deserving undergraduate student in The Fu Foundation School of Engineering and Applied Science.

Anna Kazanjian and Guy Longobardo Scholarship (2007)

Donald D. MacLaren Scholarship (1995)
For an undergraduate student who is studying biochemical engineering. Established by Donald D. MacLaren (1945).


Ernest Marquardt Scholarship (1968)
Bequest of Ernest Marquardt (1912).

Louis F. Massa Scholarship (1952)
Bequest of Louis F. Massa (1890).

Ralph Edward Mayer Scholarship (1924)
Contributed by friends in memory of Professor Ralph Edward Mayer.

Henry Michel Scholarship (2005)
Gift of Mrs. Mary-Elizabeth Michel in memory of Henry Michel (1949). Scholarship awarded to deserving undergraduate students with preference given to civil engineering majors.

Stuart Miller Endowed Scholarship in Engineering (2003)
Gift of Stuart Miller, to be used to provide support for an undergraduate engineering student.

Robert I. Pearlman Scholarship (1989)

New Hope Foundation Scholarship (2006)
Gift of Lee and Margaret Lau. Awarded to a deserving undergraduate with preference to students from Ontario, Canada, or mainland China.

A. Peers Montgomery Memorial Scholarship (1990)
Gift of the family of A. Peers Montgomery (1926).

John J. Morch Scholarship (1963)
Bequest of John J. Morch.

Seeley W. Mudd Scholarship (1958)
Gift of the Seeley W. Mudd Foundation. Several awarded annually for maintenance, not for tuition. Recipient must be a U.S. citizen, and his or her grandfather must have been born a U.S. citizen. Special application required.

Frederick Noel Nye Scholarship (1971)
Bequest of Frederick Noel Nye (1927).

Parker Family Endowed Scholarship (2001)
Gift of Peter D. Parker (1972, 1974). Income to award an annual scholarship to a needy and deserving undergraduate student in The Fu Foundation School of Engineering and Applied Science.

Robert Pele Scholarship (1925)
Gift of E. E. Olcott (1874).

Brainerd F. Phillipson Scholarship (1936)
Gift of an anonymous donor in memory of Brainerd F. Phillipson.

Andre Planiol Scholarship (1967)
Bequest of Andre Planiol for a student from France.

Robert I. Pearlman Scholarship (1989)

Robert I. Pearlman Scholarship (1989)

Robert Pele Scholarship (1925)
Gift of E. E. Olcott (1874).

Brainerd F. Phillipson Scholarship (1936)
Gift of an anonymous donor in memory of Brainerd F. Phillipson.
students in The Fu Foundation School of Engineering and Applied Science.

**Polychrome-Gregory Halpern Scholarship**
For graduate and undergraduate students in chemical engineering and applied chemistry.

**Professor William H. Reinmuth Scholarship (1988)**
Gift of Curtis Instruments, Inc., awarded in alternate years to Columbia College and the Engineering School. Preference will be given to college students studying chemistry and to engineering students studying electrochemistry. Established in honor of Professor William H. Reinmuth.

Gift of Kevin T. Roach (1977). Income to provide tuition assistance to undergraduate students in engineering at Columbia University.

**The Frederick Roese r Fund for Student Aid (1934)**
An annual loan to help pay educational expenses, which is awarded to students chosen by the Committee on Scholarships. The amount is individually determined and is to be repaid only if and when the student can do so without personal sacrifice. Repayments go into the Frederick Roese r Research Fund for research in physics and chemistry.

Edgar Lewisohn Rossin Scholarship (1949)
Bequest of Edgar L. Rossin, to provide a scholarship for students in mining engineering.

Harry B. Ryker (1947)
Bequest of Miss Helen L. Ryker in memory of her brother, Harry Benson Ryker (1900).

Thomas J. Sands Endowed Scholarship Fund (2001)
Gift of Thomas J. Sands to support a scholarship for a needy and deserving undergraduate student at The Fu Foundation School of Engineering and Applied Science.

Peter K. Scaturro Scholarship Fund (1997)
Gift of Peter K. Scaturro (1982, 1985) to be used to support scholarships to students in SEAS or Columbia College, with preference given to scholar-athletes from Archbishop Molloy H.S. in Briarwood, Queens, NY.

Norman A. Schefer Scholarship (1999)
Gift of Norman A. Schefer (1950) and Fay J. Lindner Foundation. Awarded annually to a deserving and talented student at the School of Engineering.

Samuel Y. Sheng Scholarship (2007)

Mark Schlowsky-Fischer Scholarship (2005)
Gift of George Schlowsky (1965) in memory of Mark Schlowsky-Fischer (1997). Scholarship awarded to deserving undergraduate students with preference given to computer science majors.

Ralph J. Schwarz Scholarship (1993)
Gift of the Class of 1943 and other donors in memory of Ralph J. Schwarz (1943). To be awarded to academically outstanding students who require financial aid.

David C. and Gilbert M. Serber Memorial Scholarship (1950)
Gift of the Serber family, for a student in civil engineering, in honor of David Serber (1896).

Gift of Hemant and Varsha Shah to support undergraduate female minority students.

Jared K. Shaper Scholarship
For deserving and qualified candidates for degrees in engineering.

Silent Hoist and Crane Company (1950)
Gift of the Silent Hoist and Crane Company.

David W. Smyth Scholarship (1957)
Bequest of Mrs. Millicent W. Smyth, in memory of her husband, David W. Smyth (1902).

Gift of Gene F. Straube (SEAS 1950, CC 1949). The fund shall provide scholarships to undergraduate students who graduated from a high school or prep school in northern California, and who are pursuing studies in electrical engineering, computer engineering, or computer science.

Steve Tai and Kin-Ching Wu Endowed Scholarship Fund (2001)
Gift of Steve Tai (1980) for an annual scholarship to a needy and deserving undergraduate student at The Fu Foundation School of Engineering and Applied Science.

Tai Family Scholarship (2003)
Gift of Timothy Tai to be used to support Asian students demonstrating financial need and outstanding academic potential, with preference given to Hong Kong, Taiwanese, mainland Chinese, and Chinese-American applicants for admission. A T. Tai Family Scholar will be named in a first-year class, and with suitable academic achievement and continuing need, would retain that honor until graduation.

Grace C. Townsend Scholarship (1941)
Bequest of Miss Grace C. Townsend.

Theodosios and Ekaterine Typaldos Endowed Scholarship Fund (2000)
Gift of Andreas (1969) and Renee Typaldos and the Community Foundation of New Jersey. Awarded to deserving undergraduates. Preference is given to Greek-American students.

Upton Fellowship
For the children of employees of D. C. Heath and Company of Lexington, Massachusetts.

Kenneth Valentine Memorial Scholarship (1986)
Bequest of Julia H. Valentine, in memory of Kenneth Valentine (1914). Awarded annually with preference given to students in chemical engineering.

Frank Vanderpoel Scholarship (1936)
Bequest of Frank Vanderpoel.
William E. Verplanck Scholarship (1957)
Gift of Mrs. T. Bache Bleecker and Edward F. Verplanck (1912) in memory of their father, William E. Verplanck (1876).

Arnold Von Schrenk Scholarship (1943)
Bequest of Mrs. Helen von Schrenk in memory of her husband, Arnold von Schrenk.

George Wascheck Scholarship
Bequest of George Wascheck (1926).

J. Watumull Scholarship (1989)
For students in the Graduate School of Arts and Sciences and in the Engineering School who are of East Indian ancestry.

Wells and Greene Scholarship
Bequest of Josephine Wells Greene.

Herbert A. Wheeler Scholarship (1923)
Gift of Herbert A. Wheeler.

Frederick C. Winter Scholarship (1966)
Gift of various donors in memory of Frederick C. Winter (1943).

William F. Wurster Scholarship (1974)
Awarded to a student of chemical engineering and applied chemistry. Gifts of William F. Wurster (1913).

Robert H. and Margaret H. Wyld Scholarship
Gift of Robert H. (1904) and Margaret H. Wyld.

Max Yablick Memorial Scholarship (1986)
Bequest of Max Yablick (1914). Awarded annually with preference given to graduates of Hebrew day schools and to students in the Combined Plan Program with Yeshiva University.

Theresa Ann Yeager Memorial Scholarship (1983)
Gift of the family of Theresa Ann Yeager (1981) to support a woman who is enrolled in The Fu Foundation School of Engineering and Applied Science.

RESIDENCE HALL SCHOLARSHIPS

Class of 1887 Mines Residence Scholarship
Awarded annually to a third-year degree candidate, with preference given to descendants of members of the Class of 1887 Mines.

Class of 1896 Arts and Mines Scholarship
Awarded annually to a degree candidate in Columbia College, the Engineering School, or the Graduate School of Architecture and Planning, with preference given to descendants of members of the Class of 1896 Arts and Mines.

Class of 1916 College and Engineering Fund
Gift of the Class of 1916 College and Engineering.

ANNUAL GIFT FELLOWSHIPS AND SCHOLARSHIPS

Each year the University receives gifts of money, some of which are renewals, for fellowships and scholarships. The fellowships and scholarships made available in recent years as a result of such gifts are:

Asian Columbia Alumni Association Scholarship (1999)
General financial aid for Asian students.

Columbia-Whitman Memorial Scholarship
Awarded from time to time to a Whitman College preengineering junior for study in the Columbia Engineering School toward the B.S. degree. Maximum value: full tuition and fees for the academic year. The holder may apply for renewal.

Con Edison Minority and Female Scholarship Program
To aid deserving and promising minority or female students from within the Con Edison service territory who will be pursuing a career in engineering, by providing a renewable scholarship of at least $1,500 and a job internship. Financial need must be demonstrated.

Consolidated Natural Gas Company Fellowship
For graduate students in chemical engineering and applied chemistry.

DuPont Fellowship
In chemical engineering.

Everard A. Elledge Memorial Scholarship (1985)
Gift of Carol G. Elledge, in memory of Everard A. Elledge (1942).

Ioannou Scholarship (1999)
Donated by Constantine and Cecilia Ioannou, Constantine D & B, Ltd. Awarded to a deserving undergraduate, preference given to a Greek-American student.

Moses and Hannah Malkin Scholarship Fund Gift (2004)
Gift of Moses and Hannah Malkin for an undergraduate engineering scholarship.

Monsanto Chemical Company Scholarship
Open to students in Barnard College, Columbia College, and the Engineering School who are pursuing a program of study in chemical engineering or directed toward it.

Louis Morin Scholars and Fellows (2000)
Gift of the Louis Morin Charitable Trust. Designated for Jewish undergraduates, Ph.D.s, and postdocs.

The National Action Council for Minorities in Engineering Inc. Incentive Grants Program
Renewable grants ranging from $250 to $2,500 for minority students in good academic standing who continue to have financial need. These awards supplement the funds a student raises through work, family, schools, foundations, and government grant programs.

New York Chapter of the American Society for Metals Scholarship
In metallurgy.

Procter and Gamble Fellowship
In chemical engineering and applied chemistry.
Gifts of Benjamin A. Tarver Sr. and various donors in memory of Benjamin A. Tarver Jr. (2004), who passed away on April 8, 2002.

The Weinig Scholars Program at the School of Engineering and Applied Science (1995)
For engineering students who are of high academic achievement.

Westmoreland Davis Fellowship
For male graduate students from Virginia.

MEDALS AND PRIZES

American Society of Civil Engineers Associate Member Forum Award
Awarded annually to that member of the graduating class in civil engineering who has been most active in promoting the aims of the Society.

American Society of Civil Engineers Robert Ridgeway Award
Awarded to the senior showing the most promise for a professional career in civil engineering.

American Society of Mechanical Engineers
In recognition of outstanding efforts and accomplishments on behalf of the American Society of Mechanical Engineers Student Section at Columbia University.

The Applied Mathematics Faculty Award
Awarded to an outstanding senior in the applied mathematics program.

The Applied Physics Faculty Award
Awarded to an outstanding graduating senior in the applied physics program.

Edwin Howard Armstrong Memorial Awards
Awarded by the Faculty of Electrical Engineering to one outstanding graduating senior and one outstanding candidate for the M.S. degree, to honor the late Edwin Howard Armstrong, professor of electrical engineering and noted inventor of wideband FM broadcasting, the regenerative circuit, and other basic circuits of communications and electronics.

Theodore R. Bashkow Award
A cash award presented to a computer science senior who has excelled in independent projects. This is awarded in honor of Professor Theodore R. Bashkow, whose contributions as a researcher, teacher, and consultant have significantly advanced the art of computer science.

Charles F. Bonilla Medal
The Bonilla Medal is an award for outstanding academic merit. It is presented annually to that student in the graduating class in the Department of Chemical Engineering who best exemplifies the qualities of Professor Charles F. Bonilla.

The Tullio J. Borri '51 Award in Civil Engineering
A certificate and cash prize presented annually by the Department of Civil Engineering and Engineering Mechanics to a senior for outstanding promise of scholarly and professional achievement in civil engineering. This award has been made possible by gifts from the stockholder/employees and the board of directors of the Damon G. Douglas Company, a New Jersey-based general contractor, in appreciation of Mr. Borri's many years of dedicated service and visionary leadership as chairman and president.

Computer Engineering Undergraduate Prize
Awarded each year by vote of the computer engineering faculty to an outstanding senior in the computer engineering program.

The Computer Science Department Award of Excellence
A $200 cash prize to the student who has demonstrated outstanding ability in the field of computer science.

Edward A. Darling Prize in Mechanical Engineering
Established in 1903 by a gift from the late Edward A. Darling, formerly superintendent of Buildings and Grounds; a certificate and $100 cash prize awarded annually to the most faithful and deserving student of the graduating class in mechanical engineering.

Adam J. Derman Memorial Prize
Established in 1989 by family and friends in memory of Adam J. Derman, a member of SEAS class of 1989 and a graduate student in the Department of Industrial Engineering and Operations Research. A certificate and cash prize awarded annually by the Department of Industrial Engineering and Operations Research to a member of the graduating class who has demonstrated exceptional ability to make computer-oriented contributions to the fields of industrial engineering and operations research.

The William L. Everitt Student Awards Of Excellence
Given to two students who rank in the top 10 percent of their class, have an active interest in telecommunications, and are active in a professional organization.

Zvi Galil Award for Improvement in Engineering Student Life
Given annually to the student group that most improves engineering student life during the academic year. Established in honor of Zvi Galil, dean of the School from 1995 to 2007.

Jewell M. Garrelts Award
Awarded to an outstanding graduating senior who will pursue graduate study in the department that was so long and successfully shepherded by Professor Jewell M. Garrelts. This award is made possible by gifts from alumni and friends of Professor Garrelts and from the Garrelts family in honor of an outstanding engineer, educator, and administrator.

A certificate and cash prize established by a gift from Roger Guarino (1951) in memory of his son. To be awarded to one outstanding senior in the Industrial Engineering and Operations Research Department who, in the opinion of the faculty and Board of Managers of the Columbia Engineering School Alumni Association, has been active in undergraduate activities and has displayed leadership, school spirit, and scholarship achievement.
William A. Hadley Award in Mechanical Engineering
Established in 1973 by Lucy Hadley in memory of her husband. The award is made annually in the form of a certificate and cash to that student in the graduating class in mechanical engineering who has best exemplified the ideals of character, scholarship, and service of Professor William A. Hadley.

Thomas “Pop” Harrington Medal
Presented annually to the student who best exemplifies the qualities of character that Professor Harrington exhibited during his forty years of teaching. The medal is made possible by Dr. Myron A. Coler.

Illig Medal
Established in 1898 by a bequest from William C. Illig, E.M., 1882, and awarded by the faculty to a member of the graduating class for commendable proficiency in his or her regular studies.

Eliahu I. Jury Award
Established 1991 for outstanding achievement by a graduate student in the areas of systems communication or signal processing.

Charles Kandel Award
Medal and cash prize presented annually by the Columbia Engineering School Alumni Association to that member of the graduating class who has best promoted the interests of the School through participation in extracurricular activities and student-alumni affairs.

The Andrew P. Kosoresow Memorial Award for Excellence in Teaching and Service
Awarded each year by the Department of Computer Science to up to three computer science students for outstanding contributions to teaching in the department and exemplary service to the department and its mission.

Dongju Lee Memorial Award
Established in 2005 by family and friends in memory of Dongju Lee (DJ), graduate student in the Department of Civil Engineering and Engineering Mechanics, 1999–2003. A certificate and cash prize awarded annually by the department to a doctoral student specializing in geological/environmental engineering and of outstanding promise for a career in research and academia.

Sebastian B. Littauer Award
Established in 1979 in honor of Professor Littauer, a certificate and cash prize presented annually by the Department of Industrial Engineering and Operations Research to a senior for outstanding promise of scholarly and professional achievement in operations research.

Mechanical Engineering Certificate of Merit
In recognition of excellence in undergraduate studies.

Henry L. Michel Award in Civil Engineering
Established by the Columbia Engineering School Alumni Association in memory of Henry L. Michel (1949), who built Parsons Brinkerhoff and MacDonald into one of the world’s leading engineering companies. A certificate and cash prize is presented annually by the Department of Civil Engineering and Engineering Mechanics to a student or group of students in the Civil Engineering Department who demonstrate outstanding promise of leadership and professional achievement in civil and construction engineering. The award is in support of a project with emphasis on the construction industry in which the students participate.

Paul Michelman Award for Exemplary Service to the Computer Science Department
This award is given to a Ph.D. student in computer science who has performed exemplary service to the department, devoting time and effort beyond the call to further the department’s goals. It is given in memory of Dr. Paul Michelman ’93, who devoted himself to improving our department through service while excelling as a researcher.

Mindlin Scholar in Civil Engineering and Engineering Mechanics
This award will be made each year to a graduate student in the Department of Civil Engineering and Engineering Mechanics in recognition of outstanding promise of a creative career in research and/or practice. This award is made possible by gifts of friends, colleagues, and former students of Professor Raymond D. Mindlin, and, above all, by the Mindlin family. It is intended to honor the Mindlin brothers, Raymond, Eugene, and Rowland, who excelled in their respective scientific fields of engineering research, engineering practice, and medical practice.

Millman Award
A certificate and prize, in honor of Jacob Millman, awarded to two of the most outstanding teaching assistants for the academic year.

Russell Mills Award
Presented to a computer science major for excellence in computer science in memory of Russell C. Mills, a Ph.D. candidate in computer science who exemplified academic excellence by his boundless energy and intellectual curiosity.

The Moles’ Student Award in Civil Engineering
Awarded to the student in engineering whose academic achievement and enthusiastic application show outstanding promise of personal development leading to a career in construction engineering and management.

The James F. Parker Memorial Award (Mechanical Engineering Design Award)
James F. Parker served and represented Columbia engineering students as their dean from 1975 to 1984. He also distinguished himself in the pursuit and analysis of two-dimensional art. In recognition of his special combination of talents and their integration, the School of Engineering and Applied Science salutes the graduating student who has distinguished her or himself as a designer. A person of creative and innovative inclination receives the James Parker Medal, as evidenced by outstanding performance in courses integrating engineering analysis and design.

Robert Peele Prize
A prize of $500 awarded from time to time to that member of the graduating class in mining engineering who has shown the greatest proficiency in his or her course of studies.
Claire S. and Robert E. Reiss Prize
Gift of Robert Reiss, InterVentional Technologies Inc. Awarded to a graduating senior in biomedical engineering judged by faculty most likely to contribute substantially to the field.

Francis B. F. Rhodes Prize
Established in 1926 by Eben Erskine Olcott of the Engineering Class of 1874, in memory of his classmate, Francis Bell Forsyth Rhodes, School of Mines, 1874, and awarded from time to time to the member of the graduating class in materials science and metallurgical engineering who has shown the greatest proficiency in his or her course of study.

School of Engineering and Applied Science Scholar/Athlete Award
Presented from time to time by the Office of the Dean to that graduating student who has distinguished himself or herself as a varsity athlete and scholar.

School of Engineering Student Activities Award
This award is presented to an undergraduate degree candidate in The Fu Foundation School of Engineering and Applied Science who by virtue of his or her willingness, energy, and leadership has significantly contributed to the co-curricular life of the School.

Robert Simon Memorial Prize
The Robert Simon Memorial Prize was established in 2001 to honor Robert Simon, a Columbia alumnus who spent a lifetime making valuable contributions to computational and mathematical sciences, and is awarded annually by the Department of Applied Physics and Applied Mathematics to the doctoral student who has completed the most outstanding dissertation. Should no dissertation qualify in a given year, the prize may be awarded to either the most outstanding student who has completed a Master of Science degree in the department or to the most outstanding graduating senior in the department.

Richard Skalak Memorial Prize
The Richard Skalak Memorial Prize was founded in recognition of the pioneering contributions of Richard Skalak to the development of the biomedical engineering program at Columbia University. Dr. Skalak was an inspirational teacher and scholar who taught students and colleagues to appreciate the value of broad interactions between engineering and medicine, particularly in the fields of cardiovascular mechanics, tissue engineering, and orthopedics. The Richard Skalak Memorial Prize is awarded annually to a senior biomedical engineering student who exemplifies the qualities of outstanding engineering scholarship and breadth of scientific curiosity that form the basis for lifelong learning and discovery.

George Vincent Wendell Memorial Medal
Established in 1924 by the friends in the alumni and faculty of the late Professor George Vincent Wendell to honor and perpetuate his memory; a certificate and medal awarded annually by choice of the class and the faculty to that member of the graduating class who best exemplifies his ideals of character, scholarship, and service.

Undergraduate Citation in Civil Engineering
University and School Policies, Procedures, and Regulations
REGISTRATION AND ENROLLMENT

Registration is the mechanical process that reserves seats in particular classes for eligible students. It is accomplished by following the procedures announced in advance of each term’s registration period.

Enrollment is the completion of the registration process and affords the full rights and privileges of student status. Enrollment is accomplished by the payment or other satisfaction of tuition and fees and by the satisfaction of other obligations to the University.

Registration alone does not guarantee enrollment; nor does registration alone guarantee the right to participate in class. In some cases, students will need to obtain the approval of the instructor or of a representative of the department that offers a course. Students should check this bulletin, their registration instructions, the Directory of Classes, and also with an adviser for all approvals that may be required.

To comply with current and anticipated Internal Revenue Service mandates, the University requires all students who will be receiving financial aid or payment through the University payroll system to report their Social Security number at the time of admission. Newly admitted students who do not have a Social Security number should obtain one well in advance of their first registration.

International students should consult the International Students and Scholars Office, located at 524 Riverside Drive (212-854-3587), for further information.

Special billing authorization is required of all students whose bills are to be sent to a third party for payment. Students who are not citizens of the United States and who need authorization for special billing of tuition and/or fees to foreign institutions, agencies, or sponsors should go to the International Students and Scholars Office with two copies of the sponsorship letter.

University Regulations

Each person whose enrollment has been completed is considered a student of the University during the term for which he or she is enrolled unless his or her connection with the University is officially severed by withdrawal or for other reasons. No student enrolled in any school or college of the University shall at the same time be enrolled in any other school or college, either of Columbia University or of any other institution, without the specific authorization of the dean or director of the school or college of the University in which he or she is first enrolled.

The privileges of the University are not available to any student until enrollment has been completed. Students are not permitted to attend any University course for which they are not officially enrolled or for which they have not officially filed a program unless they have been granted auditing privileges.

The University reserves the right to withhold the privileges of registration and enrollment or any other University privilege from any person who has outstanding financial, academic, or administrative obligations to the University.

Continuous registration until completion of all requirements is obligatory for each degree. Students are exempted from the requirement to register continuously only when granted a voluntary or medical leave of absence by their Committee on Academic Standing (for undergraduate students) or the Office of Graduate Student Services (for graduate students).

Registration Instructions

Registration instructions are announced in advance of each registration period. Students should consult these instructions for the exact dates and times of registration activities. Students must be sure to obtain all necessary written course approvals and advisers’ signatures before registering. Undergraduate students who have not registered for a full-time course load by the end of the add period will be withdrawn from the School, as will graduate students who have not registered for any course work by the end of the add period. International students enrolled in graduate degree programs must maintain full-time status until degree completion.

DEGREE REQUIREMENTS AND SATISFACTORY PROGRESS

Undergraduate

Undergraduate students are required to complete the School’s degree requirements and graduate in eight academic terms. Full-time undergraduate registration is defined as at least 12 semester credits per term. However, in order to complete the degree, students must be
averaging 16 points per term. Students may not register for point loads greater than 21 points per term without approval from the Committee on Academic Standing.

To be eligible to receive the Bachelor of Science degree, a student must complete the courses prescribed in a faculty-approved major/program (or faculty-authorized substitutions) and achieve a minimum cumulative grade-point average (GPA) of 2.0. While the minimum number of academic credits is 128 for the B.S. degree, some programs of the School require a greater number of credits in order to complete all the requirements. Undergraduate engineering degrees are awarded only to students who have completed at least 60 points of course work at Columbia.

Undergraduates in the programs accredited by the Engineering Accreditation Commission of the ABET (chemical engineering, civil engineering, Earth and environmental engineering, electrical engineering, industrial engineering, and mechanical engineering) satisfy ABET requirements by taking the courses in prescribed programs, which have been designed by the departments so as to meet the ABET criteria.

**Attendance**

Students are expected to attend their classes and laboratory periods. Instructors may consider attendance in assessing a student’s performance and may require a certain level of attendance for passing a course.

**Graduate**

A graduate student who has matriculated in an M.S. program or is a special student is considered to be making normal progress if at the completion of 9 credits, he or she has earned a cumulative GPA of 2.5. Candidates in the Doctor of Engineering Science (Eng.Sc.D.) and professional programs are expected to achieve a 3.0 grade point average at the completion of 9 points of course work.

Thereafter, graduate students are considered to be making minimum satisfactory progress if they successfully complete at least 75 percent of all courses they have registered for as candidates for the degree with grades of C- or better. Students placed on academic probation because of their grades are nonetheless considered to be making minimum satisfactory progress for their first term on probation (see chapter “Academic Standing,” following).

Degree requirements for master’s and professional degrees must be completed within five years; those for the doctoral degrees must be completed within seven years. A minimum cumulative grade-point average of 2.5 (in all courses taken as a degree candidate) is required for the M.S. degree; a minimum GPA of 3.0 is required for the professional degree and the Doctor of Engineering Science (Eng.Sc.D.) degree. The minimum residence requirement for each Columbia degree is 30 points of course work completed at Columbia.

**Changes in Registration**

A student who wishes to drop or add courses or to make other changes in his or her program of study after the add/drop period must obtain the signature of his or her adviser. A student who wishes to drop or add a course in his or her major must obtain department approval. The deadline for making program changes in each term is shown in the Academic Calendar. After this date, undergraduate students must petition their Committee on Academic Standing; graduate students must petition the Office of Graduate Student Services. For courses dropped after these dates, no adjustment of fees will be made. Failure to attend a class without officially dropping the class will result in a grade indicating permanent unofficial withdrawal (UW).

**Transfer Credits**

Undergraduate students may obtain academic credit toward the B.S. degree by completing course work at other accredited institutions. Normally, this credit is earned during the summer. To count as credit toward the degree, a course taken elsewhere must have an equivalent at Columbia and the student must achieve a grade of at least C. The institution must be an accredited four-year college. To transfer credit, a student must obtain prior approval from his or her adviser and the department before taking such courses. Courses may only be taken elsewhere if a student is behind in points. A course description and syllabus should be furnished as a part of the approval process. Courses
taken before the receipt of the high school diploma may not be credited toward the B.S. degree. A maximum of 6 credits may be credited toward the degree for college courses taken following the receipt of a high school diploma and initial enrollment.

Graduate students are not eligible for transfer credits.

Examinations

Midterm examinations: Instructors generally schedule these in late October and mid-March.

Final examinations: These are given at the end of each term. The Master University Examination Schedule is available online and is confirmed by November 1 for the fall term and April 1 for the spring term. This schedule is sent to all academic departments and is available for viewing on the Columbia Web site. Students should consult with their instructors for any changes to the exam schedule. Examinations will not be rescheduled to accommodate travel plans.

Note: If a student has three final examinations scheduled during one calendar day, as certified by the Registrar, an arrangement may be made with one of the student’s instructors to take that examination at another, mutually convenient time during the final examination period. This refers to a calendar day, not a twenty-four-hour time period. Undergraduate students unable to make suitable arrangements on their own should contact their adviser. Graduate students should contact the Office of Graduate Student Services.

Transcripts and Certifications

The University abides by the provisions of the Federal Family Educational Rights and Privacy Act (FERPA) of 1974. This act ensures a wide range of rights, including but not limited to information about student records that the University maintains, who maintains them, who has access to them, and for what purposes access is granted. The act also permits the University to release “directory information” without a student’s consent. In addition, the act guarantees students access to their records and restricts the access of others.

Students who wish to restrict access to their directory information may do so on the Morningside campus at the Student Service Center, 205 Kent. The guidelines are available on Columbia Web. Questions about the interpretation of the guidelines should be referred to the University’s General Counsel, 412 Low Library.

You may obtain an official transcript of your academic record at Columbia University by writing to:

Student Service Center
Columbia University
Mail Code 9202
1150 Amsterdam Avenue
New York, NY 10027

Attention: Transcripts

Please include the following information with your request: current and former names; personal identification number (P!D) if known; schools attended and dates of attendance; degrees awarded and dates awarded; number of transcripts desired and complete address for each; your current address and telephone number; your signature authorizing the release of your transcript. You may also order transcripts in person at 205 Kent Hall on the Morningside campus (9:00 a.m.–5:00 p.m., Monday–Friday). Currently enrolled students may order transcripts for themselves and for colleges and universities via the Student Services Web page at www.columbia.edu/cu/students. If you need an official printed report, you must request a transcript (please see Transcripts and Certifications above).

All graduate students must have a current mailing address on file with the Registrar’s Office.

Transcript Notations

The grading system is as follows:

A, excellent; B, good; C, satisfactory; D, poor but passing; F, failure (a final grade not subject to re-examination). Occasionally, P (Pass) is the only passing option available. The grade-point average is computed on the basis of the following index: A=4, B=3, C=2, D=1, F=0. Designations of + or – (used only with A, B, C) are equivalent to 0.33 (i.e., B+ =3.33; B– = 2.67). Grades of P, INC, UW, and NU will not be included in the computation of the grade-point average.

The mark of R (registration credit; no qualitative grade earned) is not accepted for degree credit in any program. R credit is not available to undergraduate students. In some divisions of the University, the instructor may stipulate conditions for the grade and report a failure if those conditions are not satisfied. The R notation will be given only to those students who indicate, upon registration and to the instructor, their intention to take the course for R, or who, with the approval of the instructor, file written notice of change of intention with the Registrar not later than the last day for change of program. Students wishing to change to R credit after this date are required to submit the Dean’s written approval to the Registrar. A course which has been taken for R credit may not be repeated later for examination credit. The mark of R is automatically given in Doctoral Research Instruction courses.

Report of Grades

Students are notified by e-mail when grades are submitted. Grades can then be viewed the following day by using the Student Services Online feature located on the Student Services home page at www.columbia.edu/students. If you need an official printed report, you must request a transcript (please see Transcripts and Certifications above).

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The mark of R (registration credit; no qualitative grade earned) is not accepted for degree credit in any program. R credit is not available to undergraduate students. In some divisions of the University, the instructor may stipulate conditions for the grade and report a failure if those conditions are not satisfied. The R notation will be given only to those students who indicate, upon registration and to the instructor, their intention to take the course for R, or who, with the approval of the instructor, file written notice of change of intention with the Registrar not later than the last day for change of program. Students wishing to change to R credit after this date are required to submit the Dean’s written approval to the Registrar. A course which has been taken for R credit may not be repeated later for examination credit. The mark of R is automatically given in Doctoral Research Instruction courses.
The mark of UW: given to students who discontinue attendance in a course but are still officially registered for it, or who fail to take a final examination without an authorized excuse.

The mark of INC (incomplete): granted only in the case of incapacitating illness as certified by the Health Services at Columbia, serious family emergency, or circumstances of comparable gravity. Undergraduate students request an INC by filling out theIncomplete Request Form with their advising dean. The deadline is the last day of class in the semester of enrollment. Students requesting an INC must gain permission from both the Committee on Academic Standing (CAS) and the instructor. Graduate students should contact their instructor. If granted an INC, students must complete the required work within a period of time stipulated by the instructor but not to exceed one year. After a year, the INC will be automatically changed into an F or contingency grade.

The mark of YC (year course): a mark given at the end of the first term of a course in which the full year of work must be completed before a qualitative grade is assigned. The grade given at the end of the second term is the grade for the entire course.

The mark of CP (credit pending): given only in graduate research courses in which student research projects regularly extend beyond the end of the term. Upon completion, a final qualitative grade is then assigned and credit allowed. The mark of CP implies satisfactory progress.

The mark of MU (make-up examination): given to a student who has failed the final examination in a course but has been granted the privilege of taking a second examination in an effort to improve his or her final grade. The privilege is granted only when there is a wide discrepancy between the quality of the student’s work during the term and his or her performance on the final examination, and when, in the instructor's judgment, the reasons justify a make-up examination. A student may be granted the mark of MU in only two courses in one term, or, alternatively, in three or more courses in one term if their total point value is not more than 7 credits. The student must remove MU by taking a special examination administered as soon as the instructor can schedule it.

The mark of P/F (pass/fail): this grading option is designed to allow students to extend their academic inquiry into new areas of study. No course taken for pass/fail may be used to satisfy a student’s program and degree requirements. The P/F option does not count toward degree requirements for graduate students.

Credit for Internships
Students who participate in noncompensated off-campus internships may have the internships noted on their transcripts. Approval for this notation may be obtained from your adviser. Formal notification from the employer is required. Graduate students may petition the office of Graduate Student Services for this notation.

Name Changes
Students may change their name of record only while currently enrolled in the University. There is no charge for this service, but students must submit a name change affidavit to the Student Service Center. Affidavits are available from this office. When you graduate or cease to enroll in the University, your name of record is considered final and may not be changed unless you enroll again at the University.

GRADUATION
Columbia University awards degrees three times during the year: in February, May, and October. There is one commencement ceremony in May. Only students who have completed their requirements for the degree may participate in graduation ceremonies.

Application or Renewal of Application for the Degree
In general, students pick up and file an application for a degree at their schools or departments, but there are several exceptions. Candidates for master of science and professional degrees must pick up and file their application for the degree with the Student Service Center, 205 Kent Hall. Candidates for doctoral and master of philosophy degrees should inquire at their departments but must also follow the instructions of the Dissertation Office, 107 Low Library.

General deadlines for applying for graduation are November 1 for February, December 1 for May, and August 1 for October. (When a deadline falls on a weekend or holiday, the deadline moves to the next business day.) Doctoral students must deposit their dissertations two days before the above conferral dates in order to graduate.

Students who fail to earn the degree by the conferral date for which they applied must file another application for a later conferral date.

Diplomas
There is no charge for the preparation and conferral of an original diploma. If your diploma is lost or damaged, there will be a charge of $100 for a replacement diploma. Note that replacement diplomas carry the signatures of current University officials. Applications for replacement diplomas may be requested by calling the Student Service Center, Graduation, Degree Audit, and Diploma Division, 212-854-4400.
ACADEMIC STANDING

ACADEMIC HONORS

Dean’s List
To be eligible for Dean’s List honors, an undergraduate student must achieve a grade-point average of 3.5 or better and complete at least 15 graded credits with no incompletes or grades lower than C.

Honors Awarded with the Degree
At the end of the academic year, a select portion of the candidates for the Bachelor of Science degree who have achieved the highest academic cumulative grade-point average are accorded Latin honors. Latin honors are awarded in three categories (cum laude, magna cum laude, and summa cum laude) to no more than 25 percent of the graduating class, with no more than 5 percent summa cum laude, 10 percent magna cum laude, and 10 percent cum laude. Honors are awarded on the overall record of graduating seniors who have completed a minimum of six semesters at Columbia. Students may not apply for honors.

ACADEMIC MONITORING

The Fu Foundation School of Engineering and Applied Science Committee on Academic Standing determines academic policies and regulations for the School except in certain instances when decisions are made by the faculty as a whole. The Committee on Academic Standing is expected to uphold the policies and regulations of the Committee on Instruction and determine when circumstances warrant exceptions to them.

The Office of Graduate Student Services will monitor the academic progress of graduate students in consultation with the departments.

Academic performance is reviewed by advisers at the end of each semester. The Committee on Academic Standing meets, in consultation with the departments, to review undergraduate grades and progress toward the degree.

Indicators of academic well-being are grades that average above 2.0 each term, in a coordinated program of study, with no incomplete grades.

Possible academic sanctions include:
- Warning: C– or below in any core science course; low points toward degree completion
- Academic Probation: Students will be placed on academic probation if they
  - fall below a 2.0 GPA in a given semester
  - have not completed 12 points successfully in a given semester
  - are a first-year student and have not completed chemistry, physics, University Writing, Gateway Lab, and calculus during the first year.
  - receive a D, F, UW, or unauthorized incomplete in any first-year/sophomore required courses
  - receive a D, F, UW or unauthorized incomplete in any course required for the major
  - receive straight C’s in the core science courses (chemistry, calculus, physics)
- Continued Probation: Students who are already on probation and fail to meet the minimum requirements as stated in their sanction letter
- Strict Probation: Students who are already on probation and are far below minimum expectations; this action is typically made when there are signs of severe academic difficulty
- Dismissal: Students who have a history of not meeting minimum requirements will be dismissed from The Fu Foundation School of Engineering and Applied Science.

MEDICAL LEAVE OF ABSENCE

A medical leave of absence for an undergraduate student is granted by the Committee on Academic Standing to a student whose health prevents him or her from successfully pursuing full-time study. Undergraduates who take a medical leave of absence are guaranteed housing upon their return. A medical leave of absence for a graduate student is granted by the Office of Graduate Student Services. Documentation from a physician or counselor must be provided before such a leave is granted. In order to apply for readmission following a medical leave, a student must submit proof of recovery from a physician or counselor. A medical leave is usually for a period of one year but cannot be longer than two years. If the student does not return within the two-year timeframe, they will be permanently withdrawn from the School.

The Office of Graduate Student Services will monitor the academic progress of graduate students in consultation with the departments.

A voluntary leave of absence may be granted by the Committee on Academic Standing to undergraduate students who request a temporary withdrawal from The Fu Foundation School of Engineering and Applied Science for a nonmedical reason. Students considering a voluntary leave must discuss this option in advance with their advising dean. Voluntary leaves are granted for a period of one calendar year only; VLOAs will not be granted for one semester, or for more than one year. Students must be in good academic standing at the time of the leave, and must be able to complete their major and degree in eight quarters. Students may not take courses for transferable credit while on leave. Finally, students who choose to take voluntary leaves are not guaranteed housing upon return to the University. International students should contact the International Students and Scholars Office to ensure that a leave will not jeopardize their ability to return to SEAS.
LEAVE FOR MILITARY DUTY

Any student who is a member of the National Guard or other reserve component of the armed forces of the United States or of the state-organized militia and is called or ordered to active duty will be granted a military leave of absence for the period of active duty and for one year thereafter. Upon return from military leave of absence, the student will be restored to the educational status attained prior to being called or ordered to such duty without loss of academic credits earned, scholarships or grants awarded, or tuition or other fees paid prior to the commencement of active duty. The University will credit any tuition or fees paid for the period of the military leave of absence to the next enrollment period or will refund the tuition and fees paid to the student, at the student’s option. Students returning from military duty are guaranteed housing.

Students in need of a military leave of absence should contact the Dean of Students for their school.

INVOLUNTARY LEAVE OF ABSENCE POLICY

The Dean of Students or his/her designee may place a student on an involuntary leave of absence for reasons of personal or community safety. This process will be undertaken only in extraordinary circumstances when there is compelling information to suggest that the student is engaging in or is at heightened risk of engaging in behavior that could lead to serious injury to others, including as a result of physical or psychological illness. In addition, the involuntary leave process may be initiated if, based on an individualized assessment from Counseling and Psychological Services or other University personnel, it is determined that there is a significant risk that the student will harm him/herself, and that the risk cannot be eliminated or reduced to an acceptable level through reasonable and realistic accommodations and/or on-campus supports.

This policy will not be used in lieu of disciplinary actions to address violations of Columbia University rules, regulations, or policies. A student who has engaged in behavior that may violate rules, regulations, or policies of the University community may be subject to the Dean’s Discipline Process of his/her particular school. A student may be required to participate in the disciplinary process for his/her school coincident with placing the student while on an involuntary leave of absence. A student who is placed on an involuntary leave of absence while on academic and/or disciplinary status will return on that same status.

Before an involuntary leave is considered, efforts may be made to encourage the student to take a voluntary medical leave of absence. These procedures are described in the Medical Leave of Absence Policy on page 230. A readmission process may still be required of a student electing a voluntary medical leave to determine his/her readiness to return to school. A student will not be deemed ready to return to school if returning may increase the risk of self-harm and/or harm to others.

International students are advised that an involuntary leave of absence will likely affect their student visa status and should consult with the International Students and Scholars Office (ISSO). When safety is an immediate concern, the Dean of Students or his/her designee may remove a student from the campus pending final decision on an involuntary leave. If this action is deemed necessary, the student will be given notice of the removal. An opportunity to be heard by the Dean of Students and, if desired, appeal the final decision will be provided at a later time.

For the complete policy and guidelines, consult your advising dean in the Center for Student Advising.

REQUIRED MEDICAL LEAVE FOR STUDENTS WITH EATING DISORDERS

With eating disorders, a medical leave is sometimes necessary to protect the safety of a student. Usually this is because the student’s illness is advanced enough to require hospitalization or intensive day treatment beyond the scope of University medical and psychological resources. A medical leave is also sometimes deemed necessary when an individual student’s eating disorder has negatively impacted the integrity of the University’s learning environment.

Before an involuntary medical leave is considered, efforts will be made to encourage the student to take a voluntary medical leave, thus preserving, to the extent possible, confidentiality and privacy. The policy will be invoked only in extraordinary circumstances, when a student is unable or unwilling to request a voluntary medical leave of absence.

For the complete policy and guidelines, consult your advising dean in the Center for Student Advising.

READMISSION

Students seeking readmission to The Fu Foundation School of Engineering and Applied Science must submit evidence that they have achieved the purposes for which they left. Consequently, specific readmission procedures are determined by the reasons for the withdrawal. Further information for undergraduate students is available in the Center for Student Advising. Graduate students should see the Office of Graduate Student Services.

Students applying for readmission should complete all parts of the appropriate readmission procedures by June 1 for the autumn term or October 1 for the spring term.
LIFE IN THE ACADEMIC COMMUNITY
The Fu Foundation School of Engineering and Applied Science within Columbia University is a community. Admitted students, faculty, and administrators come together and work through committees and other representative bodies to pursue and to promote learning, scholarly inquiry, and free discourse. As in any community, principles of civility and reasoned interaction must be maintained. Thus, methods for addressing social as well as academic behaviors exist.

RULES OF UNIVERSITY CONDUCT
The Rules of University Conduct (Chapter XLIV of the Statutes of the University) provide special disciplinary rules applicable to demonstrations, rallies, picketing, and the circulation of petitions. These rules are designed to protect the rights of free expression through peaceful demonstration while at the same time ensuring the proper functioning of the University and the protection of the rights of those who may be affected by such demonstrations.

The Rules of University Conduct are University-wide and supersede all other rules of any school or division. Minor violations of the Rules of Conduct are referred to the normal disciplinary procedures of each school or division (“Dean’s Discipline”). A student who is charged with a serious violation of the Rules has the option of choosing Dean’s Discipline or a more formal hearing procedure provided in the Rules.

All University faculty members, students, and staff members are responsible for compliance with the Rules of University Conduct. Copies of the full text are available at the Office of the University Senate, 406 Low Memorial Library.

DISCIPLINE
The continuance of each student upon the rolls of the University, the receipt of academic credits, graduation, and the conferring of the degree are strictly subject to the disciplinary powers of the University.

Although ultimate authority on matters of student discipline is vested in the Trustees of the University, the Dean of the School and his staff are given responsibility for establishing certain standards of behavior for SEAS students beyond the regulations included in the Statutes of the University and for defining procedures by which discipline will be administered.

We expect that in and out of the classroom, on and off campus, each student in the School will act in an honest way and will respect the rights of others. Freedom of expression is an essential part of University life, but it does not include intimidation, threats of violence, or the inducement of others to engage in violence or in conduct which harasses others. We state emphatically that conduct which threatens or harasses others because of their race, sex, religion, disability, sexual orientation, or for any other reason is unacceptable and will be dealt with very severely. If each of us at Columbia can live up to these standards, we can be confident that all in our community will benefit fully from the diversity to be found here. Any undergraduate student who believes he or she has been victimized should speak with an adviser in the Center for Student Advising, a member of the Residential Programs staff, or a member of the Office of Judicial Affairs; graduate students should speak with an officer in the Office of Graduate Student Services.

While every subtlety of proper behavior cannot be detailed here, examples of other actions that would subject a student to discipline are:

- dishonesty in academic assignments or in dealings with University officials, including members of the faculty
- knowingly or recklessly endangering the health or safety of others
- intentionally or recklessly destroying, damaging, or stealing property
- possession, distribution, or use of illegal drugs
- possession of weapons
- refusal to show identification at the request of a University official; failure to respond to the legitimate request of a University official exercising his or her duty
- threatening, harassing, or abusing others
- violating local, state, or federal laws
- violating the “Rules of University Conduct” (copies of which are available in 406 Low Library and other locations mentioned above)
- violating the rules of the residence halls as outlined in the “Guide to Living”; this also applies to all fraternity and sorority housing
- violating the University’s Alcohol Policy
- violating the University’s Sexual Assault Policy (see page 239)
- violating the rules governing Columbia University Information Technology
(CUIT) policies and procedures
• selling or otherwise commercializing
  notes (whether taken in class by a
  student or distributed to the class
  by an instructor), syllabi, exams, or
  content on a University or individual
  faculty member Web site that is not
  accessible to anyone outside of the
  University community
• representing any commercial interest
  on campus or operating any business
  on campus without authorization from
  the Associate Dean of Career Services

DISCIPLINARY PROCEDURES
Many policy violations that occur in the
Residence Halls rules are handled by the
Associate Directors of Residential
Programs. Some serious offenses are
referred directly to the Assistant Dean
for Judicial Affairs. Violations in
University Apartment Housing are han-
dled by building managers and housing
officials. Some serious offenses are
referred directly to the School’s housing
liaison in the Office of Graduate Student
Services.

Most violations of rules concerning
fraternities or sororities as organizations
are handled by the Assistant Director of
Greek Life and Leadership. Some seri-
ous offenses are referred directly to the
Office of Judicial Affairs.

In matters involving rallies, picketing,
and other mass demonstrations, the
Rules of University Conduct outlines
procedures.

The Office of Judicial Affairs (located
within the Division of Student Affairs) is
responsible for all disciplinary affairs
concerning undergraduate students that
are not reserved to some other body.

The Office of Graduate Student Services
is responsible for all disciplinary affairs
concerning graduate students that are
not reserved to some other body.

Dean’s Discipline Process for
Undergraduate Students
The purpose of the Dean’s Discipline
process is twofold. First, it is used to
determine the accused student’s
responsibility for the alleged violation(s)
of SEAS or University policy(ies). In addi-
tion, it is an opportunity for the student
to engage in a meaningful conversation
regarding his or her role as a member of
the Columbia community. The Dean’s
Discipline process is not an adversarial
process, nor is it a legalistic one, and
therefore the technical rules of evidence
applicable to civil and criminal court
cases do not apply.

After a complaint is received a stu-
dent may be removed from housing
and/or placed on interim suspension by
the Student Affairs staff if it is deter-
mined that the student’s behavior makes
his or her presence on campus a danger
to the normal operations of the institu-
tion, or to the safety of himself or herself
or others or to the property of the
University or others.

When a complaint is received, the
Office of Judicial Affairs determines
whether Dean’s Discipline is an appro-
priate response or if the complaint should
be referred elsewhere. If Dean’s
Discipline is to occur, a student is
informed in writing of the complaint
made against him/her and of the time
and place of the hearing. At the hearing,
at least two members of the staff of the
Dean of Student Affairs present the
accused student with the information
that supports the allegation that he/she
has violated SEAS or University
policy(ies). The student is then asked to
respond and will be given an opportunity
to present information on his or her
behalf.

At the conclusion of the hearing, the
hearing administrators will make a deter-
mination, based on all of the information
available to them, regarding whether the
accused student is responsible for the
violation. The standard of proof that the
hearing administrators will use to make this
determination is the preponderance of
the evidence standard. This standard
allows for a finding of responsibility if the
information provided in the hearing
shows that it is more likely than not that
a violation of Columbia policy(ies)
occurred. If the student is found respon-
sible, the degree of seriousness of the
offense and the student’s previous disci-
plinary record, if any, will determine the
severity of the sanction that will be
issued. The student will be notified of
the outcome of the hearing in writing.

A student found responsible after a
hearing has the right to request an
appeal of the decision and the resulting
sanctions. There are three grounds upon
which an appeal of the decision may be
made. A student found responsible for
the violation of Columbia policy(ies) may
request a review of the decision if (1) the
student has new information, unavailable
at the time the hearing; (2) the student
has concerns with the process that may
change or affect the outcome of the
decision; or (3) the student feels that
the sanction issued is too severe. The
request for review must be made in
writing to the individual indicated in the
decision letter and must be received within ten calendar days (or as indicated in the hearing outcome letter) after the student receives notice of the hearing outcome. For more information about the discipline process for undergraduate students, please visit the Office of Judicial Affairs Web site at www.studentaffairs.columbia.edu/judicial affairs.

**Discipline Process for Graduate Students**

When sufficient evidence exists, a student is charged with a particular offense and a hearing is scheduled. Present at a hearing for graduate students are the charged student and at least two members of the Office of Graduate Student Services staff. At the hearing, the student is presented with the evidence that supports the accusation against him or her and is asked to respond to it. The student may then offer his or her own evidence and suggest other students with whom the deans or their designee might speak. On the basis of the strength of the evidence and the student's response, the deans or their designee reach a determination and notify the student of their decision after the hearing. The student can be exonerated, found guilty of the accusations, or found not guilty due to insufficient evidence; if he or she is found to have committed an infraction, the penalty can range from a warning to disciplinary proceedings against a student.

A student alleged to have engaged in academic dishonesty will be subject to the Dean's Discipline process (see page 233). Students found responsible for academic dishonesty may face reports of such offenses on future recommendations for law, medical, or graduate school. The parents or guardians of students found responsible may also be notified.

**ACADEMIC DISHONESTY**

Academic dishonesty includes but is not limited to intentional or unintentional dishonesty in academic assignments or in dealing with University officials, including faculty and staff members.

Here are the most common types of academic dishonesty:

- plagiarism (copying word for word or paraphrasing without proper citation or acknowledgment from a written or electronic source)
- cheating on examinations
- unauthorized collaboration on an assignment
- receiving unauthorized assistance on an assignment
- copying computer programs
- forgery
- submitting work for one course that has already been used for another course
- unauthorized distribution of assignments and exams
- lying to a professor or University officer
- obtaining advance knowledge of exams or other assignments without permission

A student alleged to have engaged in academic dishonesty is subject to the Dean's Discipline process (see page 233).

Students found responsible for academic dishonesty may face reports of such offenses on future recommendations for law, medical, or graduate school. The parents or guardians of students found responsible may also be notified.

**ACADEMIC INTEGRITY**

Academic integrity defines a university and is essential to the mission of education. At Columbia students are expected to participate in an academic community that honors intellectual work and respects its origins. In particular, the abilities to synthesize information and produce original work are key components in the learning process. As such, academic dishonesty is one of the most serious offenses a student can commit at Columbia and can be punishable by dismissal.

Students rarely set out with the intent of engaging in academic dishonesty. But classes are challenging at Columbia, and students will often find themselves pressed for time, unprepared for an assignment or exam, or feeling that the risk of earning a poor grade outweighs the need to be thorough. Such circumstances lead some students to behave in a manner that compromises the integrity of the academic community, disrespects their instructors and classmates, and deprives them of an opportunity to learn. In short, they cheat. If you ever find yourself in such circumstances, you should immediately contact your instructor and your adviser for advice. Just keep in mind how hard you have worked to get to this point in your academic career, and don't jeopardize your Columbia education with a moment of unwise decision making.

The easiest way to avoid the temptation to cheat in the first place is to prepare yourself as best you can. Here are some basic suggestions to help you along the way:

- Understand what your instructors deem as academic dishonesty and their policy on citation and group collaboration.
- Clarify any questions or concerns about assignments with instructors as early as possible.
- Develop a timeline for drafts and final edits of assignments and begin preparation in advance.
- Avoid plagiarism: acknowledge people's opinions and theories by carefully citing their words and always indicating sources.
- Utilize the campus's resources, such as the advising centers and Counseling and Psychological Services, if you are feeling overwhelmed, burdened, or pressured.
- Assume that collaboration in the completion of assignments is prohibited unless specified by the instructor.

**Plagiarism and Acknowledgment of Sources**

Columbia has always believed that learning to write effectively is one of the most important goals a college student can achieve. Students will be asked to do a great deal of written work while at Columbia: term papers, seminar and laboratory reports, and analytic essays of different lengths. These papers play a major role in course performance, but
more important, they play a major role in intellectual development. Plagiarism, the use of words or ideas belonging to others without quotation marks or proper citation, is considered one of the most serious violations of academic integrity and is a growing problem on university campuses.

One of the most prevalent forms of plagiarism involves students using information from the Internet without proper citation. While the Internet can provide a wealth of information, sources obtained from the Web must be properly cited just like any other source. If you are uncertain how to properly cite a source of information that is not your own, whether from the Internet or elsewhere, it is critical that you do not hand in your work until you have learned the proper way to use in-text references, footnotes, and bibliographies. Faculty members are available to help as questions arise about proper citations, references, and the appropriateness of group work on assignments. You can also check with the Undergraduate Writing Program. Ignorance of proper citation methods does not exonerate one from responsibility.

**Personal Responsibility, Finding Support and More Information**

A student’s education at Columbia University is comprised of two complementary components: a mastery over intellectual material within a discipline and the overall development of moral character and personal ethics. Participating in forms of academic dishonesty violates the standards of our community at Columbia and severely inhibits a student’s chance to grow academically, professionally, and socially. As such, Columbia’s approach to academic integrity is informed by its explicit belief that students must take full responsibility for their actions, meaning you will need to make informed choices inside and outside the classroom. Columbia offers a wealth of resources to help students make sound decisions regarding academics, extracurricular activities, and personal issues. If you don’t know where to go, see your class dean.
RESERVATION OF UNIVERSITY RIGHTS
This bulletin is intended for the guidance of persons applying for or considering application for admission to Columbia University and for the guidance of Columbia students and faculty. The bulletin sets forth in general the manner in which the University intends to proceed with respect to the matters set forth herein, but the University reserves the right to depart without notice from the terms of this bulletin. The bulletin is not intended to be, and should not be regarded as, a contract between the University and any student or other person.

ATTENDANCE
Students are held accountable for absences incurred owing to late enrollment.

RELIGIOUS HOLIDAYS
It is the policy of the University to respect its members’ religious beliefs. In compliance with New York State law, each student who is absent from school because of his or her religious beliefs will be given an equivalent opportunity to register for classes or make up any examination, study, or work requirements that he or she may have missed because of such absence due to religious beliefs, and alternative means will be sought for satisfying the academic requirements involved.

Officers of administration and of instruction responsible for scheduling of academic activities or essential services are expected to avoid conflict with religious holidays as much as possible. If a suitable arrangement cannot be worked out between the student and the instructor involved, they should consult the appropriate dean or director. If an additional appeal is needed, it may be taken to the Provost.

ACADEMIC DISCIPLINE
See “Discipline,” page 232.

THE FEDERAL FAMILY EDUCATIONAL RIGHTS AND PRIVACY ACT (FERPA)

COLUMBIA UNIVERSITY OMBUDS OFFICE
The Ombuds Office is a neutral and confidential resource for informal conflict resolution, serving the entire Columbia University community—students, faculty, and employees.

For further information, contact Ombuds Officer Marsha Wagner or Associate Ombuds Officer Bathabile K. S. Mthombeni at 660 Schermerhorn Extension; telephone: 212-854-1234; e-mail: ombuds@columbia.edu; Web site: www.columbia.edu/cu/ombuds. On Wednesdays the Ombuds Officer is at the Columbia Medical Center office, 101 Bard Hall, 50 Haven Avenue; telephone: 212-304-7026

OFFICE OF EQUAL OPPORTUNITY AND AFFIRMATIVE ACTION
The University’s Office of Equal Opportunity and Affirmative Action (EOAA) has overall responsibility for the University’s equal opportunity and nondiscrimination policies and has been designated to coordinate compliance activities under these policies and applicable federal, state, and local laws. Students, faculty, and staff may contact the EOAA Office to inquire about their rights under the University’s policies, request mediation or counseling, or seek information about filing a complaint. Complaints by students against students are governed by the Equal Educational Opportunity and Student Nondiscrimination Policies and Procedures on Discrimination and Harassment, which are available online at www.columbia.edu/cu/vpaa/oeaa/docs/student_discrim.html. Complaints by students against employees are governed by the Equal Employment Opportunity and Nondiscrimination Policies and Procedures on Discrimination, Discriminatory Harassment and Sexual Harassment, which are available online at www.columbia.edu/cu/vpaa/oeaa/docs/nondispol.html. All students and applicants for admission are protected from coercion, intimidation, interference, or retaliation for filing a complaint or assisting in an investigation under any of the applicable policies and laws. For further information, contact Susan Rieger, Associate Provost, Office of Equal Opportunity and Affirmative Action, Columbia University, 103 Low Library.
Equal Educational Opportunity and Student Nondiscrimination Policies

Columbia University is committed to providing a learning environment free from unlawful discrimination and harassment and to fostering a nurturing and vibrant community founded upon the fundamental dignity and worth of all of its members. Consistent with this commitment and with applicable laws, it is the policy of the University not to tolerate unlawful discrimination or harassment in any form and to provide students who feel that they are victims of discrimination or harassment with mechanisms for seeking redress. Columbia University does not discriminate against any person in the administration of its educational policies, admissions policies, scholarship and loan programs, and athletic and other University-administered programs or permit the harassment of any student or applicant on the basis of race, color, sex, gender (including gender identity and expression), pregnancy, religion, creed, marital status, partnership status, age, sexual orientation, national origin, disability, military status, or any other legally protected status. Nothing in this policy shall abridge academic freedom or the University’s educational mission. Prohibitions against discrimination and harassment do not extend to statements or written materials that are germane to the classroom subject matter.

Definitions

For purposes of these policies and procedures, discrimination, discriminatory harassment, and sexual harassment are defined as follows:

Discrimination is defined as (1) treating members of a protected class less favorably because of their membership in that class; or (2) having a policy or practice that has a disproportionately adverse impact on protected class members.

Discriminatory harassment is defined as substantially interfering with an individual’s educational experience by subjecting him or her to severe or threatening conduct or to repeated humiliating or abusive conduct, based on his or her membership in a protected class. This includes sexual harassment, which is described below in further detail.

Unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature constitute sexual harassment when: (1) submission to such conduct is made either explicitly or implicitly a term or condition of an individual’s education; or (2) submission to or rejection of such conduct by an individual is used as the basis for academic decisions affecting that individual; or (3) such conduct has the purpose or effect of unreasonably interfering with an individual’s academic performance or creating an intimidating, hostile, demeaning, or offensive academic or living environment.

Romantic Relationship Advisory Statement

Consensual, romantic relationships between faculty and other employees and students are generally not considered sexual harassment and are not prohibited by University policy. These relationships, however, are susceptible to being characterized as nonconsensual, and even coercive, if there is an inherent power differential between the parties, and can lead to complaints of sexual harassment. The full text of the Romantic Relationship Advisory Statement may be found online at www.columbia.edu/cu/vpaa/eoaa/docs/romance.html.

Disability Accommodation

Students seeking an accommodation for a disability should contact the Office of Disability Services at 212-854-2388.

University Procedures Regarding Issues of Discrimination and Discriminatory Harassment

Any person who believes that he or she has been the subject of discrimination or discriminatory harassment may initially choose to deal with the alleged offender directly. The University also offers several options for those seeking the intervention of the offices and individuals who are authorized to respond to their complaints. These include informal counseling, mediation, and formal processes for having their complaints reviewed.
Confidential Guidance and Counseling

The University has crafted a “safe haven” for those individuals who want to approach a knowledgeable person for confidential advice or to solicit feedback regarding their interpretation of events. Individuals who wish to take advantage of this option may contact either the University Ombuds Officer (see www.columbia.edu/cu/ombuds), or a member of the University Panel on Discrimination and Sexual Harassment (see www.columbia.edu/cu/ombuds). These officers are not authorized to conduct formal investigations.

Mediation

Students may choose to resolve their complaints through mediation by the Office of Equal Opportunity and Affirmative Action, the University Ombuds Office, or the Mediation Clinic at Columbia Law School. Mediation is an informal, voluntary, and confidential process whereby parties can participate in a search for a fair and workable solution. Guidelines for mediation by the EOAA Office or the Mediation Clinic may be found on the Web at www.columbia.edu/cu/vpaa/eoaa/docs/mediation.pdf.

Formal Complaint Procedures

Procedure for Complaint against Another Student

Dean’s Discipline

Student complaints of discrimination or discriminatory harassment against another student should be filed with the Dean of the school in which the accused student is enrolled. Complaints against students are investigated under the appropriate Dean’s Discipline procedure of the accused student’s school. Students found to have engaged in discrimination or discriminatory harassment will be subject to discipline up to and including expulsion.

Procedure for Complaint against a Student Organization

Students who wish to file a complaint of discrimination or discriminatory harassment against a student organization should do so in consultation with the Dean of Students of their own school.

Procedure for Complaint against a Member of the Faculty or Staff

Office of Equal Opportunity and Affirmative Action

Student complaints of discrimination or discriminatory harassment against a University employee should be filed with the Office of Equal Opportunity and Affirmative Action. These complaints will be processed under the Equal Employment Opportunity and Nondiscrimination Policies and Procedures on Discrimination, Discriminatory Harassment and Sexual Harassment.

Grievances Procedures

Students should consult SEAS policies on Student Grievances, Academic Concerns and Complaints (see page 236) for the appropriate procedure to complain about a faculty member’s conduct in an instructional setting. The policy may be found online at: www.engineering.columbia.edu/about_seas/grievances.php.
SEXUAL ASSAULT POLICY

On February 25, 2000, the University Senate adopted a Sexual Misconduct Policy and Disciplinary Procedure that can be used as an alternative to Dean’s Discipline; the policy and procedure have been renamed the Sexual Assault Policy and the Disciplinary Procedure for Sexual Assault respectively. The policy prohibits sexual assault by any student and is University wide, applying to all students in all schools of the University, including Teacher’s College and Barnard College. The Disciplinary Procedure for Sexual Assault is an option that applies to all students with the exception of students within the Law School, Jewish Theological Seminary, and/or Union Theological Seminary. Complaints of sexual assault for these schools are addressed through Dean’s Discipline. If the student being accused attends CC/SEAS, the Disciplinary Procedure for Sexual Assault will be the exclusive mechanism for filing a complaint.

Copies of the policy and procedure are available from the Manager of the Disciplinary Procedure for Sexual Assault, 701A Lerner, Mail Code 2617, 2920 Broadway, New York, NY 10027; telephone: 212-854-1717; fax: 212-854-2728; www.columbia.edu/cu/sexualmisconduct. The policy and procedure can also be found in the Office of the Dean of Students of every school.

Policy

The University’s Policy on Sexual Assault requires that standards of sexual conduct be observed on campus, that violations of these standards be subject to discipline, and that resources and structures be sufficient to meet the physical and emotional needs of individuals who have experienced sexual assault. Columbia University’s policy defines sexual assault as nonconsensual, intentional physical contact of a sexual nature, such as unwelcome physical contact with a person’s genitals, buttocks, or breasts. Sexual assault occurs when the act is committed either by (a) physical force, violence, threat or intimidation; (b) ignoring the objections of another person; (c) causing another’s intoxication or impairment through the use of drugs or alcohol; or (d) taking advantage of another person’s incapacitation, state of intimidation, helplessness, or other inability to consent.

Complaint Resolution Options

Three University-based options are available for resolution of complaints of sexual assault against a student:

1. Dean’s Discipline within the school of the charged student, with the exception of the schools listed above;
2. the University’s Disciplinary Procedure for Sexual Assault; or
3. mediation through an accredited mediator affiliated with the University, such as the Ombuds Officer.

Complaints may also be filed with the New York City Police Department.

Choosing to pursue a disciplinary action can be a difficult and confusing decision. The Manager of the Disciplinary Procedure for Sexual Assault is available to assist you in understanding your options for complaint resolution, as are trained peer advocates from the Rape Crisis/Anti-Violence Support Center.

Helen Arnold, Manager
Disciplinary Procedure for Sexual Assault
hva2002@columbia.edu
701A Lerner, Mail Code 2617
2920 Broadway
New York, NY 10027
212-854-1717
fax: 212-854-2728
www.columbia.edu/cu/sexualmisconduct

Complaints about nonstudent members of the University community should be directed to the Office of Equal Opportunity and Affirmative Action at Columbia, the Dean of Studies Office at Barnard, or the Office of the Associate Dean at Teachers College.
The following procedures are part of a process to ensure that student concerns about experiences in the classroom or with faculty are addressed in an informed and appropriate manner.

Due to the size and diverse nature of our scholarly community, each school maintains its own processes for addressing issues raised by students, including their concerns about experiences in the classroom or with faculty at their school. Experience has shown that most student concerns are best resolved in a collaborative way at the school level. The Fu Foundation School of Engineering and Applied Sciences (SEAS) offers several informal paths for students to use, as described in this statement.

If a student’s concerns are not satisfied through this process, or if the student believes that a direct complaint to the Dean is more appropriate, formal grievance procedures are available through the Vice Dean of the School. These procedures should be used for complaints about SEAS faculty. For those faculty who are not members of SEAS, the student should consult the procedures of the school in which they serve.

For academic complaints relating to SEAS faculty, these procedures, like those of other schools, provide for a final appeal to the University Provost.

The procedures under item A do not take the place of the grievance procedures already established to address disputes over grades, academic dishonesty, or issues of behavioral concerns as they relate to student conduct (see item B). They also should not be used when students believe that they have been the victim of sexual harassment or discrimination (see item C) or that faculty have engaged in scholarly or scientific misconduct (see item D).

We welcome students’ thoughts on ways to clarify or enhance these procedures. If you are an Engineering student, please e-mail Vice Dean Morton Friedman at friedman@columbia.edu.

A. COMPLAINTS ABOUT FACULTY AND STAFF ACADEMIC MISCONDUCT

In fulfilling their instructional responsibilities, faculty are expected to treat their students with civility and respect. They “should make every effort to be accurate and should show respect for the rights of others to hold opinions differing from their own. They should confine their classes to the subject matter covered by the course and not use them to advocate any cause” (2000 Faculty Handbook). A fuller description of faculty rights and obligations may be found in the Faculty Handbook, which is online at www.columbia.edu/cu/vpaa/fhb/main.html. Students who feel that members of the Engineering faculty have not met those obligations may take the following steps (the procedure below also applies to complaints against instructional and administrative staff):

1. Students are encouraged to seek a resolution to their complaints about faculty misconduct by talking directly with the faculty member. If they feel uncomfortable handling the situation in this manner, they may ask for help from a departmental faculty mediator, who will assist students with complaints about faculty members, other academic personnel, or administrators.

   The name of the faculty mediator is posted in the department office and on the departmental Web page. Students may also ask the department chair or administrator to direct them to the faculty mediator. The faculty mediator tries to resolve any issue by informal meetings with the student and others, including faculty as seems appropriate. Students who are dissatisfied with the outcome may request a meeting with the department chair. The chair will review the mediator’s recommendation and seek informally to resolve the student’s complaint.

2. Students may bring their concerns to the University’s Ombuds Officer, who serves as an informal, confidential resource for assisting members of the University with conflict resolution. The Ombuds Officer provides information, counseling, and referrals to appropriate University offices and will also mediate conflicts if both parties agree. The Ombuds Officer does not have the authority to adjudicate disputes and does not participate in any formal University grievance proceedings. Further information on the Ombuds Office may be found at www.columbia.edu/cu/ombuds/.

3. Students may seek a grievance hearing if informal mediation fails. The grievance procedures students should follow will depend upon the school within which the faculty member is
appointed and the nature of the alleged misconduct.
If the faculty member holds an appointment in SEAS, the student may use the procedures described below to address the issues listed below. If the faculty member belongs to another school, students must use the procedure of that school. They may, however, ask for help from the departmental faculty mediator, chair, and the School’s deans in identifying and understanding the appropriate procedures.

Conduct that is subject to formal grievance procedure includes:
• failure to show appropriate respect in an instructional setting for the rights of others to hold opinions differing from their own;
• misuse of faculty authority in an instructional setting to pressure students to support a political or social cause; and
• conduct in the classroom or another instructional setting that adversely affects the learning environment.

Formal grievance procedure at SEAS
If the informal mediation mentioned above failed, the student should compose and submit to the Vice Dean of the School a written statement documenting the grievance and should also include a description of the remedy sought. This should be done no later than 30 working days after the end of the semester in which the grievance occurred.

The Vice Dean will review the complaint to determine if a grievance hearing is warranted. If so, the Vice Dean will convene an ad hoc committee consisting of the Assistant Dean for Graduate Student Services (graduate students) or the Associate Dean of Student Affairs (undergraduate students), who acts as chair; a faculty member chosen by the Vice Dean; and a student chosen by one of the student councils (an undergraduate or a graduate student to correspond to the status of the student grieving).

The faculty member is given the student’s letter of complaint and invited to submit a written response. The Committee reviews both statements and is given access to any other written documents relevant to the complaint. It will normally interview both the grievant and the faculty member and may, at its discretion, ask others to provide testimony. The merits of the grievance are evaluated within the context of University and SEAS school policy.

The investigative committee serves in an advisory capacity to the Dean of the School. It is expected to complete its investigation in a timely manner and submit a written report to the Dean, who may accept or modify its findings and any recommendations it may have made to remedy the student’s complaint. The Dean will inform both the student and the faculty member of his decision in writing.

The committee ordinarily convenes within 10 working days of receiving the complaint from the Vice Dean and ordinarily completes its investigation and sends the Dean its report within 30 working days of convening. The Dean normally issues his or her decision within 30 working days of receiving the committee’s report.

The Dean may discipline faculty members who are found to have committed professional misconduct. Any sanctions will be imposed in a manner that is consistent with the University’s policies and procedures on faculty discipline. In particular, if the Dean believes that the offense is sufficiently serious to merit dismissal, he or she can initiate the procedures in Section 75 of the University Statutes for terminating tenured appointments, and nontenured appointments before the end of their stated term, for cause.

Either the student or the faculty member may appeal the decision of the Dean to the Provost. Findings of fact, remedies given the student, and penalties imposed on the faculty member are all subject to appeal. A written appeal must be submitted to the Provost within 15 working days of the date of the letter informing them of the Dean’s decision.

Normally, the Provost will take no longer than 30 working days to evaluate an appeal. The Provost usually confines his or her review to the written record but reserves the right to collect information in any manner that will help to make his or her decision on the appeal.

The Provost will inform both the student and the faculty member of his or her decision in writing. If the Provost decides that the faculty member should be dismissed for cause, the case is subject to further review according to the procedures in Section 75 of the University Statutes, as noted above.
Otherwise the decision of the Provost is final and not subject to further appeal. All aspects of an investigation of a student grievance are confidential. The proceedings of the grievance committee are not open to the public. Only the student grievant and the faculty member accused of misconduct receive copies of the decisions of the Dean and the Provost. Everyone who is involved with the investigation of a grievance is expected to respect the confidentiality of the process.

**B. DISPUTES OVER GRADES OR OTHER ACADEMIC EVALUATIONS**

The awarding of grades and all other academic evaluations rests entirely with the faculty. If students have a concern relating to a particular grade or other assessment of their academic work, the student first should speak with the instructor of the class to understand how the grade or other evaluation was derived and to address the student’s specific concern.

If the students do not feel comfortable speaking with the class instructor about the matter, they should then bring the issue to the attention of their class dean (undergraduate students) or department chair (graduate students).

If the students are unable thus to resolve the matter to their satisfaction and believe that a procedural issue is involved, they should bring the matter to the attention of the Vice Dean. The Vice Dean will work with the student and the faculty to determine whether there has been a procedural breach and if so, take immediate steps to remedy the matter. If the Vice Dean, together with appropriate faculty other than the instructor, decides that there is no need for further action, the student will be informed and the decision will be final.

**C. DISCRIMINATION AND SEXUAL HARASSMENT**

If the alleged misconduct involves discrimination and sexual harassment, a student should file a complaint with the Associate Provost for Equal Opportunity and Affirmative Action. The procedures for handling such complaints are described in the statement Discrimination and Sexual Harassment Policy and Procedure, which is on the Web at www.columbia.edu/cu/vpaa/eoaa/docs/discrim_sexharass.html.

**D. SCIENTIFIC OR SCHOLARLY MISCONDUCT**

Complaints against the School’s faculty that allege scientific or scholarly misconduct are evaluated using other procedures. These are contained in the Columbia University Institutional Policy on Misconduct in Research, available at www.columbia.edu/research/policy_misconduct.pdf.
Directory of University Resources
ADMISSIONS (GRADUATE)
See Graduate Student Services

ADMISSIONS (UNDERGRADUATE)
212 Hamilton, 212-854-2522
Mail Code 2807
Jessica Marinaccio, Dean
jm996@columbia.edu
Alice Huang, Associate Director
ah704@columbia.edu

ADVISING CENTERS
See Center for Student Advising

ALICE!, COLUMBIA UNIVERSITY’S HEALTH EDUCATION PROGRAM
See Health Services at Columbia

CENTER FOR CAREER EDUCATION
East Campus, Lower Level
212-854-5609
Mail Code 5727
www.careereducation.columbia.edu
careereducation@columbia.edu

CENTER FOR STUDENT ADVISING
Lavinia Lorch, Senior Assistant Dean
lel52@columbia.edu
Sunday Coward, Assistant Dean
sfc15@columbia.edu
Andrew Plaa, Assistant Dean
ap50@columbia.edu
Ellen Richmond, Assistant Dean
ecr13@columbia.edu
Nathaniel Wood, Jr., Assistant Dean
nw4@columbia.edu
Dahlia Adu-Peasah, Advising Dean
da333@columbia.edu
Brianna Avery, Advising Dean
ba129@columbia.edu
Leora Brovman, Advising Dean
lb2258@columbia.edu
Angie Carillo, Advising Dean
ac2335@columbia.edu
Jason Collado, Advising Dean
cj2783@columbia.edu
Manoushka Constant, Advising Dean
mlc2122@columbia.edu
Alex España, Advising Dean
aae2003@columbia.edu
Rob Ferraiuolo, Advising Dean
rf149@columbia.edu
Joshua Gaynor, Advising Dean
jwg2112@columbia.edu
Chad Gifford, Advising Dean
chg7@columbia.edu
Dawn Hemphill, Advising Dean
dh2239@columbia.edu
Elizabeth McArdle, Advising Dean
em2500@columbia.edu
Jay Orenduff, Advising Dean
jo109@columbia.edu
Tara Spencer, Advising Dean
Tms2105@columbia.edu
Marcela Calidonio, Program Coordinator
mdc2019@columbia.edu
Jennifer Prudencio, Advising Counselor
jmp2163@columbia.edu
Lindsay Sage, Advising Counselor
ls2680@columbia.edu
Timekah Clare, Administrative Assistant
tjc2101@columbia.edu
Glenda Gonzalez, Administrative Assistant
gg2312@columbia.edu
Joyce Osei, Administrative Assistant
jao2130@columbia.edu
Donna Peters, Administrative Assistant
dvp2@columbia.edu
Margaret Temple, Administrative Assistant
mat51@columbia.edu
Nkemdilim Ukwu, Administrative Assistant
nu2113@columbia.edu
Tamara White, Administrative Assistant
tw2128@columbia.edu

COLUMBIA COLLEGE AND SCHOOL OF ENGINEERING AND APPLIED SCIENCE CORE CURRICULUM
PROGRAM OFFICES
Center for the Core Curriculum
202 Hamilton, 212-854-2453
Mail Code 2811
Roosevelt Montas, Associate Dean of the Core Curriculum
rm63@columbia.edu
Art Humanities
826 Schermerhorn, 212-854-4505
Mail Code 5517
Professor Holger Klein, Chair

Music Humanities
621 Dodge, 212-854-3825
Mail Code 1813
Chair to be announced

Contemporary Civilization
202 Hamilton, 212-854-2453
Mail Code 2811
Professor Michael Stanislawski, Chair

Literature Humanities
202 Hamilton, 212-854-2453
Mail Code 2811
Professor Gareth Williams, Chair
All inquiries concerning Lit Hum should be directed to the Center for Core Curriculum (listed above).

University Writing
Writing Center
Undergraduate Writing Program
310 Philosophy, Mail Code 4995
212-854-3886
Professor Joseph Bizup, Director
Nicole Wallack, Associate Director
uwwp@columbia.edu (for general inquiries)
writingcenter@columbia.edu (for Writing Center)

COLUMBIA VIDEO NETWORK
540 S. W. Mudd, 212-854-8210
Mail Code 4719
Grace Chung, Executive Director
cvn-director@columbia.edu

COMPUTING SUPPORT CENTER
Walk-in Support Center
102 Philosophy, Mail Code 4926
212-854-1919
consultant@columbia.edu

COUNSELING AND PSYCHOLOGICAL SERVICES
See Health Services at Columbia

DEAN OF COLUMBIA COLLEGE
208 Hamilton, 212-854-2441
Mail Code 2805
Austin E. Quigley, Dean of the College
eaq1@columbia.edu
Kathryn Yatrakis, Dean of Academic Affairs
kby1@columbia.edu

DEAN OF THE FU FOUNDATION
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
510 S. W. Mudd, 212-854-2993
Mail Code 4714
Gerald A. Navratil, Interim Dean
gan2@cs.columbia.edu

Morton B. Friedman, Vice Dean
friedman@columbia.edu
Anna Marie O’Neill, Associate Dean
amr16@columbia.edu
Jack McGourty, Associate Dean
jm723@columbia.edu

DEVELOPMENT AND ALUMNI RELATIONS AT THE FU FOUNDATION
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
510 S. W. Mudd, 212-854-4472
Mail Code 4718
Leslie Murphy, Director of Development
lm2343@columbia.edu
Ryan Carmichael, Parents Fund Program Officer
lrc2533@columbia.edu
Alessandra Garber, Development Officer
ag2091@columbia.edu
Leah Blalock, Associate Director
lbw2122@columbia.edu
Margaret R. Kelly, Associate Director
mk321@columbia.edu
Timothy G. Greene, Stewardship Officer
tg2016@columbia.edu
Lindsay N. Montanari, Alumni Relations Coordinator
lm2583@columbia.edu
Scott T. Kelly, Alumni Relations Coordinator
stk2110@columbia.edu
DINING SERVICES
See Housing and Dining

DISABILITY SERVICES
See Health Services at Columbia

EARL HALL/ST. PAUL’S CHAPEL
212-854-6242, Mail Code 2008
Jewelnel Davis, University Chaplain
212-854-1493
chaplain@columbia.edu

DIVISION OF STUDENT AFFAIRS OFFICE: COLUMBIA COLLEGE AND THE FU FOUNDATION SCHOOL OF ENGINEERING AND APPLIED SCIENCE
405 Lerner
212-854-2446, 212-854-2961
Mail Code 2607
Costantino Colombo, Dean of Student Affairs
c69@columbia.edu
Kathleen Finn, Assistant Manager to the Dean
kf2163@columbia.edu
Shari Wilson, Administrative Assistant
dw13@columbia.edu
David X. Cheng, Assistant Dean of Student Affairs/Research and Planning
dcx1@columbia.edu
Kathryn Wittner, Associate Dean of Student Affairs/Student and Alumni Programs
kb4@columbia.edu
Elizabeth Girgis, Chief Administrative Officer
emg@columbia.edu
Theresa McKenzie, Senior Associate Director, Student Affairs Central Business Office
tm2050@columbia.edu
Yeny Vargas, Senior Associate Director, Student Affairs Central Business Office
yv2003@columbia.edu
Eleanor J. B. Daugherty, Associate Dean of Student Affairs/Administration and Planning
ejd2006@columbia.edu

Cristina Stevenson, Director of Events and Communications
cs2654@columbia.edu
Events Manager to be appointed

ENGINEERING AND APPLIED SCIENCE DEPARTMENTS AND PROGRAMS

Applied Physics and Applied Mathematics
200 S. W. Mudd, 212-854-4457
Mail Code 4701
Professor Irving P. Herman, Chair
iph1@columbia.edu
Professor Ismail C. Noyan, Vice Chair
icn2@columbia.edu
Program in Applied Mathematics
Program in Applied Physics
Program in Materials Science and Engineering
Program in Medical Physics

Biomedical Engineering
351 Engineering Terrace
212-854-4460, Mail Code 8904
Professor Van C. Mow, Chair
vcm1@columbia.edu
Professor Andrew F. Laine, Vice Chair
al418@columbia.edu

Chemical Engineering
801 S. W. Mudd, 212-854-4453
Mail Code 4721
Professor Alan C. West, Chair
acw17@columbia.edu

Civil Engineering and Engineering Mechanics
610 S. W. Mudd, 212-854-3143
Mail Code 4709
Professor Christian Meyer, Chair
cm25@civil.columbia.edu

Computer Science
450 Computer Science, 212-939-7000
Mail Code 0401
Professor Henning Schulzrinne, Chair
hgs@cs.columbia.edu

Earth and Environmental Engineering
(Henry Krumb School of Mines)
918 S. W. Mudd, 212-854-2905
Mail Code 4711
Professor Klaus Lackner, Chair
kl2010@columbia.edu

Electrical Engineering
1312 S. W. Mudd, 212-854-3105
Mail Code 4712
Professor Shi-Fu Chang, Chair
sfchang@ee.columbia.edu

Industrial Engineering and Operations Research
331 S. W. Mudd, 212-854-2941
Mail Code 4704
Professor Clifford Stein, Chair
cliff@ieor.columbia.edu

Mechanical Engineering
220 S. W. Mudd, 212-854-2966
Mail Code 4703
Professor Y. Lawrence Yao, Chair
yly1@columbia.edu

EQUAL OPPORTUNITY AND AFFIRMATIVE ACTION OFFICE
103 Low Library, 212-854-5511
Mail Code 4333
Susan Rieger, Associate Provost
sr534@columbia.edu

FINANCIAL AID AND EDUCATIONAL FINANCING (UNDERGRADUATE)
407 Lerner, 212-854-3711
Mail Code 2802
Nanette DiLauro, Director of Financial Aid
nd143@columbia.edu
Pamela Mason, Senior Associate Director of Financial Aid and Admissions
pm520@columbia.edu
Jessica Bernier, Associate Director of Financial Aid
jb2798@columbia.edu
Jacqueline Perez, Senior Assistant Director of Financial Aid
jg363@columbia.edu
José Carlos Rivera, Senior Assistant Director of Financial Aid
jcr38@columbia.edu
Evangelia Nonis, Assistant Director of Financial Aid
edn1@columbia.edu
Marjorie Ortiz, Assistant Director of Financial Aid
mo2219@columbia.edu

FINANCIAL AID (GRADUATE)
Federal Financial Aid
(Loans, Work Study)
Financial Aid and Educational Financing
407 Lerner, 212-854-3711
Mail Code 2802
Jessica Bernier, Associate Director of Financial Aid
jb2798@columbia.edu
Jacqueline Perez, Senior Assistant Director of Financial Aid
jg363@columbia.edu
Marjorie Ortiz, Assistant Director of Financial Aid
mo2219@columbia.edu

Institutional Financial Aid
(Grants, Fellowships, Assistantships)
Graduate Student Services
524 S. W. Mudd, 212-854-6438
Mail Code 4708
Tiffany M. Simon, Assistant Dean
ms26@columbia.edu

GRADUATE STUDENT SERVICES
524 S. W. Mudd, 212-854-6438
Mail Code 4708
Tiffany M. Simon, Assistant Dean
tms26@columbia.edu
Jocelyn Morales, Admissions Officer
jm2388@columbia.edu
Jonathan Stark, Student Affairs Officer
jrs2139@columbia.edu

HEALTH SERVICES AT COLUMBIA
Primary Care Medical Services
John Jay, 3rd and 4th floors
212-854-2284
Mail Code 3601
www.health.columbia.edu
Appointments: 212-854-2284
Clinician on Call (for after-hours medical and psychological consultation)
(Sept. 1–May 31): 212-854-9797
Enrollment/Immunization Office
Wien Hall, 212-854-7210
Mail Code 3712
Emergency Medical Services (CAVA)
212-854-5555 or 99 from a campus phone
Gay Health Advocacy Project (GHAP),
including HIV Testing
212-854-7970
Student Medical Insurance Plan
Administrators: Chickering Benefit Planning Insurance Agency, Inc.
1-800-859-8471
www.aetnastudenthealth.com
Travel Medicine Clinic (CU on the Road):
212-854-2284

Alicel, Columbia University's
Health Promotion Program
Wien Hall, 212-854-5453
Mail Code 3711
www.alice.columbia.edu
Presents a wide range of health education
and skill-building programs, including Go Ask Alicel, a health question-
and-answer Internet service.

Counseling and Psychological Services
Lerner, 8th floor, 212-854-2878
Mail Code 2606
Individual, couple, and group counseling
for emotional stress, emergency consultation, and referral, as well as skill-building
workshops and outreach programs.
www.health.columbia.edu/docs/about_us/cps.html

Office of Disability Services
801 Lerner, Voice: 212-854-2388
TDD: 212-854-2378
Mail Code 2605
Coordinates services, programs, and
policies to support and arrange appropriate accommodations for students
with disabilities.

Rape Crisis/Anti-Violence Support Center (RC/AVSC)
112 Hewitt (Barnard Quad)
Business Line: 212-854-4366
24-hour Peer Advocates:
212-854-WALK (9255)
Peer Counselors (7 days a week):
212-854-HELP (4357)
Provides services and support to
survivors of sexual assault, relationship violence, childhood sexual abuse, and
other forms of violence, and assistance to the friends and loved ones of survivors.

HOUSING AND DINING
Customer Service Center
118 Hartley, 212-854-2775
Mail Code 3003

Office of Dining Services
102 Wallach, 212-854-2782
Mail Code 3001
eats@columbia.edu

Office of Housing Services
125 Wallach, 212-854-2946
Mail Code 3003
housing@columbia.edu

INTERCULTURAL RESOURCE CENTER (IRC)
552 West 114th Street, 212-854-7461
Mail Code 5512
Melinda Aquino, Senior Assistant Dean
of Student Affairs
ma2398@columbia.edu

Office of Multicultural Affairs
401 Lerner, 212-854-0720
Mail Code 2607
Ajay T. Nair, Associate Dean of Student Affairs/Office of Multicultural Affairs
atn2104@columbia.edu
INTERNATIONAL STUDENTS AND SCHOLARS OFFICE
524 Riverside Drive, Suite 200
212-854-3587
Mailing Address: 2960 Broadway,
Mail Code 5724
Richard B. Tudisco, Associate Provost and Director
isso@columbia.edu
Immigration and Documentation Services
International Student Orientation
International Student Workshops

JUDICIAL AFFAIRS
515 Lerner, 212-854-1389
Mail Code tk

LIBRARIES
Butler Library Information
234 Butler, 212-854-2271
Mail Code 1121

Engineering Library (Monell)
422 S. W. Mudd, Mail Code 4707
Circulation: 212-854-2976
Reference: 212-854-3206
Fax: 212-854-3323

MATH/SCIENCE DEPARTMENTS
Biological Sciences
600 Fairchild, 212-854-4581
Mail Code 2402
Deborah Mowshowitz, Director of Undergraduate Programs
dbm2@columbia.edu
www.columbia.edu/cu/biology

Chemistry
344 Havemeyer, 212-854-2202
Mail Code 3174
James J. Valentini, Director of Undergraduate Studies
jjv1@columbia.edu

Earth and Environmental Sciences
106 Geoscience, Lamont-Doherty Earth Observatory, 845-365-8550
Nicholas Christie-Blick, Co-director of Undergraduate Studies
ncb@ideo.columbia.edu
845-365-8821

Walter C. Pitman, Co-director of Undergraduate Studies
pitman@ldeo.columbia.edu
845-365-8397

Mathematics
410 Mathematics, 212-854-2432
Mail Code 4426
Patrick Gallagher, Director of Undergraduate Studies
pxg@math.columbia.edu

Physics
704 Pupin, Mail Code 5255
212-854-3348
Allan S. Blaer, Director of Undergraduate Studies
asb@phys.columbia.edu

Statistics
1255 Amsterdam Avenue
Room 1005, 212-851-2132
Mail Code 4690
Ji Meng Loh, Director of Undergraduate Studies
meng@stat.columbia.edu

OFFICE OF STUDENT GROUP ADVISING
505 Lerner, 212-854-4196
Mail Code 2609
Todd M. Smith, Associate Dean of Student Affairs/Office of Student Group Advising
ts2488@columbia.edu

Jason Anthony, Associate Director, Office of Student Group Advising
jla2108@columbia.edu

Walter Rodriguez, Associate Director, Office of Student Group Advising
wr2174@columbia.edu

OMBUDS OFFICE
600 Schermerhorn Ext., 212-854-1234
Mail Code 5558

PHYSICAL EDUCATION AND INTERCOLLEGIATE ATHLETICS
Dodge Physical Fitness Center
212-854-2548
Mail Code 1931
Ken Torrey, Chair, Physical Education
212-854-4001
kwt1@columbia.edu

Jacqueline Blackett, Associate Athletics Director for Student Athlete Support Services
212-854-2544
jpb3@columbia.edu
Academic and personal advising for varsity athletes.

PUBLIC SAFETY OFFICE
111 Low Library
212-854-2797 (24 hours a day)
Mail Code 4301
publicsafety@columbia.edu

James F. McShane, Associate Vice President for Public Safety
jfm2112@columbia.edu

CAMPUS EMERGENCIES: From on-campus Rolm phones dial 99 for fire, security, ambulance, or any crime problem; off-campus: 212-854-5555

Escort Service: 212-854-SAFE

RAPE CRISIS/ANTI-VIOLENCE SUPPORT CENTER (RC/AVSC)
See Health Services at Columbia

REGISTRAR
210 Kent
Mail Code 9202
John Carter, Deputy Registrar
212-854-1458
jpc11@columbia.edu

Jennifer Caplan, Associate Registrar
212-854-5596
jc12@columbia.edu

Brady Sloan, Associate Registrar
212-854-8112
bps44@columbia.edu

Lenore Hubner, Assistant Registrar
212-854-3240
lah2@columbia.edu
Melbourne Francis, Assistant Registrar
212-854-7528
mef2@columbia.edu

RESIDENTIAL PROGRAMS
515 Lerner, 212-854-6805
Mail Code 4205
Kevin Shollenberger, Senior Associate Dean of Student Affairs, Student Development, and Activities/Residential Programs
ks693@columbia.edu
Christina Boubaris, Executive Assistant
cb2262@columbia.edu
Cristen Scully Kromm, Assistant Dean for Community Development/Director of Residential Programs
cs867@columbia.edu
Hikaru Kozuma, Senior Associate Director of Residential Programs
hk2134@columbia.edu
Darleny Cepin, Associate Director of Residential Programs–East Campus
dc23@columbia.edu
Ellen Godena, Associate Director of Residential Programs–The Block
eg2356@columbia.edu
Deb Pawlikowski, Associate Director of Residential Programs–South Field
dp2309@columbia.edu
Carolyn O’Laughlin, Associate Director of Residential Programs–West Campus
c02162@columbia.edu
Scott Helfrich, Associate Director of Residential Programs–Living Learning Center (LLC)
sh2409@columbia.edu
Victoria Lopez-Herrera, Assistant Director of Greek Life and Leadership Development
vl2165@columbia.edu
Chris Becker, Administrative Assistant
rb2232@columbia.edu
Stacey Swift, Administrative Coordinator
ss3180@columbia.edu

STUDENT DEVELOPMENT AND ACTIVITIES
403 Lerner, 212-854-3611
Mail Code 2601
Kevin Shollenberger, Senior Associate Dean of Student Affairs, Student Development, and Activities/Residential Programs
ks693@columbia.edu
Cynthia Jennings, Director of New Student Orientation and Class Year Programming
cj2136@columbia.edu
Leo Pedraza, Assistant Director, Student Development and Activities
lp2341@columbia.edu
David Milch, Manager of Media, Performing Arts, and Publication Production
dm2422@columbia.edu
Benjamin Young, Director of Broadcasting and Operations (WKCR-FM)
by10@columbia.edu
Peter Cerneka, Assistant Director, Student Development and Activities
pc2371@columbia.edu
Tailisha Gonzalez, Manager for Leadership Development
tg164@columbia.edu

STUDENT SERVICE CENTER
205 Kent, 212-854-4400
Mail Code 9206
Cashiering: 212-854-1518
For quick answers to your questions, visit: askus.columbia.edu.
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