

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

THE FU FOUNDATION SCHOOL OF ENGINEERING AND APPLIED SCIENCE

Bulletin 2005–2006

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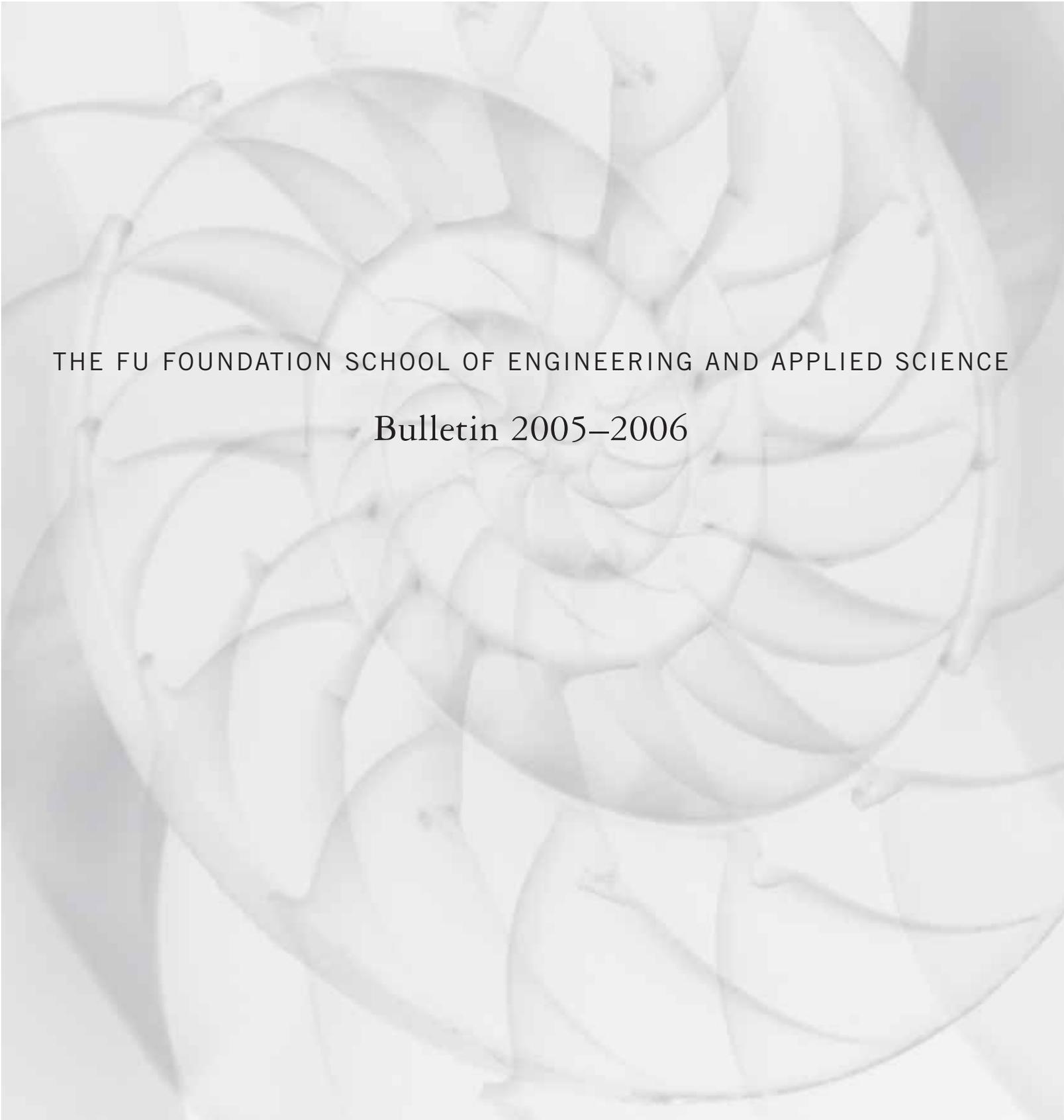
You can find the names, addresses, and phone numbers of the people who know in the Columbia University Resource List, starting on page 232 of this bulletin. Or look for us online, at <http://www.engineering.columbia.edu/>. Our online bulletin, with the latest updates, is at <http://www.engineering.columbia.edu/bulletin/>.

**Photography:**

Photos by Gabriel Amadeus Cooney, Alan Orling, René Perez, and Ken Tannenbaum.

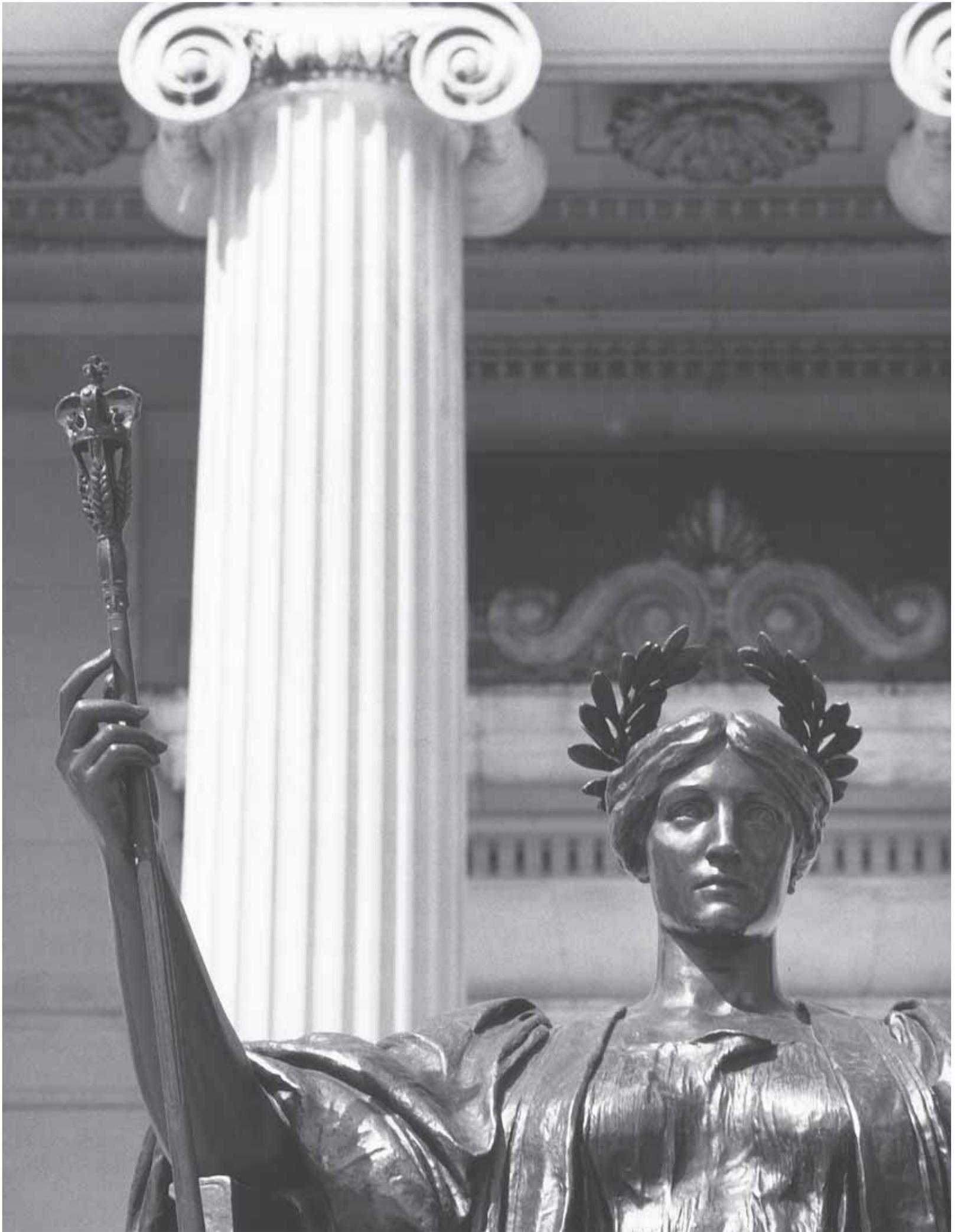


COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

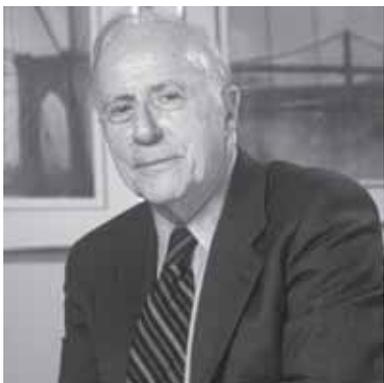


THE FU FOUNDATION SCHOOL OF ENGINEERING AND APPLIED SCIENCE

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# A Message from the Deans



The great scientist-engineer Theodore Von Karman 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 science and engineering that has resulted in “technoscience,” where the project, not the discipline, drives the research initiatives. In addition, the realization now exists that the analytical tools of engineering 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.

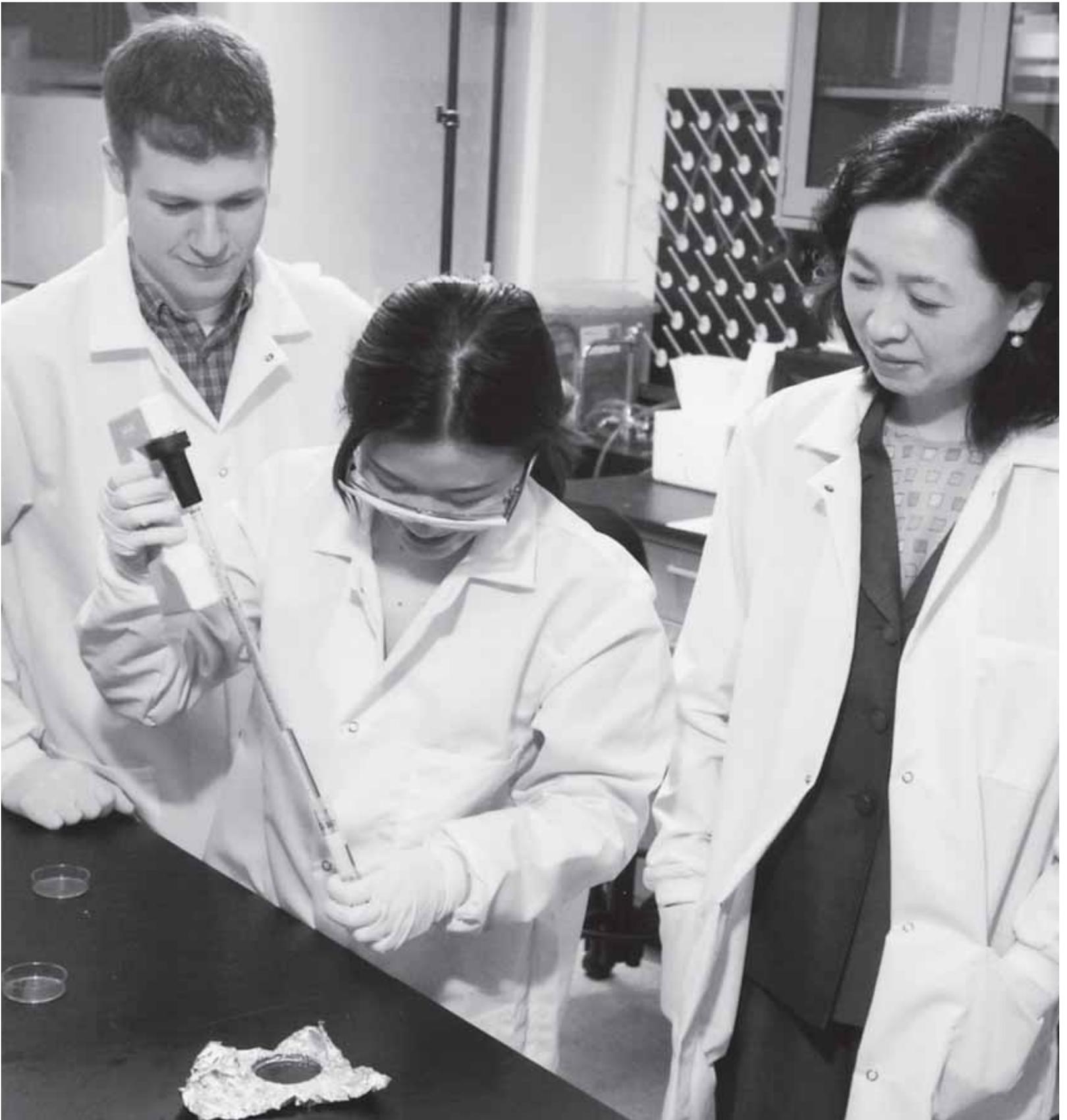
Zvi Galil  
*Dean*

Morton B. Friedman  
*Vice Dean*

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# 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.

Working around the globe, William Barclay Parsons, Class of 1882, was an engineer on the Chinese railway and the Cape Cod and Panama Canals, and, most importantly for New York, chief engineer of the city's first subway. Opened in 1904, the subway's electric cars took passengers from City Hall to Brooklyn, the Bronx, and the newly renamed and relocated Columbia University in Morningside Heights, its present location on the Upper West Side of Manhattan.

## 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—included by this time Michael Idivorsky 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.

An early 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.

But early work on radio vacuum tubes was not restricted to private industry. Working with Pupin, an engineering student named Edwin Howard Armstrong was conducting experiments with the Audion tube in the basement of Philosophy Hall when he discovered how to amplify radio signals through regenerative circuits. Graduating a year later, in the Class of 1913, Armstrong was stationed in France during the First World War, where he invented the superheterodyne circuit to tune in and detect the frequencies of enemy aircraft ignition systems. After the war Armstrong improved his method of frequency modulation (FM) and by 1931 had both eliminated the static and improved the fidelity of radio broadcasting forever.

## 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 electrical 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 course work; 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.

# Resources and Facilities

## 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. 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 every-

thing 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.; the Nevis Laboratories in Irvington, N.Y.; and the Arden Conference Center in Harriman, 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 Morningside 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 new 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 Center for Telecommunications Research to the Molecular Beam Epitaxy Laboratory. Details about specific programs' laboratories and equipment can be found in the sections describing those programs.

## SEAS Computing Facilities

The Botwinick Gateway 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 Gateway Lab 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

Academic Information Systems (AcIS) is the central organization supporting academic use of technology at Columbia University. It is a service organization whose mission is to improve the quality of instruction and research at the University through the strategic use of computing and communications technologies. AcIS also provides several core services to all faculty, students, and staff at Columbia, including email services, network services and Internet access, central Web servers, and a central ID system for managing access to computing resources.

- *ColumbiaNet*, Columbia's online information system (<http://www.columbia.edu>), provides 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.
- *High-speed Internet access* is available to faculty and staff members in their offices and in many University-owned apartment buildings, as well as to every student living in the undergraduate residence halls. With these connections, students can send e-mail, log in to Columbia computers, print to laser printers, consult library information, create their own Web pages, and access the Internet. Students, faculty, and staff can also connect to the Internet and access their e-mail using their portable computers at locations throughout the Morningside campus. For more

information, see <http://www.columbia.edu/acis/networks/>.

- *Computer accounts* provide access to e-mail, dial-up modems, online student services, ColumbiaNet, Library Web (the Libraries' online information resource), and all Internet resources. You may also use these accounts for Web publishing, accessing AcIS computer labs, and printing on AcIS laser printers. All Columbia students are eligible for an account. For complete details, see <http://www.columbia.edu/acis/accounts/>.
- *Electronic classrooms* provide multimedia capabilities such as computer and projection systems, DVD and CD-ROM players, VCRs, and audio systems. For more information, see <http://www.columbia.edu/acis/classrooms/>.
- *The Electronic Data Service (EDS)*, run jointly by AcIS and the Libraries, provides computing support for researchers with data-intensive applications, including special accounts, help using statistical software, and finding and selecting appropriate data. For more information, see <http://www.columbia.edu/acis/eds/>.
- *Public kiosks* are available in various locations around the Morningside campus for accessing ColumbiaNet and e-mail. AcIS also manages a number of on-campus computer labs and clusters, all equipped with laser printers and other services. For more information, see <http://www.columbia.edu/acis/facilities/cnet/>.
- *Noncredit computer training courses* are provided free by AcIS to students, faculty, and staff. Topics include creating a Web page, using UNIX, and using research software. For more information, see <http://www.columbia.edu/acis/training/current-semester/>.

For additional information and assistance, you can reach AcIS by any of the following methods:

Online: <http://www.columbia.edu/acis/support>

Helpdesk: 212-854-1919  
(Monday–Thursday, 8:00 a.m.–8:00 p.m.; Friday, 8:00 a.m.–5:00 p.m.)

Walk-in (Computing Support Center):  
102 Philosophy Hall  
(Monday–Thursday, 10:00 a.m.–5:00 p.m.; Friday, 12:00 noon–5:00 p.m.)

Note: Many walk-in services require an appointment in advance.

## The Columbia University Libraries

The Columbia University Libraries system is the nation's eighth largest academic library system, with 7.6 million volumes, 56,900 serials, as well as extensive collections of electronic resources, manuscripts, rare books, microforms and other nonprint formats. The collections and services are organized into 22 libraries, supporting specific academic or professional disciplines. The Library's Web site at <http://www.columbia.edu/cu/lweb> is a gateway to the print and electronic collections and services.

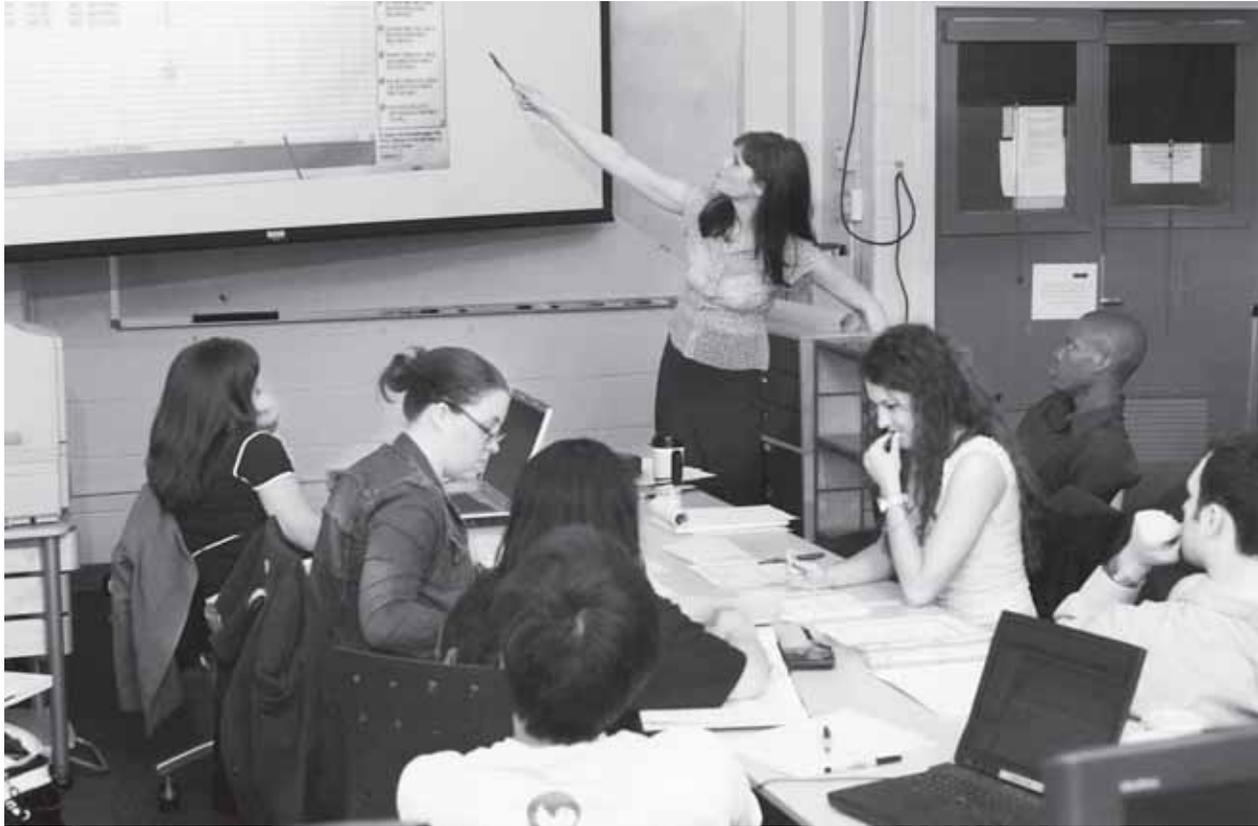
The Ambrose Monell Engineering Library, located within the Engineering School complex, has a collection of more than 250,000 volumes and over 1 million technical reports on microform. It currently subscribes to approximately 825 periodicals. Via LibraryWeb, the Engineering Library provides access to 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 Tech Books Online, Books 24x7, and NetLibrary.

## Center for Career Education

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Phone: 212-854-5609  
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<http://www.cce.columbia.edu>



The Center for Career Education helps undergraduate and graduate students and alumni learn about the relationship between their education at Columbia and life after graduation. The Center for Career Education helps students develop the competencies required beyond the classroom; to become informed about career opportunities; to understand the forces at play in the global market and the new economy, and their effect on the workplace, the workforce, and individual lives and careers; to make informed decisions about career goals; to find career opportunities related to their personal and professional objectives; and make a difference in the world. Career development is a lifelong process that includes self-assessment, curricular exploration through choice of major, competency development, networking, informational interviewing, mentoring, internships, summer work experience, study abroad, preparation for the job search and for the graduate/professional school application process, and planning for productive, rewarding lives. Above all else, it

is a generative process, which provides a foundation for achieving goals throughout life. 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.

The Center for Career Education offers programs that include career development workshops, graduate program exploration, entrepreneurship programs, and identification of full-time employment opportunities. The Center maintains a Web site (<http://www.cce.columbia.edu>) that contains information on career search strategies and tools, upcoming events, career fairs, full- and part-time job listings, internships, and work-study positions, as well as information on how to contact us. We encourage both students and alumni/ae to register online 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/ae we serve with a variety of issues, including self-assessment, career exploration, and career search tools, and strategies. Programs and workshops are conducted throughout the academic year covering a range of topics, including a series of alumni receptions addressing many career industries. Through the Career Resource Center, students are able to research employers, graduate schools, opportunities abroad, financial aid, and more.

The Center recognizes the special interests of graduate students in the University with programs and workshops that focus on both academic and nonacademic careers. Furthermore, we offer a dossier service that maintains reference files and sends out dossiers for those seeking teaching positions in independent schools, colleges, and universities. It is recommended that a candidate for a teaching position open a credentials file in the late summer or early autumn of the year preceding his or her availability for employment.

The Center manages full-time internship employment opportunities for students. The Campus Recruiting

Program is conducted throughout the academic year; students can submit their resumes and cover letters online to any of the employers listed on our database. In addition, employment opportunities are advertised year-round through the online database on MonsterTrak.com. While at Columbia, students can take advantage of internships that offer opportunities to gain first-hand knowledge of a career field. In addition, on and off-campus part-time and temporary jobs are advertised through an online database.

Furthermore, the Center for Career Education fosters entrepreneurship through the Columbia Student Enterprises (CSE), a nonprofit organization established in 1976. The organization consists of student-managed businesses such as the Bartending Agency, Campus Pages, Inside NY, CU Snacks, and the Tutoring and Translating Agency. This program promotes student initiative in business endeavors to increase services on campus that enhance the quality of student life and to create job opportunities for Columbia University students.

To gain a complete understanding of all Center for Career Education programs and resources, please come visit us in the lower level of East Campus. For additional information or questions, call 212-854-5609. We look forward to seeing you because your career concerns are our career concerns!

#### **STATISTICS FOR CLASS OF 2003 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 2004. 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 212-854-2934.

Of those seniors graduating from SEAS in the Class of 2004 who responded to this survey:

- 40% have accepted job offers
- 20% have applied for jobs and are awaiting or deciding between job offers
- 19% will be attending graduate school
- 4% have not started looking for a job
- 2% are taking the year off
- 13% 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](mailto:isso@columbia.edu)

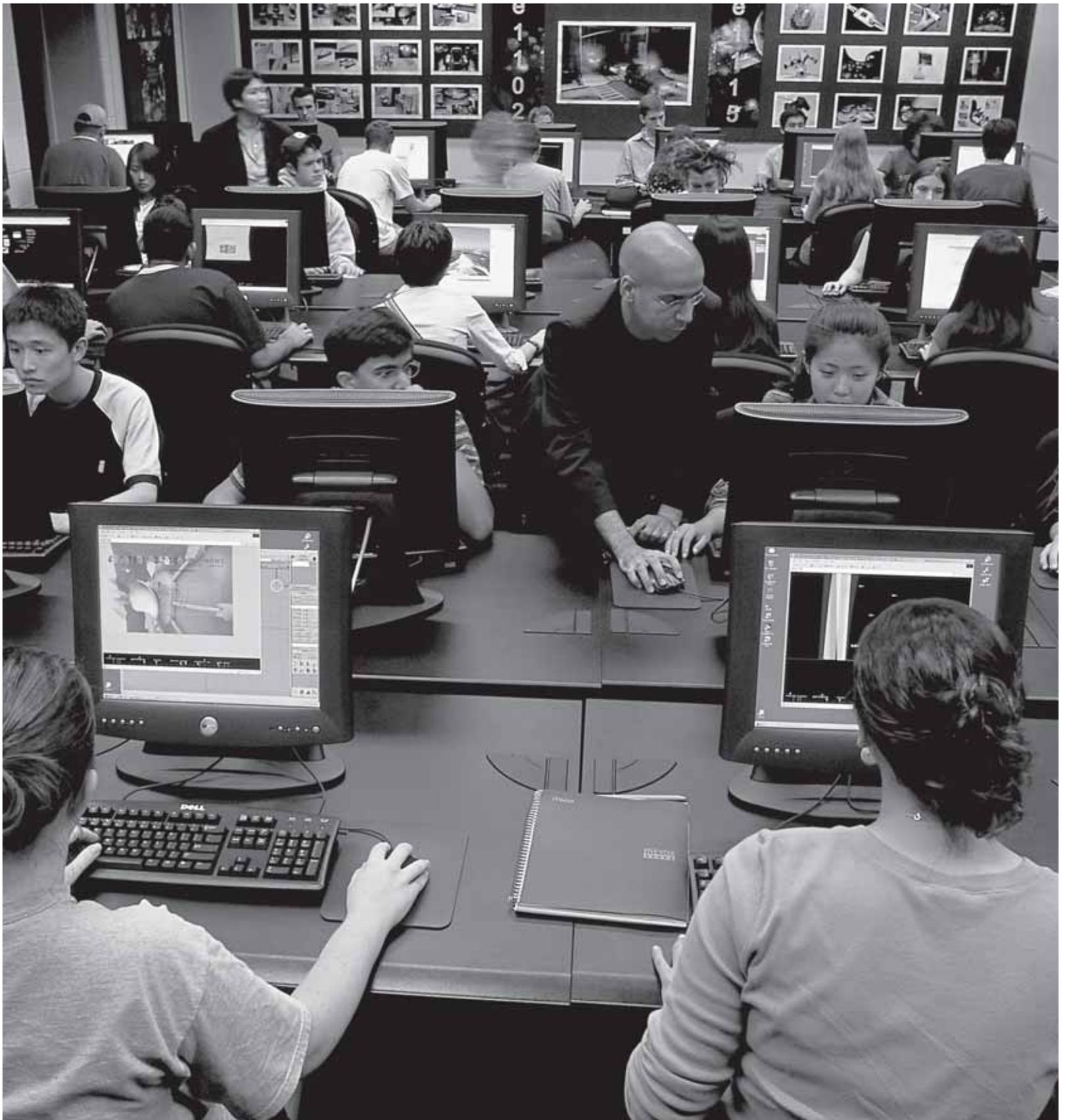
The International Students and Scholars Office (ISSO) offers many services for international students as well as American citizens and permanent residents who have received their education in another country. Services for international students include preadmission counseling, document

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 <http://www.columbia.edu/cu/isso/>, 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 the many international student clubs at Columbia and 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

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, working 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 Gateway Lab as part of their technical core requirements. Here students apply fundamental principles of engineering, calculus, physics, and chemistry 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, or for academic credit or 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 Western and other cultures 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 the 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 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 the leaders in the profession 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 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 nontechnical points (from lists A and B, below) must add up to at least 27. Neither list can be modified by class deans or faculty advisers.

- Advanced Placement (AP) credit in appropriate subject areas can be applied toward the 9-point elective nontechnical requirement.
- Students in programs (chemical engineering, civil engineering, Earth and environmental engineering, electrical engineering, industrial engineering, and mechanical engineering) certified by the Accreditation Board for Engineering and Technology (ABET) must complete at least 16 points in “clearly nontechnical” areas. Some subject areas that are considered acceptable by Columbia’s standards for nontechnical work are not acceptable by ABET standards. These areas include English composition courses and courses in the student’s own language if other than English.

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

These courses must be taken at Columbia.

	Points
1. ENGL C1010 University writing	3
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 <i>Iliad</i> on the first day of class.) or COCI C1101-C1102 Introduction to contemporary civilization or any 2 Major Cultures sequence from List A of the Major Cultures Requirement or a List A and a List B or C course in the same culture	6–8
3. One of the following two courses: HUMA W1121 Masterpieces of Western art or HUMA W1123 Masterpieces of Western music	3
4. ECON W1105 Principles of economics (This course can be satisfied through	

Advanced Placement; see the Advanced Placement chart on page 17.) 4

#### 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, music instruction, and master’s-level professional courses do not satisfy the 27-point nontechnical requirement.)

**AFRICAN-AMERICAN STUDIES:** All courses

**AMERICAN STUDIES:** All courses

**ANCIENT STUDIES:** All courses

**ANTHROPOLOGY:**

All courses in sociocultural anthropology  
All courses in archaeology except field work  
No courses in biological/physical anthropology [V1010, V1011, W3204, V3940, G4147-G4148, W4200, G4700]

**ARCHITECTURE:** No courses

**ART HISTORY AND ARCHEOLOGY:** All courses

**ASIAN AND MIDDLE EASTERN STUDIES**

All courses

**ASTRONOMY:** No courses

**BIOLOGICAL SCIENCES:** No courses

**BUSINESS:** No courses

**CHEMISTRY:** No courses

**CHINESE:** All courses

**CLASSICS:** All courses

**COLLOQUIA:** All courses

**COMPARATIVE LITERATURE AND SOCIETY**

All courses

**COMPUTER SCIENCE:** No courses

**DANCE**

All courses except performance classes

**DRAMA AND THEATRE ARTS**

All courses except performance classes and THTR BC2120 Technical production

**EARTH AND ENVIRONMENTAL SCIENCES**

No courses

**EAST ASIAN LANGUAGES AND CULTURE**

All courses

**ECONOMICS**

All courses except:  
W3412 Introduction to econometrics  
W2261-W4261 Introduction to accounting and finance  
W3025 Financial economics  
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:  
F1001 European literature–philosophical masterpieces I  
V3411 Introduction to symbolic logic  
V4431 Introduction to set theory  
CSPH W4801 Mathematical logic I: the completeness result  
Courses in logic

**PHYSICAL EDUCATION:** No courses

**PHYSICS:** No courses

**POLITICAL SCIENCE:** All courses

**PSYCHOLOGY**

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

**RELIGION:** All courses

**SEAS:**

Only:  
SCNC W1005 Science, technology and society  
BMEN E4010 Ethics for biomedical engineers

EEHS E3900 History of telecommunications

**SLAVIC LANGUAGES:** All courses

**SOCIOLOGY:**

All courses except:  
SOCL V3212 Statistics and methods

**SPANISH AND PORTUGUESE:** All courses

**SPEECH:** No courses

**STATISTICS:** No courses

**URBAN STUDIES:** All courses

**VISUAL ARTS:** No courses

**WOMEN AND GENDER STUDIES:** All courses

**WRITING**

All courses above ENGL C1010 University writing (If your major is ABET certified, please note that some subject areas that are considered acceptable by Columbia standards for nontechnical work are not acceptable according to ABET standards. One such area is English composition.)

**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 Gateway Lab. 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 profession-

al-level course chosen from the list below. The faculty strongly encourages students to schedule two of these courses. (The Botwinick Gateway 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.

**EAAE 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 E1201y: 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: micromachines 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 (<http://www.gocolumbiaions.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 and Columbia College.

## ADVANCED PLACEMENT

Prior to entering Columbia, students may have taken the College Entrance

## ADVANCED PLACEMENT CREDIT CHART

In order to receive AP credit, students must be in possession of appropriate transcripts or scores.

Subject	AP Score	Advanced Credit	Requirements or Placement Status
Art history	5	3*	No exemption from HUMA W1121
Biology	4 or 5	3	No exemption
Chemistry	4 or 5	6	Requires beginning with and completion of CHEM C3045 and C3046 with grade of C or better. (Students must consult with department for specific requirements.)
Computer science A or AB	4 or 5	3*	Exemption from COMS W1004
English Language and composition	5	3*	No exemption
English Literature and composition	5	3*	No exemption
Economics Micro & macro	5 & 4	4*	Exemption from ECON W1105 (Test must be in both with a score of 5 in one and at least 4 in the other.)
French Language	4 or 5	3*	
French Literature	4 or 5	3*	
German language	4 or 5	3*	
Government and politics United States	5	3*	
Government and politics Comparative	5	3*	
History European	5	3*	
History United States	5	3*	
Latin literature	4 or 5	3*	
Mathematics Calculus AB or BC	5	4	Requires beginning with and completion of at least Calculus IIIA (MATH V1201) with grade of C or better.
Music theory	5	3*	Exemption from MUSI V1002. MUSI V2138-V2139 determined by department.
Physics C-E&M	4 or 5	3*	No exemption
Physics C-E&M	4 or 5	3	Requires beginning with and completion of PHYS C2801 with grade of C or better.
C-MECH	4 or 5	3	Requires beginning with and completion of PHYS C2801 with grade of C or better.
Physics B	4 or 5	3	
Spanish Language	4 or 5	3*	
Spanish Literature	4 or 5	3*	

\*Up to 3 AP credits can be applied toward minor requirements.

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, physics, or English.

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 above.

## **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**

Engineering is the most international occupation. Whatever career students choose, international opportunities will expand enormously during their lifetime and the experience gained through study abroad will prove invaluable. Achieving cultural literacy in another country—some substantive understanding of another perspective on the world—will, moreover, deepen their understanding of themselves, their own society, and their values.

To be eligible for participation in a Columbia-approved study-abroad program, students must be in good academic standing and be making progress toward finishing their Core Curriculum. It is essential that students begin planning with their adviser in their first year or early in their second. Information about how to prepare for study abroad and a listing of approved study-abroad programs are obtainable on the study-abroad Web site: [www.studentaffairs.columbia.edu/studyabroad](http://www.studentaffairs.columbia.edu/studyabroad).

Generally, students go abroad the following spring semester in their sophomore year or in their junior year. Students must consult with their adviser to discuss meeting their sophomore and junior course requirements and to ensure that the desired program is acceptable and suitable to their course of study. Students who wish to study abroad for more than one semester should plan to attend the summer session at Columbia following their spring term away, as well as getting approval from their adviser. To receive permission to study abroad, students must be cleared by their class dean and then make an appointment with Dean Kathleen McDermott ([km26@columbia.edu](mailto:km26@columbia.edu)) for final approval. Students must register by November 15 for the spring semester and April 15 for the fall

semester. Students who receive approval to study abroad remain enrolled at Columbia and tuition is paid to Columbia. Columbia will, in turn, pay tuition to the sponsoring institution up to the amount of Columbia tuition. Students on financial aid will receive their financial aid while abroad and must meet with a financial aid adviser before going abroad.

In order to obtain credit toward their Columbia degree for work done abroad, students must meet with their adviser and/or a departmental representative and obtain course-by-course approvals in advance. Due to the nature of the School's curriculum, students are generally advised to fulfill their nontechnical course requirements while abroad, although they may seek approval for technical courses as well. Students must receive a grade of C or better in order to be credited for any course work done outside of Columbia.

## **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 can be found on page 19.

### **THE COMBINED PLAN (3-2) PROGRAM FOR 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.

A similar program can be planned for students at an affiliated liberal arts college. The Pre-Combined Plan Curriculum Guide is available online at <http://www.engineering.columbia.edu/admissions/cp/bachelors/>.

### **THE COMBINED PLAN AT 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. 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 two years at Columbia. 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.

For further information on the 3-2 B.A./B.S. program and the 4-2 B.S. program, contact the Assistant

Director of Admissions, 212 Hamilton Hall, Mail Code 2807, 1130 Amsterdam Avenue, New York, NY 10027. You may also e-mail questions to: [combinedplan@columbia.edu](mailto:combinedplan@columbia.edu).

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 undergraduate 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](mailto: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, please go also to <http://www.engineering.columbia.edu/admissions/cp/application/>.

#### **The Combined Plan—Affiliated Colleges and Universities**

Adelphi University, Garden City, New York  
Albertson College, Caldwell, Idaho  
Albion College, Albion, Michigan  
Alfred University, Alfred, New York  
Allegheny College, Meadville, Pennsylvania  
Arcadia University, Glenside, Pennsylvania  
Augustana College, Sioux Falls, South Dakota  
Austin College, Sherman, Texas  
Baldwin-Wallace College, Berea, Ohio  
Bard College, Annandale-on-Hudson, New York  
Barnard College, New York, New York  
Bates College, Lewiston, Maine  
Beirut University College, Beirut, Lebanon  
Beloit College, Beloit, Wisconsin  
Bethany College, Bethany, West Virginia  
Birmingham-Southern College, Birmingham, Alabama  
Bowdoin College, Brunswick, Maine  
Brandeis University, Waltham, Massachusetts  
Carleton College, Northfield, Minnesota  
Carroll College, Helena, Montana  
Centenary College of Louisiana, Shreveport, Louisiana  
Centre College, Danville, Kentucky  
Claremont McKenna College, Claremont, California  
Clark University, Worcester, Massachusetts  
Colgate University, Hamilton, New York  
College of Notre Dame, Baltimore, Maryland  
College of the Holy Cross, Worcester, Massachusetts  
College of William and Mary, Williamsburg, Virginia

Colorado College, Colorado Springs, Colorado  
Columbia College, New York, New York  
Davidson College, Davidson, North Carolina  
Denison University, Granville, Ohio  
DePauw University, Greencastle, Indiana  
Dillard University, New Orleans, Louisiana  
Doane College, Crete, Nebraska  
Drew University, Madison, New Jersey  
Earlham College, Richmond, Indiana  
Eckerd College, St. Petersburg, Florida  
Elon University, Elon, North Carolina  
Fairfield University, Fairfield, Connecticut  
Fordham University, Bronx, New York  
Franklin and Marshall College, Lancaster, Pennsylvania  
Gettysburg College, Gettysburg, Pennsylvania  
Grinnell College, Grinnell, Iowa  
Hamilton College, Clinton, New York  
Hartwick College, Oneonta, New York  
Hastings College, Hastings, Nebraska  
Hendrix College, Conway, Arkansas  
Hobart and William Smith Colleges, Geneva, New York  
Hofstra University, Hempstead, New York  
Illinois Wesleyan University, Bloomington, Illinois  
Jacksonville University, Jacksonville, Florida  
Juniata College, Huntingdon, Pennsylvania  
Kansas Wesleyan University, Salina, Kansas  
Knox College, Galeburg, Illinois  
Lawrence University, Appleton, Wisconsin  
Lewis and Clark College, Portland, Oregon  
Loyola College in Maryland, Baltimore, Maryland  
MacMurray College, Jacksonville, Illinois  
Marietta College, Marietta, Ohio  
Miami University, Oxford, Ohio  
Middlebury College, Middlebury, Vermont  
Millsaps College, Jackson, Mississippi  
Morehouse College, Atlanta, Georgia  
Muhlenberg College, Allentown, Pennsylvania  
Nebraska Wesleyan University, Lincoln, Nebraska  
Occidental College, Los Angeles, California  
Pacific Lutheran University, Tacoma, Washington  
Pitzer College, Claremont, California  
Providence College, Providence, Rhode Island  
Queens College, Flushing, New York  
Randolph-Macon College, Ashland, Virginia  
Reed College, Portland, Oregon  
Rollins College, Winter Park, Florida  
St. John Fisher College, Rochester, New York  
St. Lawrence University, Canton, New York  
Sarah Lawrence College, Bronxville, New York  
School of General Studies, Columbia University, New York, New York  
Scripps College, Claremont, California  
Seattle Pacific University, Seattle, Washington  
Simon's Rock College of Bard, Great Barrington, Massachusetts  
Spelman College, Atlanta, Georgia  
State University College, Fredonia, New York  
State University College, Geneseo, New York  
State University of New York, Binghamton, New York  
Sweet Briar College, Sweet Briar, Virginia

University of Puget Sound, Tacoma, Washington  
University of Richmond, Virginia  
University of the South, Sewanee, Tennessee  
University of the Virgin Islands, St. Thomas, Virgin Islands  
Ursinus College, Collegeville, Pennsylvania  
Wabash College, Crawfordsville, Indiana  
Washington and Lee University, Lexington, Virginia  
Wells College, Aurora, New York  
Wesleyan University, Middletown, Connecticut  
Whitman College, Walla Walla, Washington  
Whitworth College, Spokane, Washington  
Willamette University, Salem, Oregon  
William Jewell College, Liberty, Missouri  
Williams College, Williamstown, Massachusetts  
Wittenberg University, Springfield, Ohio  
Wofford College, Spartanburg, South Carolina  
Yeshiva University, New York, New York  
York College of Pennsylvania, York, Pennsylvania

## **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 Idvorsky Pupin, and Augustus Schermerhorn.

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 68 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 22.

#### **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 end 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 addition, the School cannot guarantee that a selected minor can be completed within the usual residence period needed for a major. Indeed, students choosing minors should expect to encounter scheduling difficulties. The potential for the successful completion of a minor depends on the student’s major and the minor chosen, as well as the course 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,” on page 178.

## **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 to plan an appropriate program. Students should also connect with the Office of Pre-Professional Advising to learn more about extracurricular opportunities related to premed studies. At the beginning of their junior year, students pursuing admission to professional schools must register their intent with the preprofessional office and will be assigned an adviser to assist with the application 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
- One year of organic chemistry, with lab
- One year of English
- Biochemistry or additional biology (required by a small number of 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 PROVISIONAL SECONDARY SCHOOL TEACHER CERTIFICATION**

Students may qualify for certification to teach in New York State and thirty-one other states in elementary or secondary schools. Students must apply for admission to the Certification Program and supply an essay and letters of recommendation. These forms may be downloaded from the Barnard College Office of Education Web site, <http://www.barnard.edu/education/>, or picked up in the 336 Milbank Hall office. Additional coursework is required: courses in psychology and education, including practice teaching, totaling 23–26 points of credit.

Course subjects are:

- Foundations of Education: 3 points
- Psychology: 3 points
- Pedagogical core: 17 points
- Mathematics courses required for math certification: 36 points
- Pure science courses required for science certification: 36 points, of which 15 must be in the area of the certification sought: chemistry, biology, physics, or earth science

The teacher certification program is coordinated through the Barnard College Office of Education, 336 Milbank Hall (212-854-7072).

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.

## **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 pro-

Program Title	HEGIS code	B.S.	M.S.	Professional	M.Phil.	Eng.Sc.D.	Ph.D.
Applied Mathematics	913	X	X		X		X
Applied Physics	919	X	X		X	X	X
Biomedical Engineering	905	X	X		X	X	X
Chemical Engineering	906	X	X	Chemical Engineer	X	X	X
Civil Engineering	908	X		Civil Engineer			
Civil Engineering and Eng. Mechanics	908		X		X	X	X
Combined Plan w/Affiliated College; Dual B.S. (M.S.)/B.A.	999	X	X				
Computer Engineering	999	X	X				
Computer Science	701 909	X	X	Computer Systems Engineer	X	X	X
Computer Science/Business: Dual M.S./M.B.A.	701		X				
Earth and Environmental Engineering	918	X	X		X	X	X
Earth and Environmental Engineering/Business: Dual M.S./M.B.A.	913		X				
Electrical Engineering	909	X	X	Electrical Engineer	X	X	X
Engineering Mechanics	921	X		Mechanics Engineer			
Financial Engineering	913		X				
Financial Engineering/Business: Dual M.S./M.B.A.	913		X				
Industrial Engineering	913	X	X	Industrial Engineer	X	X	X
Industrial Engineering/Business: Dual M.S./M.B.A.	913		X				
Materials Science and Engineering	915	X	X		X	X	X
Mechanical Engineering	910	X	X	Mechanical Engineer	X	X	X
Medical Physics	1299		X				
Metallurgical Engineering	914			Metallurgical Engineer			
Mining Engineering	918			Engineer of Mines			
Mining Engineering and Applied Geophysics	918		X				
Operations Research	913	X	X		X	X	X
Operations Research: Engineering and Management Systems	913	X	X*				
Solid State Science and Engineering	919		X		X	X	X

\*State approval pending.

gram 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 Junior Senior Advising Center.

## 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 above). 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.

# Undergraduate Admissions

Office of Undergraduate Admissions  
Columbia University  
212 Hamilton Hall, Mail Code 2807  
1130 Amsterdam Avenue  
New York, NY 10027

Fax: 212-854-1209  
Phone: 212-854-2522  
<http://www.studentaffairs.columbia.edu/admissions>

## 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:

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

### THE APPLICATION PROCESS

Applications should be requested from the Office of Undergraduate Admissions, which sends out an undergraduate application designed to serve both the School of Engineering and Applied Science and Columbia College.

Part 1 of the application should be filled out and submitted as early as possible along with the \$65 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 mate-

rials must be postmarked by November 1.

The October standardized test dates are the last available to Early Decision applicants, who must be certain to use the correct school referral codes to ensure that their scores are reported promptly.

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.

### APPLYING ONLINE

You are welcome to use paper application materials if you prefer. If you have access to the Internet, however, you are encouraged to use our online application procedure. Please go to <http://www.studentaffairs.columbia.edu/admissions/applications/>.

### REQUIRED STANDARDIZED TESTING

Standardized tests are required for admission according to the following guidelines:

- A. The SAT Reasoning examination consists of three sections, each graded on an 800-point scale; if you take the test more than once, you will be evaluated on the highest score you receive in any individual section. You may substitute the older version of the SAT Reasoning only if you also submit the SAT Subject Test in Writing.

- B. You may alternatively take the ACT Assessment, graded on a 36-point scale; if you take the test more than once, you will be evaluated on the highest composite score you receive. The writing component offered by the ACT Assessment is mandatory for Columbia candidates. You may substitute the older version of the ACT Assessment without the writing component only if you also submit the SAT Subject Test in Writing.
- C. In addition to either A or B above, you must also take two SAT Subject Tests. You must take any mathematics test and either physics or chemistry.
- D. Additional requirements: If you attend a school that does not give out conventional grades or if you are home-schooled, you must take two additional SAT Subject Tests in addition to all requirements outlined above.

You must register with the appropriate testing agency well in advance of the date on which you wish to be tested. You should be aware that scores on tests taken after December might not reach the Admissions Office in time for consideration. 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  
<http://www.ets.org>

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

Test of English as a Foreign Language  
Box 899  
Princeton, NJ 08451  
609-771-7100  
<http://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 17) 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 Committee on Admissions. After a rigorous selection process, the Scholars are chosen to participate throughout their four undergraduate years in academic and co-curricular enhance-

ments designed to achieve excellence in preparation for the profession.

#### HIGHER EDUCATION OPPORTUNITY PROGRAM (HEOP)

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.

For further information concerning the School of Engineering and Applied Science's Higher Education Opportunity Program, contact:

Opportunity Programs and Undergraduate Services  
Columbia University  
New York, NY 10027

Phone: 212-854-3514  
<http://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-I Reasoning Test 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.

Foreign students not exempted by the criteria given above must submit the results of the TOEFL exam with their application 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 <http://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:

- January 1–March 15 for the 3-2 Combined Plan Program
- January 1–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, contact the Office of Undergraduate Admissions at the address above, phone 212-854-

2522, or e-mail [combinedplan@columbia.edu](mailto:combinedplan@columbia.edu). (You may also visit <http://www.engineering.columbia.edu/admissions/cp/>.) 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. Campus tours are conducted every weekday by a current undergraduate at 11:00 a.m. and 3:00 p.m. Group information sessions are conducted every weekday by a member of the professional admissions staff at 10:00 a.m. and 2:00 p.m. On most Saturday mornings in the fall, and on the second Saturday of each month during the rest of the year, there is a group information session at 10:00 a.m. and a campus tour at 11:00 a.m. Tours begin and group sessions take place at the Visitors Center, 213 Low Library. No appointment is necessary for either. For more information concerning campus tours and group information sessions, contact the Office of Admissions.

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.

# Tuition, Fees, and Payments for Undergraduate Students

**T**he 2005–2006 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

Undergraduate students enrolled in The Fu Foundation School of Engineering and Applied Science pay a flat tuition charge of \$15,962 per term, regardless of the number of course credits taken.

## Mandatory Fees

Student Life fee: \$332 per term  
Health Service fee: \$329 per term  
\$175 summer  
International Services charge:  
\$50 per term (*International students only*)  
Transcript fee: \$45 (one-time charge)

## Other Fees

Application and late fees

- Application for undergraduate admission: \$65
- Application for undergraduate transfer admission: \$65
- Late registration fee during late registration: \$50
- Late registration fee after late registration: \$100

Health insurance premium

- Basic: \$545 fall  
\$837 spring/summer
- Comprehensive: \$779 fall  
\$1,202 spring/summer

Books and course materials:  
Depends upon course

Laboratory fees: See course listings

Room and board (estimated): \$9,000

## 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 \$200 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 with-

drawal 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)*

1st week	100%
2nd week	90%
3rd week	80%
4th week	80%
5th week	70%

6th week	60%
7th week	60%
8th week	50%
9th week	40%
After 9th week	0%

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.

# Financial Aid for Undergraduate Study

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: [ugrad-finaid@columbia.edu](mailto:ugrad-finaid@columbia.edu)  
<http://www.studentaffairs.columbia.edu/finaid>

Admission to Columbia is need-blind for all students who are U.S. citizens, permanent residents, or Canadian 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	\$1,600
Sophomore	\$1,800
Junior	\$2,000
Senior	\$2,100

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 one or more low-interest student loans and 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 \$400 to \$4,050.

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 both on a walk-in basis and on the Center's Web site: [www.cce.columbia.edu/cu/find\\_a\\_job/workstudy.php/](http://www.cce.columbia.edu/cu/find_a_job/workstudy.php/). For further information, including information on Columbia Student Enterprises, see the section "Center for Career Education" in this bulletin.

The *Federal Work-Study Program (FWS)* is a program to provide federal funds to create jobs on and off campus for financially needy students. Work-study jobs are available in academic

and administrative departments, laboratories, libraries, and campus dining halls. Students employed under the work-study program are paid biweekly based on the number of hours worked, and may earn up to the total amount specified in their financial aid package. The financial aid office recommends that students inquire about work-study positions in the academic department from which they will receive their degree.

## C. STUDENT LOANS

The *Federal Stafford Loan* program was authorized by Title IV of the Higher Education Act of 1965, as amended. Through this program, loans are made by banks and other commercial lenders from their own funds, with guarantees by the federal government. The interest rate on these loans is charged at a variable rate of the 91-day Treasury Bill plus 3.1 percent, with an 8.25 percent cap.

To qualify for a Federal Stafford Loan, the student and family must meet financial eligibility requirements. Eligible participants in this program may borrow up to the following amounts, with a fifth year allowed for undergraduate study:

First year	\$2,625
Sophomore	\$3,500
Junior	\$5,500
Senior	\$5,500
Total limit	\$23,000

The federal government pays the interest on these loans until repayment begins, usually six months after the borrower stops being at least a half-time student. The repayment period is up to ten years.

Students who do not qualify for the Federal Stafford Loan may borrow through the *Unsubsidized Federal Stafford Loan* program. Loan limits and the interest rate are the same under this program, but the federal government does not subsidize interest payments while the student is enrolled.

*Federal Perkins Loans*, formerly National Direct Student Loans (NDSL), are made to students with exceptional need from funds provided by the federal government, Columbia University, and

the repayment of previous loans. The interest rate is currently 5 percent. Federal regulations limit these loans to a total of:

Undergraduate	\$4,000/year
Total limit	\$16,000

Columbia makes its limited Federal Perkins Loan funds available to students demonstrating the greatest financial need.

## D. 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 social security 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 <http://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. For continuing students, the Columbia Application for Financial Aid for Continuing Students should be obtained from the financial aid office and/or downloaded in March of each year. 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 <http://www.collegeboard.com/profile/>.

Applicants who register online should complete the CSS Profile online (requires a secure browser and credit card). Continuing students do not need to register with CSS; they should obtain a PROFILE Renewal Application from the financial aid office in March of each year. 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
- February 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 <http://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 obtain a FAFSA from the Office of Financial Aid and Educational Financing in March of 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
- 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: paper version of FAFSA
- May 5:** Continuing students: online

### 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 download the Noncustodial Parent's Statement from <http://www.studentaffairs.columbia.edu/finaid/forms/>. The deadlines for returning this form to the financial aid office are:

- November 12:** First-year early decision candidates
- February 25:** First-year regular decision candidates
- April 20:** Transfer applicants
- May 3:** 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 12:** First-year early decision candidates
- February 25:** First-year regular decision candidates
- April 20:** Transfer applicants
- May 3:** 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 11:** First-year candidates (early and regular decision)
- April 20:** Transfer applicants
- May 3:** 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.

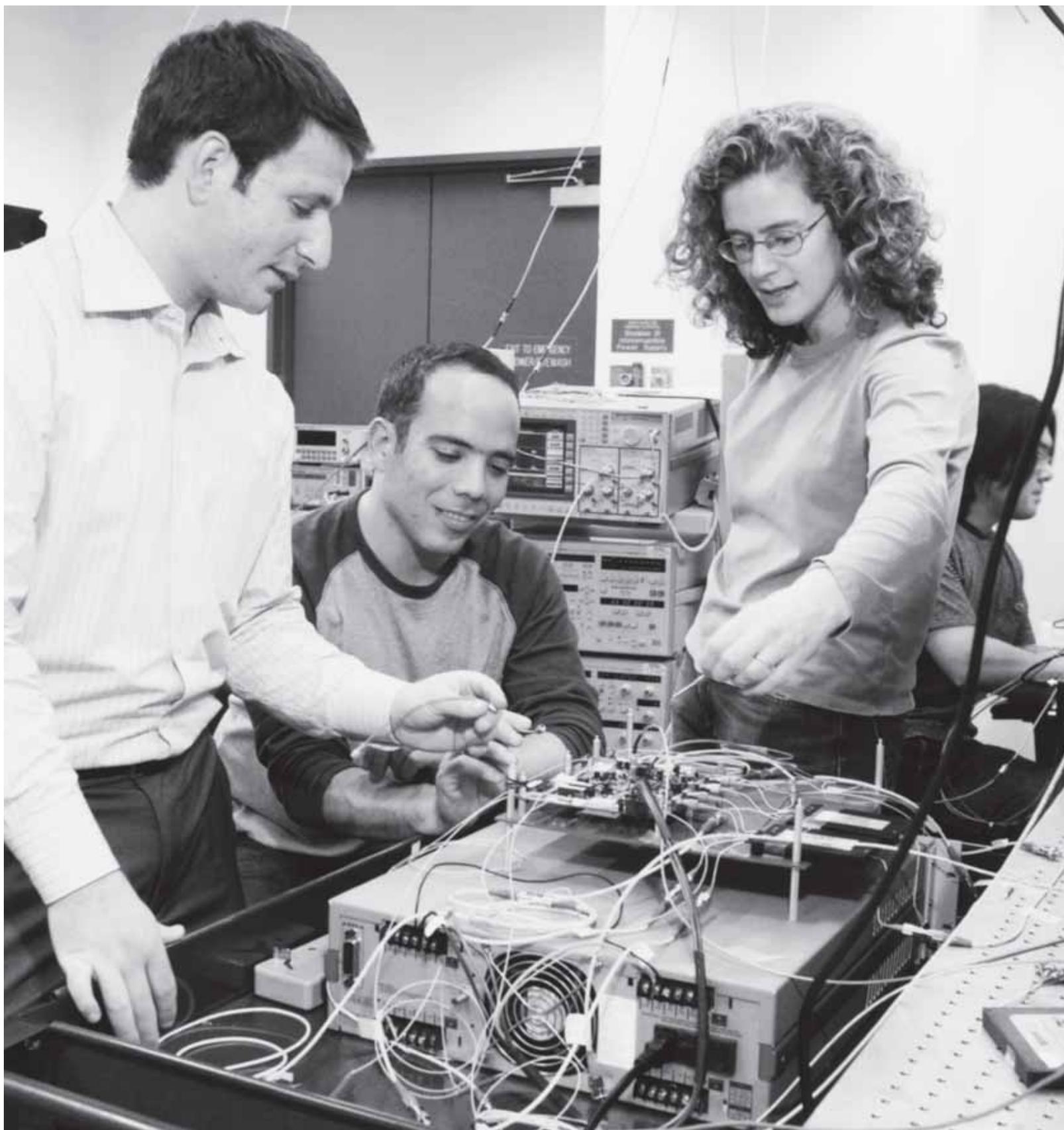
Certain countries have entered into tax treaties with the United States, which may serve to reduce this rate of withholding. However, even when such a treaty applies, the student and the University must report the full amount of such excess to the Internal Revenue Service. If a student claims tax treaty 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



# The Graduate Programs

**G**raduate 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 37 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. For this credit to be formally recognized on the student's record at Columbia, a transcript from the other institution must

be submitted to the Office of Graduate Student Services.

Competence in written and spoken English is required of every degree candidate. See page 40 for English proficiency requirements.

A candidate for any degree except a doctoral degree must file an application 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 stud-

ies, 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.

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. Failure to pass any course, including those taken in the summer session or in another school for which credit would be accepted as equivalent to a regular course in the School of Engineering and Applied Science, is counted in a student's grade-point average.

#### **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\* 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, Earth and environmental, electrical, industrial, and mechanical engineering; applied physics; applied mathematics; civil engineering and engineering mechanics; operations research;

materials science; computer science; and computer engineering.

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 and an application form. You may, in addition, e-mail questions to [seasgradmit@columbia.edu](mailto: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.

\*See the listing under the heading "The Combined Plan—Affiliated Colleges and Universities," on pages 18–19 of this bulletin.

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 complete six Residence Units. A master's degree from an accredited

institution may be accepted as the equivalent of one year of residence (30 points of credit or two Residence Units) for either doctoral degree. 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. (See Academic Calendar for last date to apply for the Eng.Sc.D. or Ph.D. 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 permitted, 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 course work beyond the minimum residence requirements, the 12 points of doctoral research instruction must still be taken in addition to the required course work.
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 credit, but no more than 15 points of course work completed as a special student may be counted toward a graduate degree.

For additional information and regulations pertaining to special students, see "Graduate Admissions."

# Columbia Video Network

Columbia Video Network  
Columbia University  
540 S. W. Mudd, Mail Code 4719  
500 West 120th Street  
New York, NY 10027

<http://www.cvn.columbia.edu>  
E-mail: [info@cvn.columbia.edu](mailto:info@cvn.columbia.edu)  
Phone: 212-854-6447

## 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's regular faculty. Faculty and students meet in specially equipped classrooms where a multicamera video setup captures the entire lecture, including the professor's notes and presentations. The recorded lectures are fully downloadable for study at home, office, or on the road; or they can be viewed via Web streaming.

CVN students take the same classes, have the same homework assignments, and take the same exams as their on-campus counterparts. The only difference is location. CVN students earn the same degrees as on-campus students: a Master of Science or professional degree from Columbia University's Fu Foundation School of Engineering and Applied Science.

## 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 session (and, occasionally, the autumn and spring terms), the CVN program makes pretape courses available.

CVN currently offers courses and degree programs in six engineering disciplines. CVN students can earn a Master of Science degree in:

- Civil engineering (construction engineering and management)
- Computer science
- Electrical engineering (with concentrations available in telecommunications engineering, new media engineering, multimedia networking, wireless and mobile communications, lightwave engineering, microelectronic circuits, and microelectronic devices)
- Engineering and management systems
- Materials science and engineering
- Mechanical engineering

Professional degrees (P.D.) are also available in computer science, electrical engineering, mechanical engineering, and industrial engineering and operations research for engineers who wish to do advanced work beyond the M.S. degree but do not wish to emphasize research.

## Student Registration

Students who have earned an undergraduate degree in engineering, mathematics, or the sciences can take classes for credit or audit without first applying to the University or taking the GRE or TOEFL exams by registering as Video Special (VS) students.

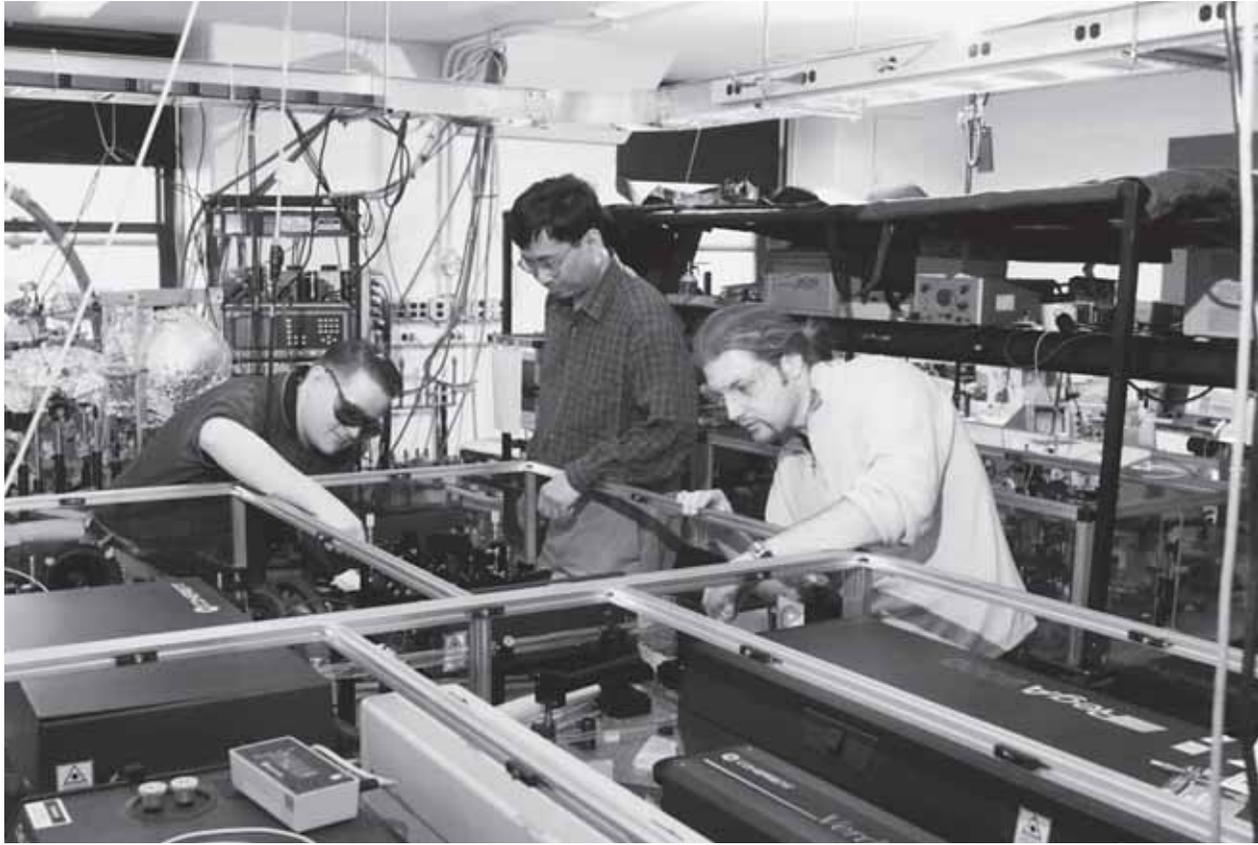
By completing the CVN registration form, including the New Student Information section, and paying the one-time VS application fee of \$55, students can begin taking classes through CVN. However, CVN strongly advises VS students to review course syllabi carefully to ensure that they have the necessary background to successfully complete the course(s) for which they register.

CVN also offers a Certificate of Professional Achievement program, with certificate programs in multiple areas of study. Candidates for the Certificate of Professional Achievement program may take classes as a VS student, but must complete the program of study as defined by the appropriate department.

## Application for Admission

Persons (including VS students taking Columbia classes for credit) interested in earning the M.S. or P.D. degree from Columbia are required to complete the Columbia University application package. All M.S. applicants (and P.D. applicants in computer science) must take the GRE general exam.

The TOEFL is required of all applicants who have earned a degree in a country where English is not the offi-



cial and spoken language. In addition, applicants must submit:

- A signed and dated application form along with the \$55 application fee
- Two letters of recommendation (only one letter is required for P.D. applicants)
- Official transcripts from all post-secondary colleges and universities attended
- Personal/professional statement
- Résumé/curriculum vitae

Although you need not be admitted to a degree-granting program to begin taking classes through CVN, you should apply as soon as possible if you would like to earn a degree from Columbia University. Earning credit as a VS student does not guarantee acceptance into a degree-granting program.

Columbia University may accept up to 6 points of credit transferred from another university and/or up to 15 points earned at Columbia as a VS student, subject to the approval of the student's adviser and the department.

## Program Benefits

The CVN program allows working professionals to enroll in courses and earn graduate engineering degrees from one of the world's great universities 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 part of the

Columbia community and are always welcome 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 with ease. Homework and exams are submitted and graded there, and course notes and other reference materials are available for downloading by students.

Professors and teaching assistants are also available to off-campus students by phone during regular office hours and by appointment. CVN's administrative staff is always available to assist off-campus students in handling routine administrative details so working professionals can devote their energies to their studies, their families, and their careers.

# Graduate Admissions

Office of Graduate Student Services  
The Fu Foundation School of  
Engineering and Applied Science  
Columbia University  
524 S. W. Mudd, Mail Code 4708  
500 West 120th Street  
New York, NY 10027

Phone: 212-854-6438

Fax: 212-854-5900

E-mail: [seasgradmit@columbia.edu](mailto:seasgradmit@columbia.edu)

Apply online at: <http://www.engineering.columbia.edu>

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 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 two official transcripts 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.

## English Proficiency Requirement

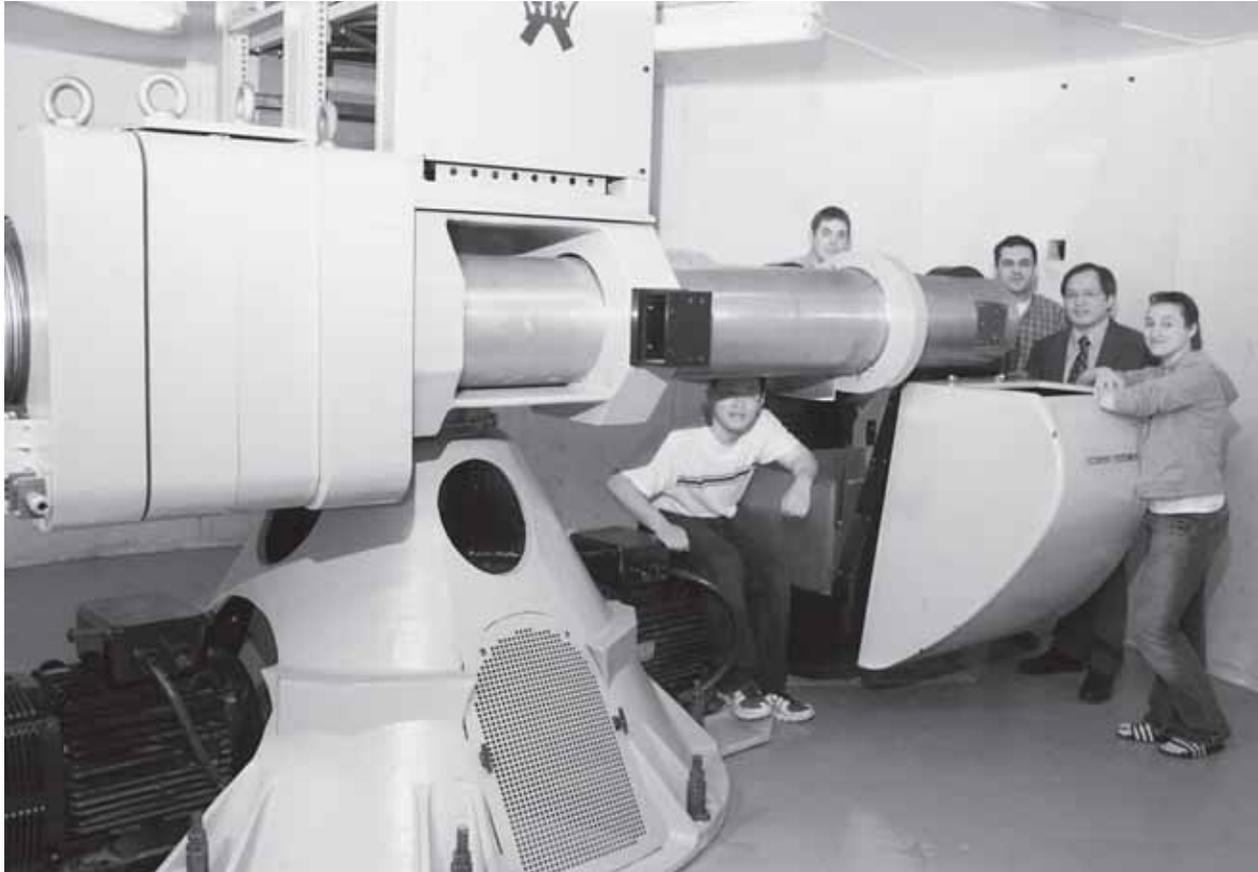
Admitted graduate students who are required to submit official TOEFL results must attain levels of proficiency as described below. Students will not be cleared for graduation unless they satisfy the following requirements:

- 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 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 \$55 is required of all degree and nondegree applicants who apply using a hard-copy application. Applicants applying online are required to pay a \$45 fee. Failure to submit the application fee can delay processing of application materials.

## Graduate Admission Calendar

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

- Fall admission application deadlines: *December 15*, for Ph.D., Eng.Sc.D., and M.S. leading to

Ph.D. programs, and all applicants for financial aid at any degree level. *February 15*, for professional, M.S. only, and nondegree 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.

## Special Student Status

Individuals who meet the eligibility requirements, who are U.S. citizens or

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 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 three days of the fall or spring semester.

If a 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.

# Tuition, Fees, and Payments for Graduate Students

The 2005–2006 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 \$1,064 per credit, except when a special fee is fixed. Graduate tuition for Ph.D. students is \$31,448, or \$15,724 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 \$1,315 per term by The Fu Foundation School of Engineering and Applied Science.

Ph.D. candidates engaged only in research are assessed \$1,315 per term for Matriculation and Facilities by the Graduate School of Arts and Sciences.

## Mandatory Fees

University facilities fee: \$130 per term  
Health Service fee: \$329 per term  
\$175 summer  
International service charge: \$50 per term (*International students only*)  
Transcript fee: \$45 (one-time charge)

## Other Fees

Application and late fees  
Application for graduate admission  
paper copy: \$55  
online: \$45  
Late registration fee  
during late registration: \$50  
after late registration: \$100  
Health insurance premium  
Basic: \$545 fall  
\$837 spring/summer  
Comprehensive: \$779 fall  
\$1,202 spring/  
summer

Books and course materials: Depends upon course

Laboratory fees: See course listings

## 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 \$200 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:

1st week	100%
2nd week	90%
3rd week	80%
4th week	80%
5th week	70%
6th week	60%
7th week	60%
8th week	50%
9th week	40%
After 9th week	0%

### 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

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.

# Financial Aid for Graduate Study

## 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 case officer.

## 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. complete an Enrollment Status 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/PINWebApp/pinindex.jsp](http://www.pin.ed.gov/PINWebApp/pinindex.jsp). 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/](http://www.fafsa.ed.gov/). Columbia University prefers that you apply for financial aid online. FAFSA-on-the-Web applications are both faster and more accurate than paper FAFSA applications. If you cannot file your FAFSA online, paper FAFSAs are available from the Office of Financial Aid and Educational Financing or can be obtained by calling the U.S. Department of Education at 800-4FED-AID. 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) in Section G of 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 complete a paper FAFSA or 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 Enrollment Status Form available from the Office of Financial Aid and Educational Financing. The Enrollment Status Form 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 15 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 to Columbia University must complete their FAFSA after January 1 and by May 1. 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 dead-

line. All continuing supported students must preregister for classes during the preregistration period.

Complete the Enrollment Status Form available from the Office of Financial Aid and Educational Financing by May 1. The Enrollment Status Sheet provides the University with information about your planned program, including the number of courses in which you plan to enroll.

## **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 44. Continuing students must preregister for classes during the preregistration period and complete the applicable forms as stated on page 44. 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 200–201 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. To apply you must have a valid U.S. Social Security number.

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](http://www.columbia.edu/cu/isso/isso.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, an Enrollment Status Sheet, 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 submitted online by going to the [www.fafsa.ed.gov](http://www.fafsa.ed.gov) Web site. However, paper FAFSAs are available from the Office of Financial Aid and Educational Financing. The

FAFSA should 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) in Section G of 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 Enrollment Status Sheet 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/](http://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 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) in Section G of 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 (<http://www.va.gov>).

### **FEDERAL FAMILY EDUCATION LOANS**

#### **Federal Subsidized Stafford Student Loan Program**

The federal subsidized Stafford Loan Program provides low interest rate loans to needy students. These loans are made by banks and are insured by both the state and federal government. As a graduate student you may borrow up to \$8,500 per year with a total aggregate borrowing limit of \$65,500 (including undergraduate loans). No interest accrues on this loan while you are at least a half-time student, and no repayment is due until six months after you cease to be enrolled at least half time. The interest rate on the loan is variable with a cap of 8.25 percent. The rate for the 2003–2004 academic year was 3.42 percent.

An origination fee of up to 3 percent will sometimes be deducted from the loan funds. Columbia University's preferred lenders have agreed to waive this fee for The Fu Foundation School of Engineering and Applied Science

graduate students who borrow from them.

#### **Federal Unsubsidized Stafford Loan Program**

The federal unsubsidized Stafford Loan Program provides additional loan eligibility beyond any subsidized Stafford amounts. You must first apply for the regular (subsidized) Stafford program, and if you meet the eligibility criteria, you will be automatically considered for the unsubsidized program. The terms and conditions of the loan are essentially the same as the subsidized Stafford loan, except the federal government does not pay the interest on the unsubsidized loan while you are in school. Although you are not required to make payments on the principle or the interest as long as you are enrolled at least half-time, interest does accrue on the loan. You may ask your lender to bill you for the loan's interest.

As a graduate student you may borrow up to a total of \$18,500 in combined subsidized and unsubsidized Stafford loans each academic year, although no more than \$8,500 of the \$18,500 can be in the form of a subsidized loan. The total amount of unsubsidized Stafford loan in any academic year may not exceed the cost of attendance minus the family contribution and minus all other financial aid (including subsidized Stafford loans) received that year.

Your combined subsidized and unsubsidized aggregate borrowing cannot exceed \$138,500. As with the subsidized Stafford loan, the interest rate on the loan is the variable with a cap of 8.25 percent. The in-school rate for the 2003–2004 academic year was 2.82 percent, and the out-of-school interest rate was 3.42 percent.

An origination fee of up to 3 percent will sometimes be deducted from the loan funds. Columbia University's preferred lenders have agreed to waive this fee for The Fu Foundation School of Engineering and Applied Science graduate students who borrow from them.

#### **Federal Perkins Loan**

If you demonstrate exceptional financial need, you may be awarded a

Federal Perkins Loan. If you are selected as a Perkins recipient, you will be notified of your selection in your financial aid award letter. No interest accrues on this loan while you are at least a half-time student, and no repayment is due until nine months after you cease to be enrolled at least half time. The interest rate on the loan is 5 percent.

### **COLUMBIA COMPREHENSIVE EDUCATIONAL FINANCING PLAN**

Columbia University, in collaboration with a number of financial providers, has developed the Columbia Comprehensive Educational Financing Plan. 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 providers have been carefully selected on the basis of their service, experience in higher education, and the terms they offer to Columbia students.

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. Created to supplement federal and institutional aid, they feature attractive terms and interest rates. 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. International students must have a valid U.S. Social Security number.

## 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](http://www.columbia.edu/cu/isso/isso.html).

### FEDERAL WORK-STUDY PROGRAM

Federal work-study jobs are on-campus jobs funded by the U.S. government 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 University Center for Career Education maintains an extensive listing of student employment opportunities, both for work-study positions and other student employment options that are not federally funded. These listings are available both on a walk-in basis and on the Center's home page: [www.cce.columbia.edu](http://www.cce.columbia.edu). For further information on Columbia Student Enterprises, see the section "Center for Career Education" on page 11 of this bulletin. The Center for Career Education (CCE) is located at East Campus, Lower Level, 212-854-5609, [www.cce.columbia.edu/](http://www.cce.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.

## Contact Information

For questions about institutional grants, fellowships, teaching and research assistantships, readerships, and preceptorships, contact your academic department.

For questions about on- or off-campus nonneed-based employment, contact the Center for Career Education (CCE), located at East Campus, Lower Level, 212-854-5609, [www.cce.columbia.edu/](http://www.cce.columbia.edu/).

For questions about federal work-study employment, New York State TAP grants, and student loans, contact:

Office of Financial Aid and Educational Financing  
Columbia University  
407 Lerner Hall, Mail Code 2802  
New York, New York 10027

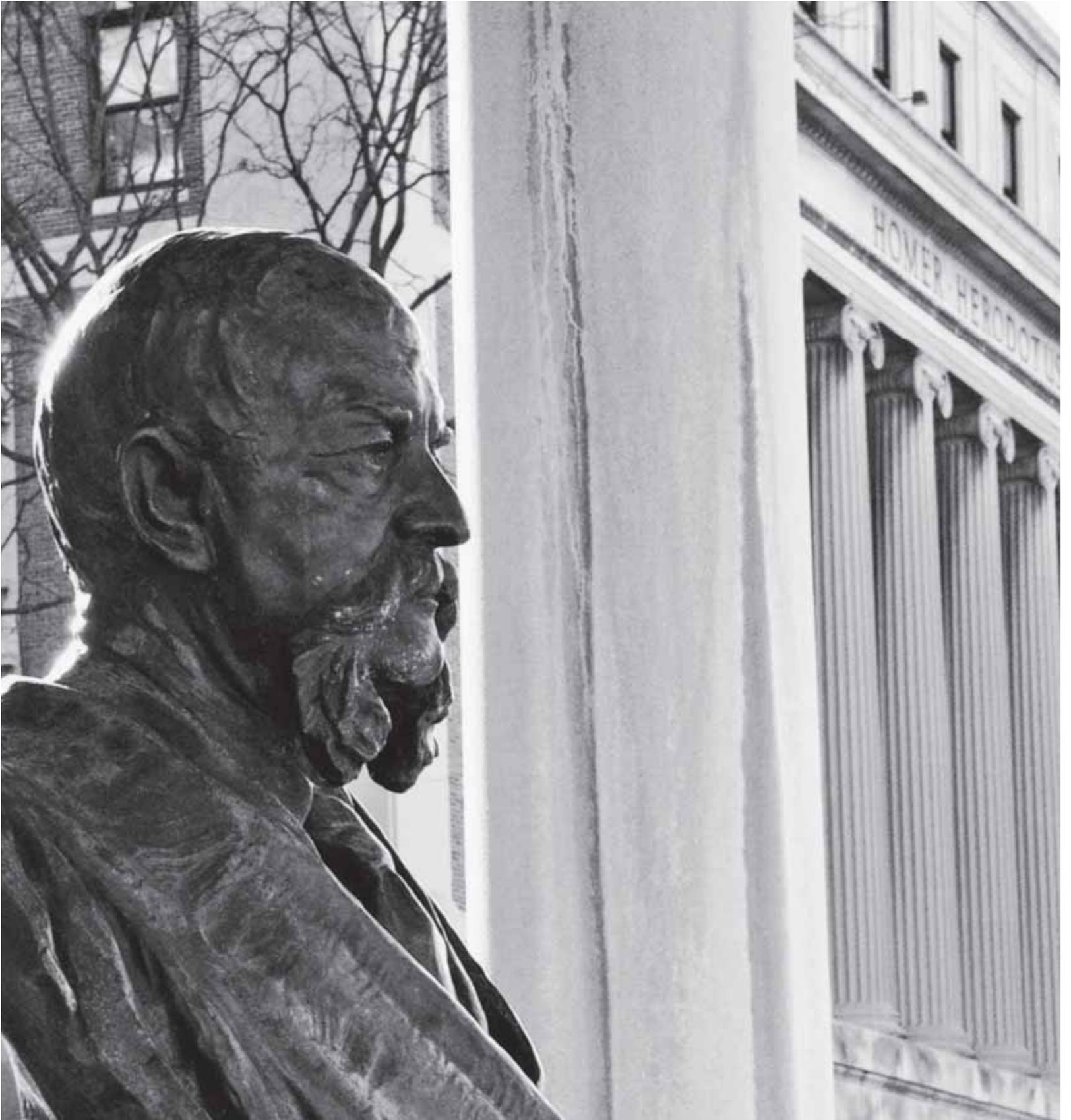
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# Faculty and Administration

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B.Eng., McGill, 1956; Ph.D., 1961

**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

**Stephen H. Unger**

*Professor of Computer Science and of Electrical Engineering*  
B.E.E., Polytechnic Institute of Brooklyn, 1952; M.S., Massachusetts Institute of Technology, 1953; Sc.D., 1957

**Rimas Vaicaitis**

*Renwick Professor of Civil Engineering*  
B.S., Illinois, 1967; M.S., 1968; Ph.D., 1970

**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., Shanaha 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**

*Professor of Chemical Engineering*  
B.S., Case Western Reserve, 1985; Ph.D., California (Berkeley), 1989

**Ward Whitt**

*Professor of Industrial Engineering and Operations Research*  
A.B., Dartmouth, 1964; Ph.D., Cornell, 1969

**Chris H. Wiggins**

*Assistant Professor of Applied Mathematics*  
B.A., Columbia, 1993; Ph.D., Princeton, 1998

**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 Wu**

*Associate Professor of Clinical Radiation Oncology (in Public Health, Environmental Health Sciences, and Applied Physics)*  
B.S., National Tsing Hua University (Taiwan), 1979; M.S., 1982; Ph.D., Kansas, 1985

**Mihalis Yannakakis**

*Percy K. and Vida L. W. 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*  
M.S., Technical University (Istanbul), 1961; Eng.Sc.D., Columbia, 1968

**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

## Faculty Members-at-Large

**R. Glenn Hubbard**  
*Dean of the Graduate School of Business*

**John Morgan**  
*Chairman, Department of Mathematics*

**Erick J. Weinberg**  
*Chairman, Department of Physics*

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

**Michael Sheetz**  
*Chairman, Department of Biological Sciences*

**Bruce Berne**  
*Chairman, Department of Chemistry*

**Austin E. Quigley**  
*Dean, Columbia College*

**Nicholas Christie-Blick**  
*Chairman, Department of Earth and Environmental Sciences*

## 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*

**Maciej P. Bieniek**  
*Renwick Professor Emeritus of Civil Engineering*

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

**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*

**Ferdinand Freudenstein**  
*Higgins Professor Emeritus of Mechanical 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*

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*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*

**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*

**Ralph J. Schwarz**  
*Thayer Lindsley Professor Emeritus of Electrical Engineering*

**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*

**Howard W. Vreeland**  
*Professor Emeritus of Graphics*

**Malcolm Wane**  
*Professor Emeritus of Mining*

**Omar Wing**  
*Professor Emeritus of Electrical Engineering*

**Edward S. Yang**  
*Professor Emeritus of Electrical Engineering*

## Administrative Officers

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*Manager, Human Resources and Facilities Services*

**Grace Chung**  
*Executive Director of Columbia Video Network*

**Costantino Colombo**  
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**Zvi Galil**  
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*Development Officer*

**Margaret Kelly**  
*Development Officer*

**Branka Kristic**  
*Executive Assistant to the Vice Dean*

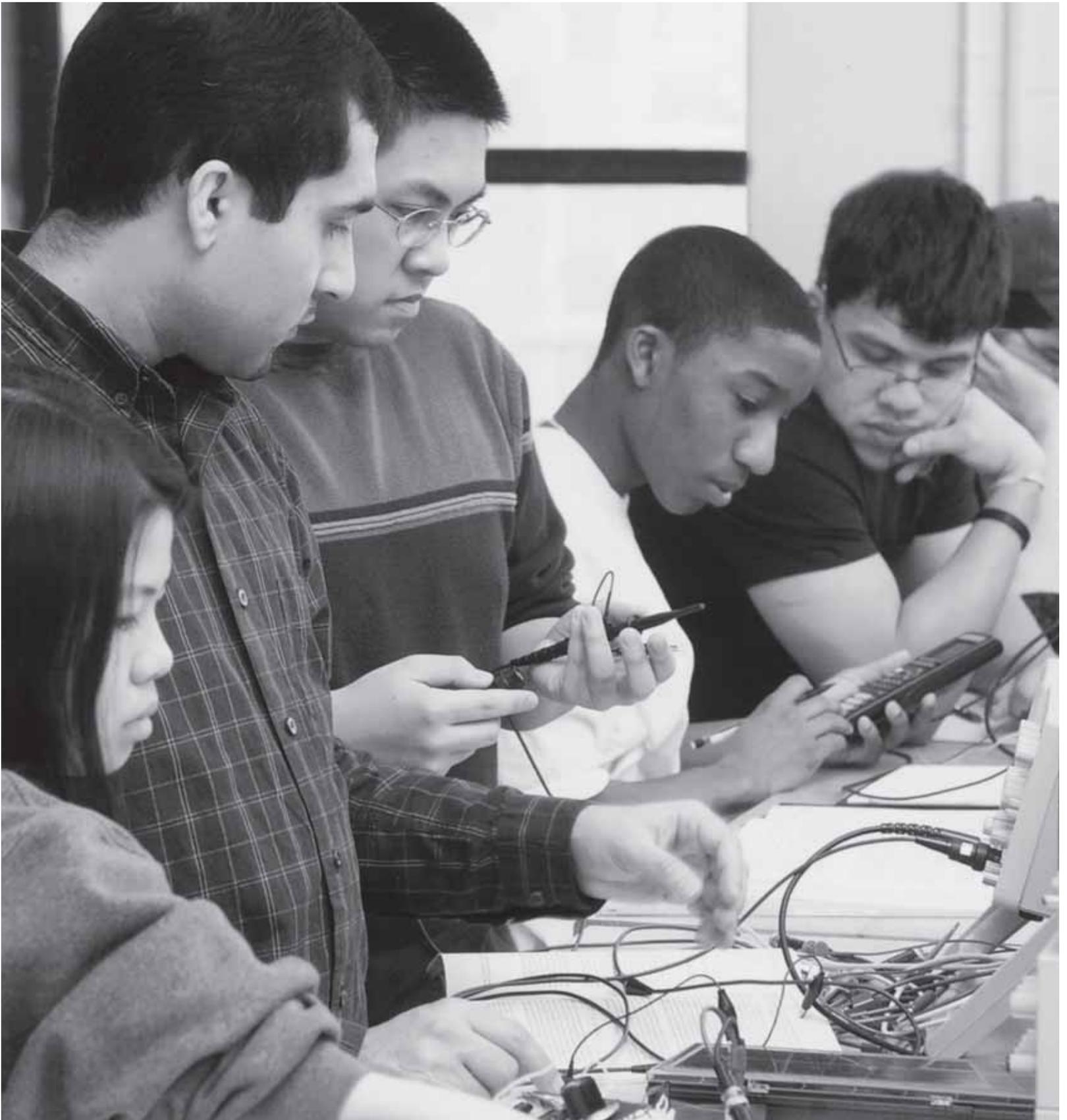
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*Executive Assistant to the Dean*

**Tiffany M. Simon**  
*Assistant Dean for Graduate Student Services*

# Departments and Academic Programs



# Key to Course Listings

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.

Course Designator	Department/Subject
AHIS	Art History
AMST	American Studies
APAM	Applied Physics/Applied Mathematics
APMA	Applied Mathematics
APPH	Applied Physics
ARCH	Architecture
ASCE	Asian Civilizations-East Asian
ASCM	Asian Civilizations-Middle East
BIOC	Biology and Chemistry
BIOL	Biology
BMEB	Biomedical Engineering/Electrical Engineering/Biology
BMEN	Biomedical Engineering
BUSI	Business
CBMF	Computer Science/Biomedical Engineering/Medical Informatics
CHAP	Chemical Engineering/ Applied Physics and Applied Math
CHEE	Chemical Engineering/Earth and Environmental Engineering
CHEM	Chemistry
CHEN	Chemical Engineering
CHME	Chemical Engineering/ Mechanical Engineering
CIEE	Civil Engineering/Earth and Environmental Engineering
CIEN	Civil Engineering
COCI	Contemporary Civilization
COMS	Computer Science
CSEEC	Computer Science/Electrical Engineering
CSOR	Computer Science/Operations Research
DNCE	Dance
EAE	Earth and Environmental Engineering

EAIA	Earth and Environmental/ International and Public Affairs
ECBM	Electrical Engineering/Computer Science/Biomedical Engineering
ECIA	Earth and Environmental Engineering/ Civil Engineering/ International and Public Affairs
ECON	Economics
EDUC	Education
EECS	Electrical Engineering/ Computer Science
EEHS	Electrical Engineering/History
EEJR	Electrical Engineering/Journalism
EEME	Electrical Engineering/ Mechanical Engineering
EESC	Earth and Environmental Sciences
ELEN	Electrical Engineering
ENGI	Engineering
ENGL	English
ENME	Engineering Mechanics
FREN	French
GERM	German
GRAP	Graphics
HIST	History
HUMA	Humanities
IEME	Industrial Engineering/ Mechanical Engineering
IEOR	Industrial Engineering and Operations Research
INAF	International Affairs
MATH	Mathematics
MEBM	Mechanical Engineering/ Biomedical Engineering
MECE	Mechanical Engineering
MSAE	Materials Science and Engineering/ Solid-State Science and Engineering
MSIE	Management Science/Industrial Engineering and Operations Research
MUSI	Music
PHED	Physical Education
PHIL	Philosophy
PHYS	Physics
POLS	Political Science
PSLG	Physiology and Cellular Biophysics
PSYC	Psychology
SCNC	Science
SIEO	Statistics/Industrial Engineering and Operations Research
SOCI	Sociology
SPAN	Spanish
STAT	Statistics

## 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
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; *y* indicates the spring semester.

## Directory of Classes

Room assignments and course changes for all courses are available online at <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.

# Applied Physics and Applied Mathematics

200 S. W. Mudd, MC 4701, 212-854-4457

Applied Physics and Applied Mathematics: <http://www.apam.columbia.edu>

Materials Science and Engineering: <http://www.seas.columbia.edu/matsci>



< CHAIR  
Professor Michael E. Mauel  
208 S. W. Mudd

DEPARTMENTAL ADMINISTRATOR  
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PROFESSORS  
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Mark A. Cane  
Earth and Environmental Sciences  
Siu-Wai Chan  
Morton B. Friedman  
Civil Engineering and Engineering Mechanics  
Irving P. Herman  
James S. Im  
David E. Keyes  
Thomas C. Marshall  
Michael E. Mauel  
Gerald A. Navratil  
Gertrude F. Neumark  
Ismail C. Noyan  
Richard M. Osgood Jr.  
Electrical Engineering

Aron Pinczuk  
Lorenzo M. Polvani  
Malvin A. Ruderman  
Physics  
Christopher H. Scholz  
Earth and Environmental Sciences

Amiya K. Sen  
Electrical Engineering  
Horst Stormer  
Wen I. Wang  
Electrical Engineering  
Michael I. Weinstein  
Cheng Shie Wu  
Radiation Oncology

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Adam H. Sobel  
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Harrish S. Bhat  
Stephen P. O'Brien  
Thomas S. Pedersen  
Chris H. Wiggins

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Barbara E. Carlson  
Anthony Del Genio

Supratik Guha  
Timothy M. Hall  
Ron L. Miller  
Arthur Ramirez  
Stephen A. Sabbagh  
Joseph P. Wright  
Yimei Zhu

ADJUNCT ASSOCIATE PROFESSORS  
Alexander R. R. Casti  
John L. Humm

ADJUNCT ASSISTANT PROFESSORS  
Samar Khatiwala  
David Maurer

SENIOR RESEARCH SCIENTISTS  
James Bialek  
Leonard Druyan  
Mark Hybertsen  
Qiancheng Ma  
Steven A. Sabbagh  
Shalom J. Wind

ADJUNCT SENIOR RESEARCH SCIENTISTS  
Joze Bevk  
David Lang

RESEARCH SCIENTISTS  
Christopher Bishop  
Brian Cairns  
Darren Garnier  
Andrea Garofalo  
George Tselioudis  
Yuanhong Zhang

ASSOCIATE RESEARCH SCIENTISTS  
Mark Adams  
Mikhail Alexandrov  
Jacek Chowdhary  
Ui-Jin Chung  
Jerry I. Dadap  
Florin Dobrian  
Igor Geogdzhayev  
Alexander Hansen  
Mark Holzer  
Liman Huang  
Alexander Limanov  
Dmitry Maslovsky  
David Maurer  
Nicolae Paniou  
Jan Perlwitz  
Holger Reimerdes  
Zhen Song  
Paul van der Wilt  
Ruoxian Ying

POSTDOCTORAL RESEARCH SCIENTISTS  
Sarbjit Banerjee

Deborah Berebichez  
John Berkery  
Sanjukta Bhowmick  
Yonghua Chen  
Yann Gallais  
Edwin Gerber  
Scott Gianelli  
Li Liu  
Catherine Naud  
Fabrice Papa  
Cristina Perez  
Oliver Pinaud  
Christian Rodehacker  
Anastasia Romanou  
Christian Scheck  
Sergey Shchelkunov  
Elena Shevchenko  
Aaron C. Sontag

ASSOCIATE  
John C. Arbo

SPECIAL LECTURERS  
Daniel N. Beshers  
C. K. Chu



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 162–163.

## CURRENT RESEARCH ACTIVITIES IN APPLIED PHYSICS AND APPLIED MATHEMATICS

### Plasma physics and controlled fusion.

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;

## APPLIED PHYSICS PROGRAM: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS<sup>1</sup></b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and ODE (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) C1601 (3.5) C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	C1403 (3) C2601 (3.5) Lab W3081 (2)	C1494 (3) Lab C2699 (3)
<b>CHEMISTRY/BIOLOGY</b> (choose one course)	CHEM C1403 (3), or higher <b>or</b> BIOL W2001 (4), or higher			
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ALP0006 (0)	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101 <b>or</b> V2001 (4) HUMA C1121 <b>or</b> C1123 (3)	HUMA C1002, C1102 <b>or</b> V2002 (4) ECON W1105 (4) <b>and</b> W1155 recitation (0)
<b>REQUIRED TECH ELECTIVES</b>	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see page 16)			
<b>COMPUTER SCIENCE</b>	A computer language of the student's choice at the 1000 level or higher			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>Students with advanced standing may start the calculus sequence at a higher level.

(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 Atomics, 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, nonlinear optics, ultrafast optoelectronics, photonic switching, optical physics of surfaces, laser-induced crystallization, photon integrated circuits, energy transfer in molecules, and laser chemistry.

**Solid-state physics.** Research in solid-state physics covers nanoscience and nanoparticles, the optical spectroscopy of semiconductor structures that are subjected to high pressure, 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 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, 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, genetic regulatory networks, and functional genomics, including collaborations with Columbia's Center for Computational Biology and Bioinformatics (C2B2) and Columbia's

APPLIED PHYSICS: THIRD AND FOURTH YEARS					
	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII	
REQUIRED COURSES	PHYS W3003 (3) Mechanics	APPH E3100 (3) Intro. to quantum mechanics	APPH E4300 (3) Applied electrodynamics	Course in second AP area (3)	
	MSAE E3111 (3) Thermodynamics	APPH E3300 (3) Applied electromagnetism	APPH E4100 (3) Quantum physics	APPH E4018 (2) Laboratory	
	APMA E3101 (3) Applied math. I	APMA E3102 (3) Applied math. II	Course in first AP area (3)		
	APPH E4901 (1) Seminar		APPH E4903 (2) Seminar		
ELECTIVES	TECH <sup>1</sup>	3 points	3 points	2 points	9 points
	NONTECH OR TECH	3 points	3 points	3 points	3 points
TOTAL POINTS	16	15	16	17	

<sup>1</sup>Must include at least 2 points of laboratory courses.

<sup>2</sup>Students who take PHYS W3081 in the first or second year may use that lab to fulfill the requirement of 2 points of lab in the third or fourth year.

Genomic Information Systems Laboratory (GISL). Extensive collaborations exist with national climate research centers (e.g., 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, geophysical/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 Atomics 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 recently jointly constructed LOX, a new plasma confinement experiment incorporating a levitated superconducting ring. The Columbia Non-neutral Torus is an experiment

devoted to the first study of non-neutral plasmas confined on magnetic surfaces. The Columbia Linear Machine (CLM) is a continuously operating, linear mirror device for the study of collisionless plasma instabilities, plasma transport, and feedback stabilization. Columbia's Collisionless Terrella Experiment is a continuously operated experiment that can be configured either to study plasma transport in magnetospheric geometry or to study the generation of nonlinear electrostatic potentials.

Experimental research in solid-state physics and laser physics is conducted within the department and also in association with the Columbia Center for Integrated Science and Engineering and the School of Mines. Facilities include laser processing and spectroscopic apparatus, ultrahigh vacuum chambers for surface analysis, picosecond and femtosecond lasers, a molecular beam epitaxy machine, and photo-lithography and thin film fabrication systems. Within this field, the Laser Diagnostics and Solid-State Physics Laboratory conducts studies in laser spectroscopy of semiconductor thin films and superlattices, and laser

APPLIED MATHEMATICS PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS<sup>1</sup></b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202(3) and ODE (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) ————— C1601 (3.5) ————— C2801 (4.5) —————	C1402 (3) ————— C1602 (3.5) ————— C2802 (4.5) —————	C1403 (3) ————— C2601 (3.5) ————— Lab W3081 (2)	➤ C1494 (3) ➤ Lab C2699 (3)
<b>CHEMISTRY/BIOLOGY</b> (choose one course)	CHEM C1403 (3), or higher <b>or</b> BIOL W2001 (4), or higher			
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ————— ALP0006 (0) —————	➤ C1010 (3) ➤ Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101 <b>or</b> V2001 (4) HUMA C1121 <b>or</b> C1123 (3)	HUMA C1002, C1102 <b>or</b> V2002 (4) ECON W1105 (4) <b>and</b> W1155 recitation (0)
<b>REQUIRED TECH ELECTIVES</b>	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see page 16)			
<b>COMPUTER SCIENCE</b>	A computer language of the student's choice at the 1000 level or higher			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>Students with advanced standing may start the calculus sequence at a higher level.

diagnostics of thin film processing. The Laser Lab focuses on the study of materials under high pressure, laser surface chemical processing, and new semiconductor structures. Research is also conducted in the shared characterization laboratories and clean room operated by the NSF Materials Research Science and Engineering Center and the NSF Nanoscale Science and Engineering Center.

The department maintains an extensive network of workstations and desktop computers. The research of the Plasma Lab is supported by a dedicated data acquisition/data analysis system, and the applied math group has access to a Beowolf cluster. Through the Internet, researchers in the department are currently using supercomputing facilities at the National Center for Atmospheric Research, the San Diego Supercomputing Center, the National

Energy Research Supercomputer Center in Berkeley, California, the National Leadership Class Facility at Oak Ridge, Tennessee, 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 160.

### 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 page 161.

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 page 64. All technical electives are normally at the 3000 level or above.

APPLIED MATHEMATICS: THIRD AND FOURTH YEARS					
	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII	
<b>REQUIRED COURSES</b>	APMA E3101 (3) <sup>1</sup> Applied math. I: linear algebra	APMA E3102 (3) <sup>1</sup> Applied math. II: partial differential equations	MATH W4061 (3) Modern analysis	APMA E3900 (3) <sup>3</sup> Research	
	APMA E4901 (1) Seminar	STAT W4107 (3) Statistical inf.	APMA E4903 (4) Seminar		
	SIEO W4105 (3) <sup>2</sup> Probability	APMA E4300 (3) Computational math. I: introduction to numerical methods	APMA E4101 (3) Applied math. III: dynamical systems		
	APMA E4204 (3) <sup>1</sup> Complex variables				
<b>ELECTIVES</b>	<b>MAJOR-RELATED</b>			0 or 3 points	
	<i>Includes courses designated: MATH, APMA, STAT, and COMS</i>				
	<b>OTHER TECHNICAL</b>	3 points	3 points	3 points	3 or 6 points
<i>Other approved science, engineering, economics, or finance courses</i>					
	<b>NONTECH</b>	3 points	3 points	3 points	3 or 6 points
<b>TOTAL POINTS</b>	16	15	16	15	

<sup>1</sup>MATH V2010 may be substituted for APMA E3101; APMA E4200 or MATH V3028 may be substituted for APMA E3102; MATH V3002 may be substituted for APMA E4204.

<sup>2</sup>SIEO W3658 may be substituted for SIEO W4105.

<sup>3</sup>With an adviser's permission, an approved technical elective may be substituted.

## 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:

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### DYNAMICAL SYSTEMS

APMA E4101 or PHYS G4003

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### LASER PHYSICS: APPH E4112

NUCLEAR SCIENCE: APPH E4010

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### PLASMA PHYSICS: APPH E4301

PHYSICS OF FLUIDS: APPH E4200

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### CONDENSED MATTER PHYSICS:

PHYS G4018

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### BIOPHYSICAL MODELING: APMA E4400

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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*. 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.

## 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 a 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:** Solid-state physics

**APMA E4101y:** Applied mathematics, III: 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

**APPH E4200x:** Physics of fluids

**APPH E4210y:** Geophysical fluid dynamics

**EESC W4008y:** Introduction to atmospheric science

**ESC W4925x:** Introduction to physical oceanography

**EES W4930y:** Earth's oceans and atmosphere

### B. SOLID EARTH GEOPHYSICS

**APPH 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

#### • 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 E4101y:** Applied mathematics, III: 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)

### B. INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

**IEOR E4003x:** Industrial economics

**IEOR E4201x:** The engineering of management, I

**IEOR E4202y:** The engineering of management, II

### C. FINANCE

**SIEO W4150x,y:** Probability and statistics (J)

**IEOR E4106y:** Introduction to operations research: stochastic models (J)

**IEOR E4700x:** Introduction to financial engineering

**MATH W4071x:** Mathematics of finance

• **Mathematics Applicable to Physics**  
Applied physics students can specialize in the mathematics that is applicable to physics. This specialization is particularly useful for students interested in theoretical physics

**APMA E4101y:** Applied mathematics, III: dynamical systems

**APMA E4001y:** Principles of applied mathematics

**APMA E4300y:** Computational mathematics, I: introduction to numerical methods

**SIEO W4150x,y:** Introduction to probability and statistics

**MATH V3386x:** Differential geometry

**MATH W4386x-W4387y:** Geometrical concepts in physics

**APMA E4204x:** Functions of a complex variable (J)

• **Fundamental Mathematics in Applied Mathematics**

This specialization is intended for students who desire a more solid foundation in the mathematical methods and underlying theory. For example, this specialization could be followed by students with an interest in graduate work in applied mathematics.

**APMA E4101y:** Applied mathematics, III: dynamical systems

**SIEO W4150x,y:** Introduction to probability and statistics (J)

**MATH V3386x:** Differential geometry

**MATH W4386x-W4387y:** Geometrical concepts in physics

**MATH W4032x:** Fourier analysis

**MATH W4062y:** Mathematical analysis, II

• **Quantitative Biology**

Traditionally biology was considered a descriptive science in contrast to the quantitative sciences that are based 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**

**RECOMMENDED:**

**BIOL C2005x-C2006y:** Introduction to molecular and cellular biology, I & II

**APMA E4400y:** Introduction to biophysical modeling

**OTHER TECHNICAL ELECTIVES (A COURSE IN A 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 other 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:** Computational mathematics, I: introduction to numerical methods

**MATH V3020x:** Number theory and cryptography (J)

**COMS W3137x,y:** 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

**APMA E4990y:** Introduction to parallel scientific computation

• **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 161.

## 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. A list of approved courses in basic physics, mathematics, and applied physics is available from the department office.

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.

#### **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 provides preparation toward certification by the American Board of Medical Physics. The program consists of a core curriculum of health physics and radiation physics courses and a practicum. A comprehensive examination is required for graduation. Specific course requirements are *APPH E4010, E4710/11, E4500, E4550, and E4600*, and, in the Mailman School of Public Health, *EHSC P6313, P6330, P9319, and P9330*. Some opportunities for specialization exist, and a description of the core curriculum and approved electives is available from the department office.

#### **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 approximately one year after the written qualifying examination, is required of all doctoral candidates.

#### **M.S., ENG.SC.D., AND PH.D. PROGRAMS IN MATERIALS SCIENCE AND ENGINEERING**

See page 162.

#### **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 159.

#### **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 nanomaterials, 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, equipment for the study of optical properties, and the instruments in the shared facilities of the Materials Research Science and Engineering Center and the Nanoscale Science and Engineering Center. There are also significant resources for electrical and optical experimentation at low temperatures and high magnetic fields. Specific course requirements for the solid-state physics doctoral program are set with the academic adviser, in consultation with the Committee on Materials Science and Engineering/Solid-State Science and Engineering.

## 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

*Lect: 3. 3 pts. Professor Mauel.*  
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 E3100y Introduction to quantum mechanics

*Lect: 3. 3 pts. Professor Pedersen.*  
Prerequisites: PHYS C1403 or the equivalent, and differential and integral calculus. Corequisite: APMA E3101 or the equivalent. Basic concepts and assumptions of quantum mechanics, Schrodinger's equation, solutions for one-dimensional problems including square wells, barriers and the harmonic oscillator, intro-

duction to the hydrogen atom, atomic physics and x-rays, electron spin.

### APAM E3105x Programming methods for scientists and engineers

*Lect: 2.5. Lab: 1. 3 points. Not given in 2005–2006.*  
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 Navratil.*  
Corequisite: 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.

### APPH E4010x Introduction to nuclear science

*Lect: 3. 3 pts. Professors Marshall and Mauel.*  
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 the Rutherford nuclear atom; properties of the nucleus. Radioactivity: decay chains, types of decay, half-lives, dating. Nuclear reactions, compound nucleus, cross sections. Models for alpha and beta decay; model of deuteron; scattering and nuclear forces. Interaction of radiation with matter, and detection of nuclear radiation. Artificial radioactivity, neutrons, neutron reactions, and neutron slowing down; moderators.

### APPH E4018y Applied physics laboratory

*Lab: 4. 2 pts. Professors Herman and Pedersen.*  
Prerequisite: ELEN E3401 or the equivalent. Typical experiments are in the areas of plasma physics, microwaves, laser applications, optical spectroscopy physics, and superconductivity.

### APPH E4100x Quantum physics of matter

*Lect: 3. 3 pts. Professor Herman.*  
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. Not given in 2005–2006.*  
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

*Lect: 3. 3 pts. Not given in 2005–2006.*  
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.

### 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 Sobel.*  
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

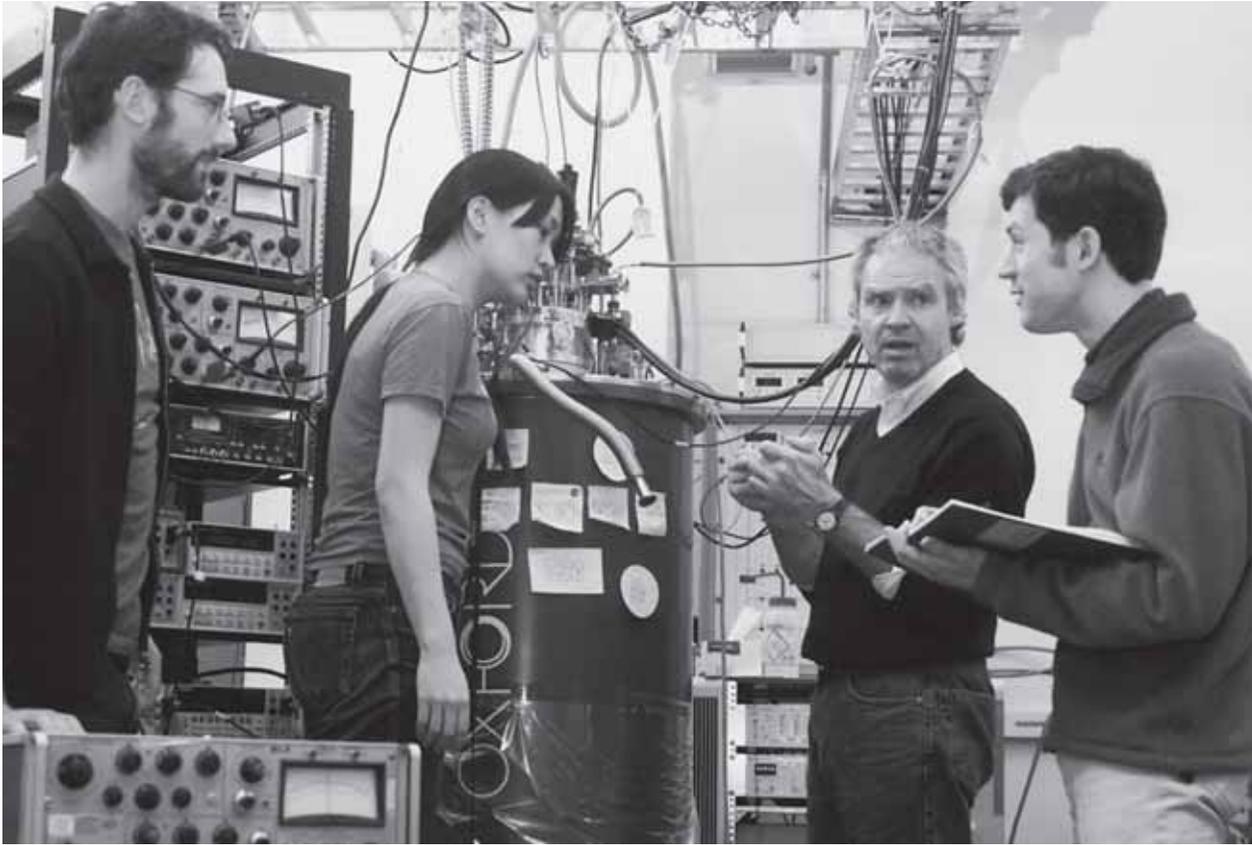
*Lect: 3. 3 pts. Professor Khaliwala.*  
Prerequisites: APMA E3101 and E3102 or the equivalents and APPH E4100x or the equivalent, or permission of the instructor. Fundamental concepts in the dynamics of rotating, stratified flows. Geostrophic and hydrostatic balances, potential vorticity, f and beta 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 Navratil.*  
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. Not given in 2005–2006.*  
Prerequisite: APPH E4300. Definition of a plasma. Plasmas in laboratories and nature, plasma production. Motion of charged particles in elec-



tric and magnetic fields, adiabatic invariants. Heuristic treatment of collisions, diffusion, transport, 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 E4010. 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. E. A. Christman.*

Prerequisites: APPH E4010. Corequisites: APPH E4010. Basic radiation physics: radioactive decay, radiation producing devices, characteristics of the different types of radiation (photons, charged and uncharged particles) and mecha-

nisms 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 E4710x-E4711y Radiation instrumentation and measurement laboratory, I and II**

*Lect: 1. Lab: 4. 3 pts. J. C. Arbo.*

Prerequisite or corequisite: APPH E4010.

Lab fee: \$35 each term. E4710: theory and use of  $\alpha$ ,  $\beta$ ,  $\gamma$ , 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; TLD dosimetry; radioactive tracers; dual energy  $x$ -ray absorptiometry; diagnostic  $x$ -ray and fluoro Q/C; planar gamma camera imaging; image analysis.

**APPH E4901x Seminar: problems in applied physics**

*Lect: 1. 1 pt. Professor Stormer.*

Required for all applied physics majors in the junior year. Discussion of specific and self-contained problems in areas such as applied electro-dynamics, physics of solids, and plasma physics. Topics change yearly.

**APPH E4903x Seminar: problems in applied physics**

*Lect: 1. Tutorial: 1. 2 pts. Professor Stormer.*

Required for all applied physics majors in the

senior year. Discussion of specific and self-contained problems in areas such as applied electro-dynamics, 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, stress and strain, classical electron models of metals, and periodic, nearly periodic, and more advanced analysis of electron band structure.

**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 E6090x Nanotechnology**

*Lect: 3. 3 pts. Offered in alternate years.*

*Professor O'Brien.*

Prerequisites: APPH E3100 and CHEM C1404, or equivalent 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, properties of materials as a

function of size, self-assembly, nanostructured materials. Nanoscale films and composites. Devices and applications. The "top down" manufacturing paradigm; prospects for the future. Molecular engineering, molecular electronics, nanofabrication, bionanotechnology. Imaging and manipulating at the atomic scale. Nanotechnology in industry.

**APPH E6091y Magnetism and magnetic materials**

*Lect: 3. 3 points. Offered in alternate years. Not given in 2005–2006.*

*Prerequisite: MSAE E4206, APPH E6081, or the equivalent. Types of magnetism. Band theory of ferromagnetism. Magnetic metals, insulators, and semiconductors. Magnetic nanostructures: ultrathin films, superlattices, and particles. Surface magnetism and spectroscopies. High-speed magnetization dynamics. Spin electronics.*

**APPH E6101x Plasma physics, I**

*Lect: 3. 3 points. Professor Mauel.*

*Prerequisite: APPH E4300. Motion of charged particles in space- and time-varying electromagnetic fields. Kinetic description of plasmas. Collisional Boltzmann equation and collision operators in Fokker-Planck forms. Classical transport equations and collisional relaxation processes. Linear electrostatic and electromagnetic waves in field-free plasmas. Vlasov equation and Landau damping.*

**APPH E6102y Plasma physics, II**

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

*Prerequisite: APPH E6101x. Linear waves in magnetized and homogeneous plasmas. Fluid theory of equilibrium and stability for toroidal plasmas, including ballooning and tearing instabilities. Drift instabilities and kinetic theory of transport.*

**APPH E6110x Laser interactions with matter**

*Lect: 3. 3 pts. Offered in alternate years. Not given in 2004–2005.*

*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-E9143y Applied physics seminar**

*Sem: 3. 3 pts. Instructor to be announced.*

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 Applied mathematics, I: linear algebra**

*Lect: 3. 3 pts. Professor Spiegelman.*

Matrix algebra, elementary matrices, inverses, rank, determinants. Computational aspects of solving systems of linear equations: existence-uniqueness of solutions, Gaussian elimination, scaling, ill-conditioned systems, iterative techniques. Vector spaces, bases, dimension. Eigenvalue problems, diagonalization, inner products, unitary matrices.

**APMA E3102y Applied mathematics, II: 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 Casti.*

*Prerequisites: Introductory linear algebra required. Ordinary differential equations recommended. Review of finite-dimensional vector spaces and elementary matrix theory. Linear transformations, change of basis, eigenspaces. Matrix representation of linear operators and diagonalization. Applications to difference equations, Markov processes, ordinary differential equations, and stability of nonlinear dynamical systems. Inner product spaces, projection operators, orthogonal bases, Gram-Schmidt orthogonalization. Least squares method, pseudo-inverses, singular value decomposition. Adjoint operators, Hermitian and unitary operators, Fredholm Alternative Theorem. Fourier series and eigenfunction expansions. Introduction to the theory of distributions and the Fourier Integral Transform. Green's functions. Application to partial differential equations.*

**APMA E4101x Applied mathematics, III: dynamical systems**

*Lect: 3. 3 pts. Professor Weinstein.*

*Prerequisites: MATH E1210 and PHYS W3003, or their equivalents. Introduction to nonlinear differential equations and dynamical systems and their chaotic behavior. Topics include Lagrangian and Hamiltonian formulation of mechanics, phase space dynamics. Critical points and stability. Systems of linear differential equations. Solving simple nonlinear differential equations. Onset of chaos. Systems with dissipation, limit points and cycles, strange attractors.*

**APMA E4200x Partial differential equations**

*Lect: 3. 3 pts. Professor Casti.*

*Prerequisite: a course in ordinary differential equations. Techniques of solution of partial differential equations. Separation of the variables. Orthogonality and characteristic functions, nonhomogeneous boundary value problems. Solutions in orthogonal curvilinear coordinate systems. Applications of Fourier integrals, Fourier and Laplace transforms. Problems from the fields of vibrations, heat conduction, electricity, fluid dynamics, and wave propagation are considered.*

**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 Computational mathematics, I: introduction to numerical methods**

*Lect: 3. 3 pts. Professors Polvani and Spiegelman.*

*Prerequisites: Knowledge of FORTRAN, C, or any other programming language and APMA E3101. Introduction to fundamental ideas of numerical*

analysis commonly used by engineers. Development is in the context of modern computing systems and includes methods of subroutinizing algorithms and using libraries of programs. Topics include numerical solutions of algebraic systems, eigenvalue problems, numerical integration, finite differences, difference equations and their solutions, solution of linear and nonlinear ordinary and partial differential equations, stability, consistency, and convergence.

#### **APMA E4400y Introduction to biophysical modeling**

*Lect: 3. 3 pts. Professor Wiggins.*

Prerequisites: Advanced calculus or instructor's approval. 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. Bioinformatics as applied to reverse engineering of naturally occurring networks and to forward engineering of synthetic biological networks. Mathematical and physical aspects of functional genomics.

#### **APMA E4901x Seminar: problems in applied mathematics**

*Lect: 1. 0 or 1 pt. Professor Wiggins.*

This course is required for all applied mathematics majors in the junior year. Prerequisites or corequisites: APMA E4200 and E4204, or their equivalents. For 1 pt. credit, term paper required. 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 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.

#### **APAM E4990x 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 advanced undergraduate students and graduate students in engineering, physical sciences, biological sciences, and other fields.

#### **APMA E6209x Approximation theory**

*Lect: 2. 3 pts. Offered in alternate years.*

*Not given in 2005–2006.*

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: APMA E3102 or E4200.

Approximate analytic methods for solving partial differential equations. Types of partial differential equations. Notions of well-posed problems. Characteristics. Perturbation methods. Linear and nonlinear waves. Adjoint operators. Green's functions. Asymptotic methods and bifurcation.

#### **APMA E6302x Numerical analysis of partial differential equations**

*Lect: 2. 3 pts. Professor Keyes.*

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**

*Lect: 2. 3 pts. Not given in 2005–2006.*

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. x: Professor Bal; y: Professor Wright.*

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**

*Lect: 2. 3 pts. Offered in alternate years.*

*Not given in 2005–2006.*

Prerequisite: APMA E4204 or the equivalent.

Asymptotic treatment of ordinary and partial differential equations in problems arising in applied mathematics. Asymptotic series. Asymptotic evaluation of integrals. Expansion of solutions of ordinary differential equations: connection problem and turning points. Stoke's phenomenon. Differential equations with a parameter: "boundary layer" phenomenon. Application to partial differential equations: problems from fluid dynamics, wave propagation theory, electromagnetic theory.

#### **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.*

Problems 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 163.

# Biomedical Engineering

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<http://www.bme.columbia.edu>



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 X. Edward Guo  
 Andreas H. Hielscher  
 Jeffrey W. Holmes  
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 Paul Sajda

ASSISTANT  
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 Barclay Morrison III  
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ADJUNCT PROFESSORS  
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ADJUNCT ASSOCIATE  
 PROFESSOR  
 Alvin Wald

ADJUNCT ASSISTANT  
 PROFESSOR  
 Edward J. Ciaccio

AFFILIATES  
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 Professor of Computer  
 Science

Dimitris Anastassiou  
 Professor of Electrical  
 Engineering

Ernest W. April  
 Associate Professor of  
 Anatomy and Cell  
 Biology

Aniruddha Das  
 Assistant Professor of  
 Psychiatry

Robert DeLaPaz  
 Professor of Radiology

Shunichi Homma  
 Associate Professor of  
 Medicine

Kung Ming Jan  
 Associate Professor of  
 Clinical Medicine

Zheng Feng Lu  
 Assistant Professor of  
 Clinical Radiology

Elizabeth S. Olson  
 Assistant Professor of  
 Otolaryngology/Head  
 and Neck Surgery

Richard N. Pierson  
 Professor of Clinical  
 Medicine

John Pile-Spellman  
 Professor of Radiology  
 and Neurosurgery

R. Theodore Smith  
 Associate Professor of  
 Ophthalmology

Henry M. Spotnitz  
 George G. Humphreys  
 II Professor of Surgery



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,

**BIOMEDICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS  
CLASS OF 2006**

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV	
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3)	
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) ———→ C1601 (3.5) ———→ C2801 (4.5) ———→	C1402 (3) ———→ C1602 (3.5) ———→ C2802 (4.5) ———→	C1403 (3) C2601 (3.5)		
<b>CHEMISTRY</b> (three tracks, choose one)	C1403 (3.5) ———→ C2407 (4) ———→ C3045 (3.5) ———→	C1404 (3.5) ———→ and Lab C1500 (3) either semester C2507 (3) C3046 (3.5), C2507 (3) ———→	C3443 (3.5) C3545 (3)		
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ———→ ALP0006 (0) ———→	C1010 (3) Z1003 (4)			
<b>COMPUTER SCIENCE</b> (choose one course)	COMS W1003 or W1004 or W1007 or W1009 (3)				
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)			
<b>GATEWAY LAB</b>	E1102 (4) either semester				
<b>NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101 or V2001 (4) HUMA W1121 (4) or W1123 (3)	HUMA C1002, C1102 or V2002 (4) ECON W1105 (4) and W1155 recitation (0)	
<b>TRACK-SPECIFIC COURSES</b>	<b>CELL &amp; TISSUE ENG.</b>	Professional-level course (see page 16) (any semester)			MATH E1210 ODE (3) CHEM C3444 (3) <sup>1</sup> CHEM C3543 (3) <sup>1</sup>
	<b>BIOMECH.</b>	Professional-level course (see page 16) (any semester)			MATH E1210 ODE (3) ENME E3105 (4)
	<b>BIOMED. IMAGING</b>	Professional-level course (see page 16) (any semester)			MATH E1210 ODE (3) COMS W3133 (3)

<sup>1</sup>These chemistry courses are not required for students who took the third chemistry track in semesters I-III.

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, and Mow), cardiovascular biomechanics (Professors Costa, Holmes, and Homma), cellular and tissue engineering and artificial organs (Professors

**BIOMEDICAL ENGINEERING: THIRD AND FOURTH YEARS  
CLASS OF 2006**

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES: ALL TRACKS</b>	BIOL C2005 (4) Molec. & cell. biol.  BMEN E4001 (3) Quantitative physiol. I  BMEN E3810 (3) BME laboratory I  APMA E3101 (3) Applied math. I	BIOL C2006 (4) Molec. & cell. biol.  BMEN E4002 (3) Quantitative physiol. II	BMEN E3910 (4) BME design I  BMEN E3820 (3) BME laboratory II  BMEN E4010 (2) <sup>4</sup> Ethics for BMEs	BMEN 3920 (4) BME design II  BMEN E3830 (3) BME laboratory III
<b>NONTECH ELECTIVES</b>		3 points	0–3 points	0–3 points
<b>TRACK-SPECIFIC COURSES</b>	<b>CELL &amp; TISSUE ENG.<sup>1</sup></b>	BMEN E2500 (0) Technical elective (3)	Technical elective (6)  BMEN E3500 (3) Biol. transport. proc. <b>or</b> BMEN E3320 (3) Fluid biomech.	BMEN E4501 (3) Tissue eng. I  BMEN E4210 (4) Therm. biol. sys.  BMEN E4502 (3) Tissue eng. II  Technical elective (3)
	<b>BIOMECH.<sup>2</sup></b>	BMEN E2300 (0)  MECE E3100 (3) Mech. of fluids	Technical electives (6)  BMEN E3320 (3) Fluid biomech.	ENME E3113 (3) Mech. of solids  MECE E3301 (3) Thermodynamics  BMEN 4300 (3) Solid biomech.  Technical electives (6)
	<b>BIOMED. IMAGING<sup>3</sup></b>	BMEN E2400 (0)  ELEN E3801 (3.5) Signals & systems	Technical electives (6)  BMEN E4420 (3) Biosig. proc. & modeling	ELEN E4810 (3) Digital signal proc.  BMEN E4894 (3) Biomed. imaging  BMEN E4430 (3) Principles of MRI
<b>TOTAL POINTS</b>	16–16.5	19	18–19	16

<sup>1</sup>In the cell and tissue engineering track, all 12 points of technical electives must be from engineering courses.

<sup>2</sup>In the biomechanics track, of the 12 points of technical electives, at least 6 points must be from engineering courses.

<sup>3</sup>In the imaging track, of the 9 points of technical electives, at least 6.5 points must be from engineering courses.

<sup>4</sup>BMEN E4010: Ethics for biomedical engineers is a SEAS nontechnical course.

Hung, Kam, Leonard, H. H. Lu, Morrison, Sia, and Vunjak-Novakovic), auditory biophysics (Professor Olson), body composition (Professors Heymsfield and Pierson), and biomedical imaging (Professors Alderson, Brown, Ciaccio, Hielscher, 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

**BIOMEDICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS  
CLASS OF 2007**

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV	
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3)	
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) ——— C1601 (3.5) ——— C2801 (4.5) ———	C1402 (3) ——— C1602 (3.5) ——— C2802 (4.5) ———	→ C1403 (3) → C2601 (3.5)		
<b>CHEMISTRY</b> (three tracks, choose one)	C1403 (3.5) ——— C2407 (4) ——— C3045 (3.5) ———	C1404 (3.5) ——— and Lab C1500 (3) either semester → C2507 (3) C3046 (3.5), C2507 (3) ———	→ C3443 (3.5) → C3545 (3)		
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ——— ALP0006 (0) ———	→ C1010 (3) → Z1003 (4)			
<b>COMPUTER SCIENCE</b> (choose one course)	COMS W1003 or W1004 or W1007 or W1009 (3)				
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)			
<b>GATEWAY LAB</b>	E1102 (4) either semester				
<b>NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101 or V2001 (4)  HUMA W1121 (4) or W1123 (3)	HUMA C1002, C1102 or V2002 (4)  ECON W1105 (4) and W1155 recitation (0)	
<b>TRACK-SPECIFIC COURSES</b>	<b>CELL &amp; TISSUE ENG.</b>	Professional-level course (see page 16) (any semester)			MATH E1210 ODE (3) CHEM C3444 (3) <sup>1</sup> CHEM C3543 (3) <sup>1</sup>
	<b>BIOMECH.</b>	Professional-level course (see page 16) (any semester)			MATH E1210 ODE (3) ENME E3105 (4)
	<b>BIOMED. IMAGING</b>	Professional-level course (see page 16) (any semester)			MATH E1210 ODE (3) COMS W3133 (3)

<sup>1</sup>These chemistry courses are not required for students who took the third chemistry track in semesters I–III.

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 Hielscher), the Cardiac Tissue Mechanics Laboratory (Professor Holmes), the Cardiac Cell Mechanics Laboratory (Professor Costa), the Bone Bioengineering Laboratory (Professor Guo), the Cell and Tissue Engineering Laboratory (Professor Hung), and 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), and the Molecular and Microscale Bioengineering Laboratory (Professor Sia). These laboratories are supplemented with core facilities, including a tissue culture facility, a histology facility, a confocal microscope, an atomic force microscope, an epifluorescence microscope, a freezer room, a machine shop, and a specimen prep room.

**BIOMEDICAL ENGINEERING: THIRD AND FOURTH YEARS  
CLASS OF 2007**

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII	
<b>REQUIRED COURSES: ALL TRACKS</b>	BIOL C2005 (4) Molec. & cell. biol.  BMEN E4001 (3) Quantitative physiol. I  APMA E3101 (3) Applied math. I	BIOL C2006 (4) Molec. & cell. biol.  BMEN E4002 (3) Quantitative physiol. II  BMEN E3810 (3) BME laboratory I	BMEN E3910 (4) BME design I  BMEN E3820 (3) BME laboratory II  BMEN E4010 (2) <sup>4</sup> Ethics for BMEs	BMEN 3920 (4) BME design II  BMEN E3830 (3) BME laboratory III	
<b>NONTECH ELECTIVES</b>		3 points	0–3 points	0–3 points	
<b>TRACK-SPECIFIC COURSES</b>	<b>CELL &amp; TISSUE ENG.<sup>1</sup></b>	BMEN E2500 (0)  BMEN E4210 (4) Thermo. biolog. sys.  Technical elective (3)	BMEN E3500 (3) Biol. transport. proc. <b>or</b> BMEN E3320 (3) Fluid biomech.  Technical elective (3)	BMEN E4501 (3) Tissue eng. I  Technical elective (3)	BMEN E4502 (3) Tissue eng. II  Technical elective (3)
	<b>BIOMECH.<sup>2</sup></b>	BMEN E2300 (0)  MECE E3100 (3) Mech. of fluids  Technical elective (3)	BMEN E3320 (3) Fluid biomech.  Technical elective (3)	ENME E3113 (3) Mech. of solids  MECE E3301 (3) Thermodynamics	BMEN 4300 (3) Solid biomech.  Technical electives (6)
	<b>BIOMED. IMAGING<sup>3</sup></b>	BMEN E2400 (0)  ELEN E3801 (3.5) Signals & systems  Technical elective (3)	BMEN E4420 (3) Biosig. proc. & modeling  Technical elective (3)	ELEN E4810 (3) Digital signal proc.  BMEN E4894 (3) Biomed. imaging  BMEN E4430 (3) Principles of MRI	Choose two:  BMEN E4410 (3) Ultrasound imaging  BMEN E4998 (3) Biophotonics  Technical elective (3)
<b>TOTAL POINTS</b>	16–17	19	18	16	

<sup>1</sup>In the cell and tissue engineering track, all 12 points of technical electives must be from engineering courses.

<sup>2</sup>In the biomechanics track, of the 12 points of technical electives, at least 6 points must be from engineering courses.

<sup>3</sup>In the imaging track, of the 9 points of technical electives, at least 6.5 points must be from engineering courses.

<sup>4</sup>BMEN E4010: Ethics for biomedical engineers is a SEAS nontechnical course.

## 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, biomechan-

- ics, 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. 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

**BIOMEDICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS  
CLASSES OF 2008 AND LATER**

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) ——— C1601 (3.5) ——— C2801 (4.5) ———	————— C1402 (3) ——— ————— C1602 (3.5) ——— ————— C2802 (4.5)	—————> C1403 (3) —————> C2601 (3.5)	
<b>CHEMISTRY</b> (three tracks, choose one)	C1403 (3.5) ——— and Lab C1500 (3) either semester C2407 (4) ——— C3045 (3.5) ———	————— C1404 (3.5) ——— —————> C2507 (3) ————— C3046 (3.5), C2507 (3)	—————> C3443 (3.5) —————> C3545 (3)	
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ——— ALP0006 (0) ———	—————> C1010 (3) —————> Z1003 (4)		
<b>COMPUTER SCIENCE</b> (choose one course)	COMS W1003 or W1004 or W1007 or W1009 (3)			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			
<b>NONTECHNICAL REQUIREMENTS</b>			HUMA C1001, C1101, or V2001 (4)  HUMA W1121 (4) or W1123 (3)	HUMA C1002, C1102, or V2002 (4)  ECON W1105 (4) and W1155 recitation (0)
<b>TECHNICAL REQUIREMENTS</b>	Professional-level course (either semester)		ELEN E3000 Circuits & systems (3.5)	APMA E2101 ODE & lin. alg. (3)  ENME E3105 Mechanics (4)

and include courses in engineering and engineering 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 any U.S. medical school.

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, 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 000 or contact your class dean for clarification.

**BIOMEDICAL ENGINEERING: THIRD AND FOURTH YEARS  
CLASSES OF 2008 AND LATER**

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES: ALL TRACKS</b>	BIOL C2005 (4) Molec. & cell biol.  BMEN E4001 (3) Quantitative physiol. I  SIEO W3600 (3) Intro. prob. & stats.	BIOL C2006 (4) Molec. & cell. biol.  BMEN E4002 (3) Quantitative physiol. II  BMEN E3810 (3) BME laboratory I	BMEN E3910 (4) BME design I  BMEN E3820 (3) BME laboratory II  BMEN E4010 (2) <sup>4</sup> Ethics for BMEs	BMEN 3920 (4) BME design II  BMEN E3830 (3) BME laboratory III
<b>NONTECH ELECTIVES</b>	0–3 points	3 points	0–3 points	3 points
<b>TRACK-SPECIFIC COURSES</b>	<b>CELL &amp; TISSUE ENG.<sup>1</sup></b>	BMEN E2500 (0)  BMEN E4210 (4) Thermo. biolog. sys.  MSAE E3103 (3) Elements of mat. sci.	BMEN E3500 (3) Biol. transport. proc. <b>or</b> BMEN E3320 (3) Fluid biomech.  Technical elective (3)	BMEN E4501 (3) Tissue eng. I  Technical elective (3)
	<b>BIOMECH.<sup>2</sup></b>	BMEN E2300 (0)  MECE E3100 (3) Mech. of fluids	BMEN E3320 (3) Fluid biomech.  Technical elective (3)	ENME E3113 (3) Mech. of solids  MECE E3301 (3) Thermodynamics  Technical elective (3)
	<b>BIOMED. IMAGING<sup>3</sup></b>	BMEN E2400 (0)  ELEN E3801 (3.5) Signals & systems	BMEN E4420 (3) Biosig. proc. & modeling  Technical elective (3)	ELEN E4810 (3) Dig. sig. processing  BMEN E4894 (3) Biomed. imaging  BMEN E4430 (3) Principles of MRI
<b>TOTAL POINTS</b>	16–17	19	18	16

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

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

<sup>3</sup>In the imaging track, core requirements satisfy the 48 points of engineering content.

<sup>4</sup>BMEN E4010: Ethics for biomedical engineers is a SEAS nontechnical course.

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

In addition, a pre-professional 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. For the computer science requirement, students can choose *COMS W1003* or *W1004*. For the Class of 2008 and beyond, all students in biomedical engineering are required to take *APMA E2101: Introduction to applied mathematics* (ordinary differential equa-

tions and linear algebra), typically during the spring semester of their second year. *BMEN E4010: Ethics for biomedical engineers* is required in the senior year and counts as 2 points of nontechnical elective credit.

In addition to these general requirements, for the classes of 2006 and 2007, students are expected to take track-spe-

cific courses starting in the spring semester of their second year:

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**CELL AND TISSUE ENGINEERING TRACK**

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**CHEM C3444:** Organic chemistry (lecture). (required for classes of 2006 and 2007 only)

**CHEM C3543:** Organic chemistry (laboratory). (required for classes of 2006 and 2007 only)

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**BIOMECHANICS TRACK**

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**ENME-MECE E3105:** Mechanics

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**BIOMEDICAL IMAGING TRACK**

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COMS W3133: Data structures and algorithms

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**Classes of 2008 and Beyond**

For the classes of 2008 and beyond, all students should take *APMA E2101: Introduction to applied mathematics* (ordinary differential equations and linear algebra) instead of *MATH E1210: Ordinary differential equations*, and in addition to *ELEN E3000: Introduction to circuits, systems, and electronics* in the fall semester and *ENME-MECE E3105: Mechanics* in the spring semester of their second year. Please note that *CHEM C3444: Organic chemistry (lecture)* and *CHEM C3543: Organic chemistry (laboratory)* are no longer required for students in the cell and tissue engineering track.

**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 fun-

damental skills that good biomedical engineers must master. Beginning with the second semester of the 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, Laboratories, students learn through hands-on experience the principles and methods of biomedical engineering experimentation, measurement techniques, quantitative theories of biomedical engineering, fundamentals of statistics and 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 nontechnical 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 course, *Biomedical engineering design (BMEN E3910 and BMEN E3920)*, where 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 field. 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 requirements in the pre-medicine profession with no more than three additional courses. Some of these additional courses may also be counted as nonengineering technical 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 specif-

ic term that they are designated in the course tables, as conflicts may arise if courses are taken out of sequence.

**TECHNICAL ELECTIVE REQUIREMENTS**

Students are required to take 48 points of engineering content coursework toward their degree. The 48 points 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, students are advised to complete the remainder of their engineering course work by taking technical electives that are clearly engineering in nature, specifically:

1. technical elective courses with sufficient engineering content that can count toward the 48 units of engineering courses required for ABET-accredited engineering degrees:
  - 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 Materials Science program
  - f. 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*
  - g. all 3000-level or higher courses in the Earth and Environmental Engineering program

2. Any course from the following departments is 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

For the Class of 2006 and 2007, in the cell and tissue engineering track, all 12 points of technical electives must be from engineering courses; in the biomechanics track, 6 of 12 points of technical electives must be from engineering courses; and in the imaging track: 6.5 of 9 points of technical electives must be from engineering courses. For the Class of 2008, 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, core requirements satisfy the 48 points of engineering content.

The accompanying charts describe the eight-semester degree program schedule of courses leading to the bachelor's degree in biomedical engineering. For clarity, three sets of charts are included, for the classes of 2006, 2007, and 2008 and beyond.

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

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 Engineering School does not admit students holding the B.S. degree directly to doctoral studies; admission is offered either to the M.S. program or to the M.S. program/doctoral track. Admissions standards for the latter category are generally higher than for the former. Applicants holding an appropriate M.S. degree from another institution

may apply directly to the doctoral program. 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 a 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 *BMEN E6001–E6002: Advanced quantitative physiology, I and II*; two semesters of *BMEN E9700: Biomedical engineering seminar*; at least four other biomedical engineering courses; and at least one graduate-level mathematics course. 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. Students planning to proceed to the doctoral degree 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 Degree

Doctoral students must complete a program of 30 points of credits beyond the M.S. degree. At least one graduate mathematics course must be taken in addition to 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.

### 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. A candidate who fails the examination may be permitted to repeat it once at the time of the next 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 at least four 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 four semesters of doctoral studies. In accord with regulations of the School, 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

*Lect: 3. 3 pts. Professor Wald and guest lecturers.*  
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. Medical informatics and organization of the health care system. Current trends in biomedical engineering research.

### BMEN E2300x or y Biomechanics track

*0 pts.*  
Rising juniors are required to register for this course in the fall of their junior 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 fall of their junior 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 fall of their junior 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 E3150x The cell as a machine

*Lect: 3. 3 pts. Not given in 2005–2006.*  
Prerequisite: Calc. 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 Costa.*  
Prerequisites: 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.

### BMEN E3500y. Biological transport and rate processes

*Lect: 3. 3 pts. Professor Leonard.*  
Prerequisites: CHEM C3443, MATH E1210; corequisite: BIOL C2005. Convective and diffusive movement and reaction of molecules in biological systems. Kinetics of homogeneous and heterogeneous reactions in biological environments. Mechanisms and models of transport across membranes. Convective diffusion with and without chemical reaction. Diffusion in restricted spaces. Irreversible thermodynamic approaches to transport and reaction in biological systems.

### BMEN E3810y Biomedical engineering laboratory, I

*Lab: 4. 3 pts. Professor Konofaugo.*  
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 Costa.*  
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 Sia.*  
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

*Lect: 1. Lab: 3. 4 pts. Professors Sajda and Vunjak-Novakovic.*  
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, logis-

tic 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.

**BMEN E3998x or y, or s Projects in biomedical engineering**

*Hours to be arranged. 1 to 3 pts. Professors Ateshian, Brown, Costa, Guo, Hielscher, Holmes, Hung, Kam, Konofagou, Laine, Leonard, H. H. Lu, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic.*

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.

**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: organic chemistry; BIOL C2005. An introduction to the physical and chemical characteristics of biological systems, with an emphasis on subcellular biology. Thermodynamics of molecular conformational transitions, biomolecule binding and multiunit assembly, reaction kinetics, chemical pathways in cells, physical behavior of polymeric molecules, persistence length, counterion condensation, statistical mechanics of DNA, biological membranes. Topics are treated in a quantitative, mathematically intensive approach.

**BMEN E4002y Quantitative physiology, II: organ systems**

*Lect: 3. 3 pts. Professor Morrison.* Prerequisites or corequisites: organic chemistry; 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, digestive, and skeletal).

**BMEN E4010x Ethics for biomedical engineers**

*Lect: 2. 2 pts. Professor Holmes.* Prerequisite: senior status in biomedical engineering or the instructor's permission. Covers a wide range of ethics 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.

**BMEB W4011x Computational neuroscience, I: Circuits in the brain**

*Lect: 3. 3 pts. Professors Lazar and Yuste.* Prerequisite: ELEN E3801 or BIOL W3004. This course will use Dayan and Abbott's Introduction to Theoretical Neuroscience to provide a broad overview of current knowledge about computation carried out by different microcircuits present in mammalian CNS. The material covered by this course will concentrate on synaptic physiology

neuroanatomy and circuit analysis. Students will present chapters from the book and discuss relevant papers.

**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 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.

**BMEN E4103x 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 tutorial sessions may be taken with or without the associated laboratory (BMEN E4104).

**BMEN E4104x Anatomy laboratory: thorax and abdomen**

*Lab: 2. 2 pts. Professor April.* Prerequisite: graduate standing in biomedical engineering. Corequisite: BMEN E4103.

**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 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 E4108).

**BMEN E4108x Anatomy laboratory: head and neck**

*Lab: 2. 2 pts. Professor April.* Prerequisite: graduate 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. Topics in modern biology, macromolecular behavior in solutions and interfaces, protein-ligand binding, and the hydrophobic effect.

**BMEN E4300y Solid biomechanics**

*Lect: 3. 3 pts. Professor Guo.* 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**

*Lect: 3. 3 pts. Not given in 2005–2006.* 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**

*Lect: 3. 3 pts. Professor Holmes.* 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. Not given in 2005–2006.* 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. Not given in 2005–2006.*

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 overcomplete 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 Sajda.*

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 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. 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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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, I**

*Lect: 3. 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 E4580y Science and engineering of body fluids, II**

*Lect: 3. 3 pts. Professor Matsuoka.*

Prerequisites: General chemistry, organic chemistry, and basic calculus. Topics include diffusion process of electrolytes driven by the electrical potential created by the charged molecules. Active transport processes, transport set by electrical and osmological potentials as combinations of multiple parameters: anionic electrolytes. Concept of source and target for the transport of electrolytes applied to a variety of biological processes. Physiological processes are explored with clinical correlations.

**BMEN E4601y Cellular electricity**

*Lect: 2 Lab: 3. 3 pts. Professor Olson.*

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 2005–2006.*

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 surgical simulations.

**BMEN E4737x Computer control of medical instrumentation**

*Lect: 2. Lab: 1. 3 pts. Professor Ciaccio.*

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. Professor Ciaccio.*

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. 3 pts. Not given in 2005–2006.*

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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

Analysis and design of replacements for the heart, kidneys, and lungs. Specification and realization of structures for artificial organ systems.

**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**

*Lect: 3. 3 pts. Professor Hielscher.*

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 E6001x–E6002y Advanced quantitative physiology**

*Lect: 3. 3 pts. Professors Kam and Morrison.*

Prerequisites: BMEN E4001 or the equivalent, APMA E4200. Advanced modeling and quantitative analysis of selected organ systems. Three systems from the following list are analyzed in depth in any year, with emphasis on methods for modeling and quantitative analysis of biologic systems; muscle contraction, respiratory physiology, nerve transmission, pharmacokinetics, circulatory control, auditory signal processing.

**BMEN E6301y Modeling of biological tissues with finite elements**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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 E6400x Analysis and quantification of medical images**

*Lect: 3. 3 pts. Professor Laine.*

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 E6480y Computational neuroscience, II: Neural modeling and neuroengineering**

*Lect: 3. 3 pts. Not given in 2005–2006.*

Prerequisites: APMA E3101, ELEN 3202, and ELEN-BMEN E4011, or 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 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 system.

Applications of principles in neuroengineering; neural prostheses, neuromorphic systems, and biomimetics. Course will include a computer simulation laboratory.

**BMEN E9100x or y, or s Master's research**

*1 to 6 pts. Professors Ateshian, Brown, Costa, Guo, Hielscher, Holmes, Hung, Kam, Konofagou, Laine, Leonard, H. H. Lu, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic.*

Candidates for the M.S. 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**

*1 to 6 pts. Professors Ateshian, Brown, Costa, Guo, Hielscher, Holmes, Hung, Kam, Konofagou, Laine, Leonard, H. H. Lu, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic.*

Doctoral candidates are required to make an original investigation of a problem in biomedical engineering, the results of which are presented in the dissertation. No more than 12 points of credit in this course may be granted toward the degree.

**BMEN E9700x or y Biomedical engineering seminar**

*Sem: 1. 0 pts. Professor Wald.*

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 Ateshian, Brown, Costa, Guo, Hielscher, Holmes, Hung, Kam, Konofagou, Laine, Leonard, H. H. Lu, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic.*

A candidate for the Eng.Sc.D. degree in biomedical engineering must register for 12 points of doctoral research instruction. Registration may not be used to satisfy the minimum residence requirement for the degree.

**BMEN E9900x or y, or s Doctoral dissertation**

*0 pts. Professors Ateshian, Brown, Costa, Guo, Hielscher, Holmes, Hung, Kam, Konofagou, Laine, Leonard, H. H. Lu, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic.*

A candidate for the doctorate in biomedical 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.

# Chemical Engineering

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David K. Robinson  
Sheri Nidositko



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, bio-compatible 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 engineering 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 bio-active 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 with the aim of very high density magnetic storage media; self-consistent field theory 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 bioanalytical 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.

**Biophysics and Soft Matter Physics.** Theoretical and experimental biophysics of biological soft matter: actin filament growth kinetics and its role in living cell motility; DNA hybridization, melting and unzipping; DNA

microarrays in biotechnology; model gene circuits; DNA mobility in 2D microfluidics. Physics of synthetic soft matter: nano-particles in mesostructured polymer phases and phase transitions; universal scaling laws in reacting polymer systems and polymerization phenomena; polymer-interface adsorption phenomena; polymer interfacial reactions; diffusion of particles in thin polymer films; interactions of charged polymer minigels with interfaces.

##### **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 biocompatible 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

CHEMICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and E1210 (3) Ord. diff. equations
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) C1601 (3.5) C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	Lab C1493 (3) Lab W3081 (2)	
<b>CHEMISTRY</b> (three tracks, choose one)	C1403 (3.5) and Lab C1500 (3) C2407 (4) C3045 (3.5)	C1404 (3.5) C2507 (3) C3046 (3.5) and Lab C2507 (3)	C3443 (3.5)	
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ALP0006 (0)	Z1010 (4) Z1003 (4)		
<b>REQUIRED ELECTIVES</b>	<b>NONTECH</b>		One core humanities elective (4 points) <sup>2</sup>	Three core humanities electives (11 points) <sup>2</sup>
	<b>TECH</b>		Professional engineering elective (3) <sup>1</sup>	
<b>CHEM. ENG. REQUIREMENT</b>			CHEN E3100 (4) <sup>3</sup> Material & energy balances	
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			
<b>TOTAL POINTS<sup>4</sup></b>	16.5	16.5	17.5	17

<sup>1</sup>Students are encouraged to take CHEN 1040: Molecular engineering and product design.

<sup>2</sup>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).

<sup>3</sup>Should be taken in Semester III, but may be moved upon adviser's approval to Semester V if CHEM C3543: Organic chemistry lab is taken in Semester III.

<sup>4</sup>Taking the first track in each row and E1102 in Semester II.

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.

## CHEMICAL ENGINEERING: THIRD AND FOURTH YEARS

		SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES</b>		CHEN E3110 (4) Transp. phenomena I	CHEN E3120 (4) Transp. phenomena II	CHEN E4500 (4) Process & product design I	CHEN E4510 (4) Process & product design II
		CHEN E3010 (4) Principles of chem. eng. thermodynamics	CHEN E3210 (4) Chem. eng. thermodynamics	CHEN E4140 (3) Chem. & biochem. separations	
			CHEN E4230 (4) Reactor design & control	CHEN E4320 (4) Molecular phenomenon in chem. eng.	
<b>REQUIRED LABS</b>		CHEN C3543 (3) <sup>1</sup> Org. chem. lab			CHEN 3810 (4) Chem. eng. lab
<b>REQUIRED ELECTIVES</b>	<b>NONTECH</b>	3 points	3 points		3 points
	<b>TECH<sup>2</sup></b>	3 points	3 points	3 points	3 points
<b>TOTAL POINTS (normal track)</b>		17	18	14	14

<sup>1</sup>May be taken in Semester III with adviser's permission if CHEN E3100: Material and energy balances is taken in Semester V.

<sup>2</sup>The total of 12 points of required technical electives must include one chemical engineering course, one engineering course outside of chemical engineering, and 6 points of "advanced natural science" courses (i.e., chemistry, physics, biology, materials science, and certain chemical engineering courses—contact the department for a list of courses that qualify).

The laboratory also has a UV-Vis spectrometer (a Cary 50), an SLM Aminco 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 biocompatibilization 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:

1. to develop graduates who can define, formulate, and solve technical problems by effectively applying scientific, mathematical engineering, and computational tools and principles;
2. to prepare students for careers in the chemical engineering profession and provide a strong basis for alternative career paths in business and management, medicine, law, or education;
3. to develop students who have teamwork and communications skills that support and enhance their technical background;
4. to promote social responsibility, professional ethics, and service to the chemical engineering profession and to society;
5. to expose students to traditional aspects of chemical engineering and to modern applications in emerging and interdisciplinary fields.

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 biotechnology 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 required to take computer science or programming, and should in their sophomore year take *CHEN E3100: Material and energy balances* (see accompanying tables).

In the junior-senior sequence one specializes in the chemical engineering major. The accompanying table 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 accompanying tables show 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 typically engineering, math, or basic science (such as chemistry, physics, and biology) and involve quantitative analysis. Generally, technical electives must be 3000 level or above but there are important 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 SEAS but taken outside of chemical engineering (that is, a course with a designator other than *CHEN*, *CHEE*, or *CHAP*).
- One technical elective must be within chemical engineering (i.e. with the designator *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 as the required chemical engineering technical elective.

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 strongly recommended (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 179.

#### 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* or *BC2001*; *BMEN E4501* or *E4502*; and any one of several chemical engineering courses approved by the BME Department. See also page 179.

### 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 course concentrations, 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 the variety of fascinating microscopic structures, 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 relevant 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 mat-

ter, 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 E6620Y:** 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.

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. Courses in the concentration equip students in engineering and computer science to help solve technical problems encountered in the discovery, assembly, organization, and application of genomic information. The courses impart an understanding of the fundamental goals and problems of genomic science and gene-related intracellular processes; elucidate the physical, chemical, and instrumental principles available to extract sequence information from the genome; and teach the concepts used to organize, manipulate, and interrogate the genomic database.

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 Profs. 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 mechanisms 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](mailto: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, environmen-

tal 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 Calabrese Barton.*

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 E3010x Principles of chemical engineering thermodynamics**

*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 E3100x Material and energy balances**

*Lect: 4. 4 pts. Professor Shapley.*

Prerequisites: First-year chemistry and physics or equivalents. This course serves as an introduc-

tion to concepts used in the analysis of chemical engineering problems. Rigorous analysis of material and energy balances on open and closed systems is emphasized. An introduction to important processes in the chemical and biochemical industries is provided.

### **CHEN E3110x Transport phenomena, I**

*Lect: 4. 4 pts. Professor Leonard.*

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 Levicky.*

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.

### **CHEN E3810y Chemical engineering laboratory**

*Lab: 4. 4 pts. Professor Levicky.*

Prerequisite: Completion of core chemical engineering curricula through the fall semester of senior year (includes CHEN E3110, E3120, E4230, E3100, E3010, 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 engi-

neering 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. Not given in 2005–2006.*

Open to undergraduates only with the instructor's permission. Analysis of chemical process problems and engineering data, using modern mathematical methods. Analog and digital computational techniques are discussed and used to solve typical 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.

### **CHEN E4050y Principles of industrial electrochemistry**

*Lect: 3. 3 pts. Professor Duby.*

Prerequisite: CHEN E3010. 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. Not given in 2005–2006.*

Prerequisite: CHEN E3010 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. Not given in 2005-2006*

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 E4205x Electrochemical energy systems**

*Lect: 3. 3 pts. Not given in 2005-2006.*

An introductory course in electrochemistry and electrochemical engineering, emphasizing energy-producing systems such as batteries and fuel cells. Fundamental concepts of electrochemical thermodynamics, kinetics, and mass transport are introduced, with examples from these systems. In the second half of the course, emphasis is placed on the design and characterization of polymer electrolyte membrane (PEM) fuel cells.

**CHEN E4230y Reactor design and control**

*Lect: 4. 4 pts. Professor Calabrese Barton.*

Prerequisite: CHEN E3010. Reaction kinetics and applications to the design of batch and continuous reactors. Multiple reactions and non-isothermal reactors. Analysis and modeling of reactor behavior. Feedback control.

**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 E4320x Molecular phenomena in chemical engineering**

*Lect: 3. 4 pts. Not given in 2005-2006.*

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.*

Prerequisite: CHEN E3010 or the equivalent. Causes of pollution and effect on life. Legal aspects, OSHA and EPA rules. Pollution at home and at work; radon, fumes, and dust; ventilation, dust collection, carbon adsorption. Fuel and acid gases, smog and dispersion. Treatment of ground, saline, and waste water. Primary and secondary (biological) treatment. Tertiary water treatment with membranes, ion exchange, carbon, and sieves. Solid and hazardous waste. Visit New York City waste water treatment plant.

**CHEN E4500x Process and product design, I**

*Lect: 3. 4 pts. Professor Mattas.*

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 West, Odian, 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 E3010. 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. Instructor to be announced.*

Prerequisite: An elementary course in physical chemistry or thermodynamics. Organic chemistry, statistics, calculus, and mechanics are helpful, but not essential. Introduction to the chemistry and physics of high molecular weight organic polymers. Emphasizes the connection between microscopic structure and physical properties. Following a brief overview, eight topics are addressed: synthesis of polymers, properties of single polymer molecules, crystallization of polymers, polymer solution and blend thermodynamics, rubber elasticity, viscoelasticity, the glass transition, and one special topic, such as biopolymers. To develop fundamental concepts, basic theoretical treatments and illustrative experimental studies are discussed.

**CHEN E4630y Computational laboratory for synthetic and biological polymers**

*Lab: 3. 3 pts. Not given in 2005-2006.*

Prerequisite: CHEN E4620 or the instructor's permission. Computer-based laboratory for the investigation of structure and physical properties in synthetic and biological polymers. Exploits the use of advanced workstations and molecular simulations software packages. Topics include hardware/software for molecular simulations; classical, quantum, and coarse-grained simulation methods; atomic-scale structure; stereo regularity; crystal structure; long-length scale structure; physical property prediction and molecular design; analysis of spectra.

**CHEN E4640x or y Polymer surfaces and interfaces**

*Lect: 3. 3 pts. Not given in 2005-2006.*

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 characterization of interfaces, theoretical modeling of interfacial thermodynamics and structure, and practical means for surface modification.

**CHEN E4650x Biopolymers**

*Lect: 3. 3 pts. Professor Levicky.*

Structure and biological function of nucleic acids and proteins, their polymer properties and physical behavior in solutions, gene regulation, thermo-

dynamics of biopolymer reactions and transitions (e.g., DNA hybridization), and overview of select current events, research topics, and technologies related to biopolymers. Demonstrations of key online resources. The course is designed to provide students with the broad background necessary for more specialized study or research involving biopolymers in fields such as genomics, biophysics, and bionanotechnology.

**CHEN E4660y Biochemical engineering**

*Lect: 3. 3 pts. Not given in 2005-2006.*

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. Not given in 2005-2006.*

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.*

Prerequisites: BIOL C2005 and 2006, CHEM C3045 and C3046, or equivalents. Chemical and physical aspects of genome structure and organization, genetic information flow from DNA to RNA to protein. Nucleic acid hybridization and sequence complexity of DNA and RNA. Genome mapping and sequencing methods. The engineering of DNA polymerase for DNA sequencing and polymerase chain reaction, Fluorescent DNA sequencing and high-throughput DNA sequencer development. Construction of gene chip and micro array for gene expression analysis. Technology and biochemical approach for functional genomics analysis. Gene discovery and genetics database search method. The application of genetic database for new therapeutics discovery.

**CHEN E4750y The genome and the cell**

*Lect: 3. 3 pts. Professor Leonard.*

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 comparisons 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 switch-

ing of intracellular processes, transient and permanent gene activation, and cell commitment, development, and death.

**CHEN E4760x 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.

**CHEN E6050y Advanced electrochemistry**

*Lect: 3. 3 pts. Professor West.*

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.

**CHEN 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.

**CHEN 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 E6610y Polymers: synthesis of macromolecules**

*Lect: 3. 3 pts. Not given in 2005–2006.*

Prerequisite: CHEN E4620 or the instructor's permission. Mechanics of step growth polymerization (condensation) and chain growth polymerization (radical, anionic, and cationic); kinetics; stereo regulation and tacticity; copolymerization; molecular weight distribution.

**CHEN E6620y Physical chemistry of macromolecules**

*Lect: 3. 3 pts. Professor Durning.*

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**

*3 pts. Not given in 2005–2006.*

Tutorial lectures on selected topics in soft condensed matter.

**CHEN E6910y Theoretical methods in polymer physics**

*Lect: 2. 3 pts. Not given in 2005–2006.*

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**

*Lect: 2. 3 pts. Not given in 2005–2006.*

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 E8100y Topics in biology**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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**

*1 to 6 pts. The staff.*

Prescribed for M.S. and Ch.E. candidates; elective for others with the approval of the department. Degree candidates are required to conduct an investigation of some problem in chemical engineering or applied chemistry and to submit 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 thesis. The concentration in pharmaceutical engineering requires a 2-point thesis internship.

**CHEN E9500x and y, and s Doctoral research**

*1 to 15 pts. The staff.*

Prerequisite: the qualifying examinations for the doctorate. Open only to certified candidates for the Ph.D. and Eng.Sc.D. degrees. Doctoral candidates in chemical engineering are required to make an original investigation of a problem in chemical engineering or applied chemistry, the results of which are presented in their dissertations. No more than 15 points of credit toward the degree may be granted when the dissertation is accepted by the department.

**CHEN E9600x and y Advanced research problems**

*2 to 10 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.

# Civil Engineering and Engineering Mechanics

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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 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.

## PROGRAM OBJECTIVES

In developing and continually updating our program to achieve the stated mission, 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.

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 structures and the infrastructure. These include buildings, foundations, bridges, transportation facilities, nuclear and conventional power plants, hydraulic structures, and other facilities

## 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.

**Solid mechanics:** mechanical properties of new and exotic materials, constitutive equations for geologic materials, failure of materials and components, properties of fiber-reinforced concrete, damage mechanics.

- *Multihazard risk assessment and mitigation:* integrated risk studies of the civil infrastructure from a multi-hazard 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 subsur-

face 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.

**Construction materials:** cement-based materials, 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 vibroacoustics 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.

## Facilities

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 hard-wired 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.

## LABORATORIES

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 INSTITUTE OF FLIGHT STRUCTURES

The Institute of Flight Structures was

CIVIL ENGINEERING PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201	APMA E2101 Intro. to applied math.
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) C1601 (3.5) C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	Lab C1493 (3) or chem. lab  Lab W3081 (2)	
<b>CHEMISTRY</b>	one-semester lecture (3–4): C1403 or C1404 or C3045 or C2407 Lab C1502 (2) either semester or physics lab			
<b>MECHANICS</b>	ENME-MECE E3105 (4) either semester			
<b>CIVIL ENGINEERING</b>	CIEN E1201 (3) or equivalent			CIEN E3004 Urban Infra. Systems
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ALP0006 (0)	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101 or V2001 (4) HUMA C1121 or C1123 (3)	HUMA C1002, C1102 or V2002 (4) ECON W1105 (4) and W1155 recitation (0)
<b>REQUIRED TECH ELECTIVES</b>	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see page 16) EAEE E1100 is recommended for Water Res./Environ. Eng. concentrations			
<b>COMPUTER SCIENCE</b>	Computer Language: W1003 (3) or W1004 (3) (any semester)			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

established within the Department of Civil Engineering and Engineering Mechanics 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 of Civil Engineering and Engineering Mechanics 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 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 mechan-

<b>CIVIL ENGINEERING: THIRD AND FOURTH YEARS</b>					
	<b>SEMESTER V</b>	<b>SEMESTER VI</b>	<b>SEMESTER VII</b>	<b>SEMESTER VIII</b>	
<b>CORE REQUIRED COURSES</b>	ENME E3113 (3) Mech. of solids  ENME E3161 (4) Fluid mech.	CIEN E3125 (3) Structural design  CIEN E3126 (1) Computer-aided struct. design  CIEN E3141 (3) Soil mech.	CIEN E4111 (3) Uncertainty & risk in infrastructure systems  CIEN E4129 (3) Managing eng. & constr. processes	CIEN E3128 (4) Design projects <b>or</b> CIEE E4260 (4) Urban ecology studio (for water res./environ. eng. concentration)	
<b>CONCENTRATIONS</b>	<b>GEOTECH ENG. (GE) OR STRUCT. ENG. (SE)</b>	ENME E3106 (3) Dynamics & vibrations	ENME E3114 (4) Exper. mech. of materials  CIEN E3121 (3) Struct. anal.	CIEN E4332 (3) Finite element anal.  CIEN E3127 (3) Struct. design projects (SE) <b>or</b> CIEN E4241 (3) Geotech. eng. fund. (GE)	
	<b>TECH ELECTIVES</b>	3 points		3 points	12 points
	<b>CIVIL ENG. &amp; CONSTR. MNGMT.</b>		ENME E3114 (4) Exper. mech. of materials  CIEN E3121 (3) Struct. anal. <b>or</b> CIEE E3250 (3) Hydrosystems eng.	CIEN E4133 (3) Capital facility planning & financing  CIEN E3127 (3) <b>or</b> CIEN E4241 (3)	CIEN E4131 (3) Princ. of constr. tech.
	<b>TECH ELECTIVES</b>	6 points		3 points	9 points
	<b>WATER RES./ ENVIRON. ENG.</b>		CIEN E4252 (3) Environ. eng.  CIEE E3250 (3) Hydrosystems eng.  CIEN E3303 (1) Independent studies	CIEN E4163 (3) Environ. eng. wastewater	CIEN E4250 (3) Waste containm. design & practice <b>or</b> CIEN E4257 (3) contam. transport in subsurface sys.  EAEE E4006 (3) Field methods for environ. eng.
	<b>TECH ELECTIVES</b>	6 points		6 points	6 points
	<b>NONTECH ELECTIVES</b>	3 points	3 points		
<b>TOTAL POINTS</b>	16	17	15	16	

ENGINEERING MECHANICS PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and ODE (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) C1601 (3.5) C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	Lab C1493 (3) or chem. lab Lab C3081 (2)	
<b>CHEMISTRY</b>	one-semester lecture (3–4): C1403 or C1404 or C3045 or C2407 Lab C1502 (2) either semester or physics lab			
<b>MECHANICS</b>	ENME-MECE E3105 (4) either semester			
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ALP0006 (0)	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101 or V2001 (4) HUMA C1121 or C1123 (3)	HUMA C1002, C1102 or V2002 (4) ECON W1105 (4) and W1155 recitation (0)
<b>REQUIRED TECH ELECTIVES</b>	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see page 16)			
<b>COMPUTER SCIENCE</b>	Computer Language: W1003 (3) or W1004 (3) (any semester)			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

ics program requires a grade point average of B or better and maintenance of performance while in the program.

### CIVIL ENGINEERING

The prerequisites for this program are the courses listed in the First Year–Sophomore Program or their equivalents. The civil engineering program 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*. In addition, the department offers a nontechnical elective course, *W1005: Engineering and the rise of modern industry*, which is strongly recommended to all students.

### 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.

### MINOR IN ARCHITECTURE

Civil engineering program students

may want to consider a minor in architecture (see page 179).

## 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,

ENGINEERING MECHANICS: THIRD AND FOURTH YEARS					
	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII	
<b>REQUIRED COURSES</b>	ENME E3113 (3) Mech. of solids	ENME E3114 (4) Experimental mech.	CIEE E4332 (3) Finite element	ENME E4202 (3) Advanced mech.	
	ENME E3161 (4) Fluid mechanics	CIEE E3121 (3) Structural analysis	ENME E4113 (3) Advanced solids		
	APMA E3101 (3) Applied math. I	APMA E3102 (3) Applied math. II	ENME E4215 (3) Theory of vibrations		
	ENME E3106 (3) Dynamics & vibrations				
<b>ELECTIVES</b>	<b>TECH</b>	3 points	6 points	6 points	9 points
	<b>NONTECH</b>			3 points	3 points
<b>TOTAL POINTS</b>	16	16	18	15	

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 analysis and design:** 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 water-borne 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:

- **Continuum mechanics:** solid and fluid mechanics, theories of elastic and inelastic behavior, and damage mechanics
- **Vibration:** nonlinear and random vibration; 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 E1201y Design of buildings, bridges, and spacecraft

*Lect: 3. 3 pts. Professor Testa.*

Prerequisites: first-semester calculus and physics. An introduction to basic principles according to which many structures are designed, constructed, and maintained in service. Course modules cover how strength and safety are treated and the role of the computer at this design stage; performance requirements other than safety, 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.

### CIEN E3004y Urban infrastructure systems

*Lect: 3. 3 pts. Instructor to be announced.*

Introduction to (a) the infrastructure systems that support urban socioeconomic activities and (b) fundamental system design and analysis methods. Coverage of water resources, vertical, transportation, communications, and energy infrastructure. Emphasis upon the purposes that these systems serve, the factors that influence their performance, the basic mechanics that govern their design and operation, and the impacts that they have regionally and globally. Student teams complete a semester-long design/analysis project.

### CIEN E3121y Structural analysis

*Lect: 3. 3 pts. Professor Deodatis.*

Methods of structural analysis. Trusses, arches, cables, frames; influence lines; deflections, force method, displacement method, computer applications.

### CIEN E3125y Structural design

*Lect: 3. 3 pts. Professor Smyth.*

Prerequisite: ENME E3113. Design criteria for varied structural applications, including buildings and bridges; design of elements using steel, concrete, masonry, wood, and other materials.

### CIEN E3126y Computer-aided structural design

*Lect: 1. Lab: 1. 1 pt. Professor Smyth.*

Corequisite: CIEN E3125y. Introduction to software for structural analysis and design with lab. Applications to the design of structural elements and connections. Lab required.

### CIEN E3127x Structural design projects

*Lect: 3. 3 pts. Professor Testa.*

Prerequisites: CIEN E3125 and E3126 or the instructor's permission. Design projects with various structural systems and materials.

### CIEN E3128y Design projects

*Lect: 4. 4 pts. Professor Meyer.*

Prerequisite: CIEN E3125 and CIEN E3126.

Capstone design project in civil engineering. This project integrates structural, geotechnical and environmental/water resources design problems with construction management tasks and sustainability, and legal and other social issues. The project is completed in teams, and communication skills are stressed. Outside lecturers will address important current issues in engineering practice.

### CIEN E3141y Soil mechanics

*Lect: 2. Lab: 3. 3 pts. Professor Culligan.*

Prerequisite: ENME E3113. Index properties and classification; compaction; permeability and seepage; effective stress and stress distribution; consolidation; strength of soils.

### CIEN E3250y Hydrosystems engineering

*Lect: 3. 3 pts. Professor Lall.*

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.

### 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.

### 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.

### CIEN E4021x Elastic and plastic analysis of structures

*Lect: 3. 3 pts. Not given in 2005–2006.*

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

*Lect: 3. 3 pts. Professor Yanev.*

Prerequisite: CIEN E3125 or the equivalent. Types and historic development of bridge structures. Methods of analysis and design; examples. Specifications for highway and railroad bridges. Recent developments. Environmental and economic considerations. Maintenance and inspection. Selected case histories with field visits.

### CIEN E4100y Earthquake and wind engineering

*Lect: 3. 3 pts. Professor Vaicaitis.*

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 Deodatis.*

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 Managing engineering and construction processes

*Lect: 3. 3 pts. Professor Wilson.*

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 E4130y Design of construction systems

*Lect: 3. 3 pts. Professor Tirola.*

Prerequisite: CIEN E 3125 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 E4131y Principles of construction techniques

*Lect: 3. 3 pts. Instructor to be announced.*

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 E4132x Prevention and resolution of construction disputes

*Lect: 3. 3 pts. Professor Wilson.*

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. Instructor to be announced.*

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 E4135x Strategic management in design and construction**

*Lect. 3. 3 pts. Not given in 2005–2006.*  
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 Wilson.*  
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 Becher.*  
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 E4212y 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. Not given in 2005–2006.*  
Stability of framed structures in the elastic and inelastic ranges. Lateral buckling of beams. Torsional buckling of compression members. Buckling of plates of plate-stiffener combinations. Linear stability analysis of cylindrical shells and discussion of its limitations. Discussion of the semi-empirical nature of the elastoplastic relations used in the case of plates and shells.

**CIEN E4226y Advanced design of steel structures**

*Lect. 3. 3 pts. Professor Rahman.*  
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. Professor Meyer.*  
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 on 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. Not given in 2005–2006.*  
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 E4244x Geosynthetics and waste containment**

*Lect. 3. 3 pts. Not given in 2005–2006.*  
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 Liefer.*  
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**

*Lect. 3. 3 pts. Not given in 2005–2006.*  
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.

**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 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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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 E4254y Geotechnical engineering in highway design**

*Lect: 3. 3 pts. Not given in 2005–2006.*

Prerequisite: CIEN E3141. Reinforced earth slopes; static and seismic analyses; piles; flexible and rigid pavement design.

**CIEN E4255y Flow in porous media**

*Lect: 3. 3 pts. Not given in 2005–2006.*

Prerequisite: CIEE 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: 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.

**CIEE E4260x and y Urban ecology studio**

*Lect: 3. Lab: 3. 4 pts. Sect. 1x: Professors Culligan and Lall; sect. 2x: Professor Themelis.*

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.*

Prerequisites: mechanics of solids, structural analysis, elementary computer programming, linear algebra. Matrix methods of structural analysis: displacement method and flexibility methods. Principle of stationary potential energy. Rayleigh-Ritz approximation. Finite element approximation. Displacement-based elements for structural mechanics. Isoparametric formulation.

**CIEN E6131y Managing civil infrastructure systems**

*Lect: 3. 3 pts. Instructor to be announced.*

Prerequisites: IEOR 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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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 E6232x Advanced topics in concrete engineering**

*Lect: 2.5. 3 pts. Not given in 2005–2006.*

Prerequisite: CIEN E3125 or the equivalent. Behavior of concrete under general states of stress, numerical modeling of steel and concrete, finite element analysis of reinforced concrete, design of slabs and thin-shell concrete structures.

**CIEN E6246y Advanced soil mechanics**

*Lect: 2.5. 3 pts. Not given in 2005–2006.*

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 E6248y Experimental soil mechanics**

*Lect: 2.5. 3 pts. Not given in 2005–2006.*

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**

*Lect: 2.5. 3 pts. Not given in 2005–2006.*

Prerequisite: CIEN E4332 or the instructor's permission. Galerkin finite element formulation.

Convergence requirements. Element and mesh instabilities. Stress calculation. Finite elements in heat flow and dynamics. Nonlinear problems. Introduction to boundary element method.

**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 Vaicaitis.*

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, aeroelasticity, 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. Professor Betti.*

Prerequisites: PHYS C1406 and MATH V1101-V1102 and V1201. Elements of statics; dynamics of a particle and systems of particles; dynamics of rigid bodies.

## ENME E3106y 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

*Lect: 3. 3 pts. Professor Chen.*

Stress, stress resultants, equilibrium. Deformation. Material behavior in two dimensions. Thermal stresses. Problems in flexure and torsion, pressure vessels. Buckling.

## ENME E3114y Experimental mechanics of materials

*Lect: 2. Lab: 3. 4 pts. Professor Chen.*

Prerequisite: ENME E3113. Material behavior and constitutive relations. Mechanical properties of metals and cement composites. Cement hydration. Modern construction materials. Experimental investigation of material properties and behavior of structural elements, including fracture, fatigue, bending, torsion, and buckling.

## ENME E3161x Fluid mechanics

*Lect: 3. Lab: 3. 4 pts. Professor Culligan.*

Prerequisites: ENME E3105 and ordinary differential equations. Fluid statics. Fundamental principles and concepts of flow analysis. Differential and finite control volume approach to flow analysis. Dimensional analysis. Application of flow analysis: flow in pipes, external flow, flow in open channels.

## 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. Not given in 2005–2006.*

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.*

Prerequisite: ENME E3105 or the equivalent. Differentiation of vector functions. Review of kinematics. Generalized coordinates and constraint equations. Generalized forces. Lagrange's equations. Impulsive forces. Collisions. Hamiltonian. Hamilton's principle.

## ENME E4214y Theory of plates and shells

*Lect: 3. 3 pts. Not given in 2005–2006.*

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 Vaicaitis.*

Frequencies and modes of discrete and continuous elastic systems. Forced vibrations—steady-state and transient motion. Effect of damping. Exact and approximate methods. Applications.

## 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. Not given in 2005–2006.*

Foundations of continuum mechanics. General theorems of elasticity. Application to stress analysis and wave propagation.

## ENME E8320y Viscoelasticity and plasticity

*Lect: 3. 4 pts. Professor Dasgupta.*

Prerequisite: ENME E6315 or the equivalent, or the instructor's permission. Constitutive equa-

tions of viscoelastic and plastic bodies. Formulation and methods of solution of the boundary value, problems of viscoelasticity and plasticity.

## ENME E8323y Nonlinear vibrations

*Lect: 2.5. 3 pts. Not given in 2005–2006.*

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: \$175.

## GRAP E2005y Computer-aided engineering graphics

*Lect: 1.5. Lab: 2.5. 3 pts. Professor Dasgupta.*

Prerequisite: CALC 1s. 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: \$175.

## 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.

# Computer Engineering Program

Administered by both the Electrical Engineering and Computer Science Departments through a joint Computer Engineering Committee. Student records are kept in the Electrical Engineering Department.

450 Computer Science 1312 S. W. Mudd, MC 4712, 212-854-3105  
<http://www.ee.columbia.edu/~compeng>

IN CHARGE	Steven M. Nowick
Professor Kenneth L. Shepard	Associate Professor of Computer Science
1312 S. W. Mudd	Daniel Rubenstein
	Assistant Professor of Electrical Engineering
COMPUTER ENGINEERING COMMITTEE	Kenneth L. Shepard
Edward Coffman	Associate Professor of Electrical Engineering
Professor of Electrical Engineering	Stephen H. Unger
Stephen A. Edwards	Professor of Computer Science (and Electrical Engineering)
Assistant Professor of Computer Science	Charles A. Zukowski
Alexandros Eleftheriadis	Professor of Electrical Engineering
Associate Professor of Electrical Engineering	Vishal Misra
Vishal Misra	Assistant Professor of Computer Science
Assistant Professor of Computer Science	

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, but, except for the following, only with special adviser approval. Preapproved courses from other departments include: *IEOR E4004*, *IEOR E4007*, *IEOR E4106*, *APMA E3102*, *APMA E4001*, *APMA E4200*, and *APMA E4204*. Additional courses at the 3000 level or higher in other areas of engineering, math, and science can also 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 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 of programs only; actual programs may be customized in consultation with academic advisers.

**COMPUTER ENGINEERING PROGRAM: FIRST AND SECOND YEARS  
EARLY-STARTING STUDENTS**

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3) <sup>3</sup>
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) —————	————— C1402 (3) —————	➔ Lab C1493 (3) or chem. lab C1500 (3)	
	C1601 (3.5) —————	————— C1602 (3.5) —————	➔ Lab C1493 (3) or chem. lab C1500 (3)	
	C2801 (4.5) —————	————— C2802 (4.5) —————	➔ Lab W3081 (2) or chem. lab C1500 (3)	
<b>CHEMISTRY</b>	one-semester lecture (3–4) C1403 or C1404 or C3045 or C2407  Lab C1500 (3) either semester or physics lab C1493 (3)			
<b>CORE REQUIRED COURSES</b>		ELEN E1201 (3.5) Intro. to elec. eng.	ELEN E3801 (3.5) Signals & systems	COMS W3157 (3) Advanced programming  CSEE W3827 (3) Fund. of computer sys.
<b>REQUIRED LABS</b>			ELEN E3084 (1) Signals& systems lab	ELEN E3082 (1) Digital systems lab
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) —————	➔ C1010 (3) ➔ Z1003 (4)		
	ALP0006 (0) —————			
<b>REQUIRED NONTECHNICAL ELECTIVES<sup>1</sup></b>			HUMA C1001, C1101 or V2001 (4) HUMA C1121 or C1123 (3) <sup>1</sup>	HUMA C1002, C1102 or V2002 (4) ECON W1105 (4) and W1155 recitation (0)
<b>COMPUTER SCIENCE</b>	COMS W1004 (3) <sup>2</sup>	COMS W1007 (3) or W1009	W3203 (3) Discrete math.	
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>Some of these courses can be postponed to the junior or senior year to make room for taking the required core computer engineering courses.

<sup>2</sup>Only required if needed to prepare for COMS W1007/W1009.

<sup>3</sup>APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2010.

## 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.

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

**COMPUTER ENGINEERING: THIRD AND FOURTH YEARS  
EARLY-STARTING STUDENTS**

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>CORE REQUIRED COURSES</b>	SIEO W3658 (3) Probability	ELEN E3331 (3) Electr. circ.	COMS W4118 (3) Operating systems	COMS W4115 (3) Programming lang.
	COMS W3137 (3) <b>or</b> W3139 (4) Data structures	COMS W3261 (3) Models of comp.		
	ELEN E3201 (3.5) Circuit analysis	CSEE W4823 (3) Advanced logic design	<b>or</b> ELEN E4710 (3) Intro. to network eng.	
<b>REQUIRED LABS</b>	ELEN E3081 (1) Circuit analysis lab	ELEN E3083 (1) Electronic circuits lab		EECS E4340 (3) Computer hardware design <b>or</b> CSEE W4840 (3) Embedded sys. design
<b>ELECTIVES</b>	<b>TECH</b>	15 points required; see details on page 104		
	<b>NONTECH</b>	Complete 27-point requirement; see page 14 or <a href="http://www.seas.columbia.edu">http://www.seas.columbia.edu</a> for details (administered by the Class Dean)		
<b>TOTAL POINTS</b>	15	17	15 or 18	15 or 18

The primary programming languages for the computer engineering program are C and Java, and students are expected to learn both early on. The language for COMS W1007/W1009 and COMS W3137/W3139 is Java. Transfer students without a knowledge of Java should take the accelerated one-point Java course COMS W3101-03, or an equivalent, before their junior year. C is introduced in COMS W3157 and is required for several advanced courses. An accelerated one-point C course, COMS W3101, is available for students who do not have knowledge of C. Students at Columbia prior to the junior year may be able to start the third- and fourth-year courses, such as COMS W3137 and CSEE W3823, earlier.

Check the chart on page 108 for footnotes on various courses.

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. Other courses may be chosen with the prior approval of a faculty adviser in the Computer Engineering Program.

**CORE COMPUTER ENGINEERING COURSES**

- COMS W4119:** Computer networks
- CSEE W4824:** Computer architecture
- CSEE W4823:** Advanced logic design
- CSEE W4825:** Digital systems design
- CSEE W4840:** Embedded systems design
- CSEE W4861:** Computer-aided design of digital systems
- COMS W6123:** Programming environments and software tools
- COMS W6831:** Sequential logic circuits
- COMS W6832:** Topics in logic design theory
- ELEN E4321:** VLSI circuits
- ELEN E4332:** VLSI design lab
- EECS E4340:** Computer hardware design
- ELEN E4702:** Communication theory
- ELEN E4810:** Digital signal processing
- ELEN E4830:** Digital image processing

- ELEN E6761:** Computer communication networks
- ELEN E6762:** Broadband networks

The overall program must include at least 15 points of 6000-level *ELEN* 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.

**COMPUTER ENGINEERING PROGRAM: FIRST AND SECOND YEARS  
LATE-STARTING STUDENTS**

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3) <sup>3</sup>
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3)	C1402 (3)	➔ Lab C1493 (3) or chem. lab C1500 (3)	
	C1601 (3.5)	C1602 (3.5)	➔ Lab C1493 (3) or chem. lab C1500 (3)	
	C2801 (4.5)	C2802 (4.5)	➔ Lab W3081 (2) or chem. lab C1500 (3)	
<b>CHEMISTRY</b>	one-semester lecture (3–4) C1403 or C1404 or C3045 or C2407  Lab C1500 (3) either semester or physics lab C1493 (3)			
<b>CORE REQUIRED COURSES</b>		ELEN E1201 (3.5) <sup>2</sup> Intro. to elec. eng.		
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ALP0006 (0)	➔ C1010 (3) ➔ Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101 or V2001 (4) HUMA C1121 or C1123 (3)	HUMA C1002, C1102 or V2002 (4) ECON W1105 (4) and W1155 recitation (0)
<b>COMPUTER SCIENCE</b>	COMS W1004 (3) <sup>1</sup>	COMS W1007 (3) or W1009	W3203 (3) <sup>2</sup> Discrete math.	
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>Only required if needed to prepare for COMS W1007/W1009.

<sup>2</sup>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.

<sup>3</sup>APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2010.

**COMPUTER ENGINEERING: THIRD AND FOURTH YEARS  
LATE-STARTING STUDENTS**

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>CORE REQUIRED COURSES</b>	SIEO W3658 (3) <sup>1</sup> Probability	COMS W3137 (3) <b>or</b> W3139 (4) Data structures	COMS W4118 (3) Operating systems	COMS W4115 (3) Programming lang.
	COMS W3157 (3) <sup>2</sup> Advanced programming	ELEN E3331 (3) <sup>4</sup> Electr. circ.	ELEN E4710 (3) Intro. to network eng.	<b>or</b> CSEE W4823 (3) Advanced logic design
	ELEN E3201 (3.5) Circuit analysis	COMS W3261 (3) <sup>5</sup> Models of comp.		
	ELEN E3801 (3.5) Signals & systems	CSEE W3827 (3) Fund. of computer systems		
<b>REQUIRED LABS</b>	ELEN E3081 (1) <sup>3</sup> Circuit analysis lab	ELEN E3083 (1) <sup>3</sup> Electronic circuits lab		EECS E4340 (3) Computer hardware design <b>or</b>
	ELEN E3084 (1) <sup>3</sup> Signals & systems lab	ELEN E3082 (1) <sup>3</sup> Digital systems lab		CSEE W4840 (3) <sup>7</sup> Embedded sys. design
<b>ELECTIVES</b>	<b>TECH</b>	15 points required; see details on page 104 <sup>6</sup>		
	<b>NONTECH</b>	Complete 27-point requirement; see page 14 or <a href="http://www.seas.columbia.edu">http://www.seas.columbia.edu</a> for details (administered by the Class Dean)		
<b>TOTAL POINTS</b>	15	17	15 or 18	15 or 18

The primary programming languages for the computer engineering program are C and Java, and students are expected to learn both early on. The language for COMS W1007/W1009 and COMS W3137/W3139 is Java. Transfer students without a knowledge of Java should take the accelerated one-point Java course COMS W3101-03, or an equivalent, before their junior year. C is introduced in COMS W3157 and is required for several advanced courses. An accelerated one-point C course, COMS W3101, is available for students who do not have knowledge of C.

<sup>1</sup>SIEO W3600, SIEO 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 the two-point statistics course SIEO W3602.

<sup>2</sup>This course replaces the old course COMS W3156. Those who already took COMS W3156 can use it to fulfill this requirement, and use COMS W3157 as a technical elective.

<sup>3</sup>If possible, ELEN E3081 and ELEN E3082 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. These labs are equivalent to the old courses ELEN E3041 and ELEN E3042.

<sup>4</sup>Formerly ELEN E3301.

<sup>5</sup>COMS W3261 can be taken one semester later than pictured.

<sup>6</sup>The total points of technical electives can be reduced to 12 if APMA E2101 has been replaced by MATH E1201 and APMA E3101.

<sup>7</sup>This course replaces ELEN E3940, which is no longer offered.

# Computer Science

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\*Columbia Center for Computational  
 Learning Systems



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-

olving 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 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 fifty Windows XP workstations, a Unix/Linux laboratory with thirty Linux workstations, and a 15 Sun Ray thin client system. The research infrastructure includes Macs and hundreds of workstations and PCs running Solaris, Windows XP, Linux,

COMPUTER SCIENCE PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	COMS W3210 (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) ————— C1601 (3.5) ————— C2801 (4.5) —————	C1402 (3) ————— C1602 (3.5) ————— C2802 (4.5) —————	C1493 (3) or chem. lab  Lab W3081 (2)	
<b>CHEMISTRY</b>	one-semester lecture (3–4) C1403 or C1404 or C3045 or C2407 Lab C1500 (2) either semester or physics lab			
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ————— ALP0006 (0) —————	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101 or V2001 (4) HUMA C1121 or C1123 (3)	HUMA C1002, C1102 or V2002 (4) ECON W1105 (4) and W1155 recitation (0)
<b>REQUIRED TECH ELECTIVES</b>	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see page16)			
<b>COMPUTER SCIENCE</b>	COMS W1004 (3) Intro. to computer science & programming in Java	COMS W1009 (3) or COMS W1007 (3)	COMS W3157 (4) Adv. programming and COMS W3203 (3) Discrete math	COMS W3137 (4) or COMS W3139 (4) Data structures
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

and an IBM twenty-four-server BladeCenter; more than seven terabytes of disk space are backed up by a StorEdge L100 with a hundred-tape LTO2 library unit.

Research labs contain Puma 500 and IBM robotic arms; a UTAH-MIT dextrous 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 headmounted displays; a networking testbed with three Cisco 7500 backbone routers, traffic generators, 802.11b base stations and Ethernet switches, Sun Ray thin clients, and a 17-node (34CPU) IBM Netfinity cluster.

All department 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 802.11b wireless LAN coverage.

The research facility is supported by a full-time staff of professional systems 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, combinatorial 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

COMPUTER SCIENCE: THIRD AND FOURTH YEARS				
	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES</b>	COMS W3251 (3) Computational lin. algebra  COMS W3261 (3) Computer sci. theory  CSEE W3827 (3) Fund. of computer sys.	IEOR W4150 (3) <b>or</b> SIEO W3600 (4) Prob. & stat.		
<b>ELECTIVES</b>	<b>NONTECH</b>	3 points	6 points	3 points
	<b>TECH</b>	3 points	9 points	12 points
<b>TOTAL POINTS</b>	15	18 or 19	15	15

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 is Java and for COMS W3137/W3139, C/C++. COMS W1004 is waived for students who have had AP computer science in high school.

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, multi-computer design, user interfaces, VLSI applications, artificial intelligence, combinatorial 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.

#### 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. However, with the adviser's approval, 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 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 W3287,* 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*.

#### 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 E4231:** Analysis of algorithms
- COMS W4236:** Introduction to computational complexity
- COMS W4241:** Numerical algorithms and complexity

#### 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 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:** Computational learning theory  
**COMS W4995:** Math foundations of machine learning  
**COMS E6717:** Information theory  
**COMS E6772:** Advanced machine learning and perception  
**COMS E6998:** Advanced cryptography  
**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  
**COMS 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 W48xx** course  
Any **COMS W41xx** course  
**COMS W4444:** Programming and problem solving  
**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  
**COMS E6901:** Projects in computer science  
Any **COMS E61xx** or **E68xx** course (with adviser approval)

Note: No more than 6 units of project/thesis courses (*COMS W3902*, *COMS W3998*, *COMS W4901*) can count toward the major.

### 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

Any **COMS W40xx** course with adviser approval  
**COMS W4165:** Pixel processing  
**COMS W4252:** Computational learning theory  
Any **COMS W47xx** course if not used as a required course  
**COMS W4995:** Special projects I (with adviser approval; may be repeated)  
**COMS W4996:** Special projects II (with adviser approval; may be repeated)  
Any **COMS W67xx** course  
**COMS E6998:** Topics in computer science, I (with adviser approval)  
**COMS E6999:** Topics in computer science, II (with adviser approval)

#### Up to 2 courses from the following list

**COMS W3902:** Undergraduate thesis (with adviser approval; may be repeated)  
**COMS W3998:** Undergraduate projects in computer science (with adviser approval; may be repeated)  
**COMS W4901:** Projects in computer science (with adviser approval; may be repeated)  
**COMS E6901:** Projects in computer science (with adviser approval; may be repeated)

#### Up to 1 course from the following list

**COMS W4111:** Database systems  
**COMS W4160:** Computer graphics  
**COMS W4170:** User interface design  
**COMS W4999:** Computing and the humanities

Note: No more than 6 units of project/thesis courses (*COMS W3902*, *COMS W3998*, *COMS W4901*, *COMS E6901*) can count toward the major.

### 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 W4701:** Artificial intelligence  
**COMS W4712:** 3D user interface design  
**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-W4496:** 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.

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#### 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.

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#### BREADTH REQUIREMENT

Two breadth courses of the designated track.

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#### 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.

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#### THESIS

There is a required 6-point senior thesis.

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#### 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.)

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## 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, and software design.

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 computers

*Lect: 3. 3 pts. Instructor to be announced.*  
Intended primarily for students in the humanities and not available to engineering students. General introduction to computer science, including the design of algorithms and computer hardware, as well as hands-on experience with applications such as spreadsheets, databases, and the World Wide Web. Introductory programming in Java.

#### 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.

#### COMS W1004x or y Introduction to computer science and programming in Java

*Lect: 3. 3 pts. Professor Aho.*  
A general introduction to computer science designed to prepare students with no prior programming background for the major. The course develops an understanding of the fundamental concepts, algorithmic problem-solving capabilities, and programming skills critical to the CS core. Provides some programming background in Java and baseline Unix skills in preparation for COMS W1007.

#### COMS W1007x or y Object-oriented programming and design in Java

*Lect: 3. 3 pts. Professor Cannon.*  
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. Professor Kender.*  
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. Instructor to be announced.*  
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 W3157. Corequisite: COMS W3203. 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/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 W3139y Honors data structures and algorithms**

*Lect: 4. 4 pts. Instructor to be announced.*

Prerequisite: COMS W3157. 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/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. Instructor to be announced.*

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.*

Prerequisites: two terms of calculus. Introduction to computation on digital computers. Design and analysis of numerical algorithms. Numerical solution of equations, integration, recurrences, chaos, differential equations. Introduction to Monte Carlo methods. Properties of floating point arithmetic. Applications to weather prediction, computational finance, computational science, and computational engineering.

#### **COMS W3251x Computational linear algebra**

*Lect: 3. 3 pts. Professor Wozniakowski.*

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 Grunschlag.*

Prerequisites: COMS W3139 and W3203. Regular languages: deterministic and nondeterministic, finite automata, regular expressions. Contest-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.

#### **CSEE W3827x and y Fundamentals of computer systems**

*Lect: 3. 3 pts. x: Professor Unger; y: 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 multicycle processor design, introduction to pipelined processors, caches, and virtual memory.

#### **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, organiza-

tion, 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 W4111x and y Database systems**

*Lect: 3. 3 pts. x: Professor Gravano; y: instructor to be announced.*

Prerequisites: COMS W3137 as well as working knowledge of C++ or Java, or the instructor's permission. The fundamentals of database design and implementation: data modeling, logical design of relational databases, relational data definition and manipulation languages, SQL, storage and indexing techniques, query processing, transaction processing, concurrency control, recovery, security, and integrity. 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 CSEE 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. Professor Aho.*

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 environments, and compiler-compilers. A programming project is required.

#### **COMS W4118x Operating systems, I**

*Lect: 3. 3 pts. Professor Nieh.*

Prerequisites: CSEE W3827 and knowledge of C and programming tools as covered in COMS W3157 or W3101, or the instructor's permission. Design and implementation of operating systems. Topics include process management, process synchronization and interprocess communication, memory management, virtual memory, interrupt handling, processor scheduling, device management, I/O, and file systems. Case study of the UNIX operating system. A programming project is required.

**COMS W4119x and y Computer networks**

*Lect: 3. 3 pts. x: Professor Misra; y: Professor Yemini.*

Prerequisite: COMS W4118, including good knowledge of C/C++. 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 programming assignments and a lab project may be required.

**COMS W4156x or y Advanced software engineering**

*Lect: 3. 3 pts. Professor Kaiser.*

Prerequisites: Instructor's permission. Strongly recommended: At least one COMS W41xx course and/or COMS W4444. Assumes substantial prior real-world (not classroom) software development experience in at least one mainstream programming language such as C, C++, Java or C#.

Theory and practice of process life cycle, project planning, requirements capture, software design, team programming, unit and integration testing, system delivery and maintenance, process and product evaluation and improvement. Also covers component-based software engineering models such as CORBA, COM+, EJB, .NET, Web Services. Centers on an intense semester-long multi-iteration team project that requires pair programming and other agile programming practices.

**COMS W4160y Computer graphics**

*Lect: 3. 3 pts. Professor Ramamoorthi.*

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. 3pts. Professor Ramamoorthi.*

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. 3pts. 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 E4172x 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 Keromytis.*

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 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: COMS 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. 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 (eg. 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.

**CSEE W4340x Computer hardware design**

*Lect: 3. 3 pts. Instructor to be announced.*

Prerequisites: ELEN E3331 plus ELEN E3910 or 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.

**COMS W4444x Programming and problem solving**

*Lect: 3. 3 pts. Professor Ross.*

Prerequisites: COMS W3139 and W3824. Hands-on introduction to solving open-ended computational problems. Emphasis on creativity, cooperation, and collaboration. Projects spanning a variety of areas within computer science, typically requiring the development of computer programs. Generalization of solutions to broader problems, and specialization of complex problems to make them manageable. Team-oriented projects, with student presentations and in-class participation required.

**COMS W4701x or y Artificial intelligence**

*Lect: 3. 3 pts. x: 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.*

Prerequisite: 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.

**CBMF W4761x or y Computational genomics**

*Lect: 3. 3 pts. Instructor to be announced.*

Prerequisites: Either (1) ECBM E4060 or (2) COMS W1003, W1004, or W1007 and SIEO W4150, or SIEO W3600. Computational tech-

niques 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.

**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); 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.*

Prerequisite: CSEE W3827 or the equivalent. Focuses on advanced topics in modern computer architecture, illustrated by recent case studies. Fundamentals of quantitative analysis. Pipelined, out-of-order, and speculative execution. Superscalar, VLIW, and vector processors. Embedded processors. Memory hierarchy design. Multiprocessors and thread-level parallelism. Synchronization and cache coherence protocols. Interconnection networks.

**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 multilevel NAND and NOR gate circuits. Clocking schemes for one- and two-phrase 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.*  
Prerequisites: 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 W4995x or y Special topics in computer science, I**

*Lect: 3. 3 pts. x: Professor Servedio; 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 W4996x or 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 or 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 technologies concerned with development and operation of today's software systems. Reliability, security, systems management, and societal issues. Emerging software architectures such as enterprise and grid computing. Term paper and programming project. Seminar focus changes frequently to remain timely.

#### **COMS E6125y Web-enhanced information management (WHIM)**

*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 W4111. History of hypertext, markup languages, groupware, and the Web. Evolving Web protocols, formats and computation paradigms such as HTTP, XML, and Web Services. Novel application domains enabled by the Web and societal issues. Term paper and programming project. Seminar focus changes frequently to remain timely.

#### **COMS E6160x or y Topics in computer graphics**

*Lect: 2. 3 pts. Professors Ramamoorthi and Belhumeur.*  
Prerequisite: COMS W4160 or the instructor's permission. An advanced graduate course, involving study of an advanced research topic in computer graphics. Content varies between offerings, and the course may be repeated for credit. Recent offerings have included appearance models in graphics and high quality real-time rendering.

#### **COMS E6174x or y Interaction design: a perceptual approach**

*Lect: 2. 3pts. Not given in 2005–2006.*  
Prerequisite: CS W4170 or the instructor's permission. Design methodology for special-purpose user interfaces. Emphasis on how psychology and perception inform good design. Interviewing and task modeling, participatory design, and low-fidelity prototyping. Applications of brain research, graphic design and art to develop custom user interface components, screen layouts, and interaction techniques for application-specific systems.

#### **COMS W6176x or y User interfaces for mobile and wearable computing**

*Lect: 2. 3 pts. Professor Feiner.*  
Prerequisite: COMS W 4170 or the instructor's permission. Introduction to research on user interfaces for mobile and wearable computing through lectures, invited talks, student-led discussions of important papers, and programming projects. Designing and authoring for mobility and wearability. Ubiquitous/pervasive computing. Collaboration with other users. Display, interaction, and communication technologies. Sensors for tracking position, orientation, motion, environmental context, and personal context. Applications and social consequences.

#### **CSEE E6180x or y Modeling and performance**

*Lect: 2. 3 pts. x: instructor to be announced; y: Professor Misra.*  
Prerequisites: COMS W4118 and SIEO W4150. 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 contention problems, and modeling of program behaviors.

#### **COMS E6181x or y Advanced Internet services**

*Lect: 2. 3 pts. Professor Schulzrinne.*  
In-depth survey of protocols and algorithms needed to transport multimedia information across the Internet, including audio and video encoding, multicast, quality-of-service, voice-over-IP, streaming media, and peer-to-peer multimedia systems. Includes a semester-long programming project.

#### **COMS E6185x or y Intrusion and anomaly detection systems**

*Lect: 2. 2 pts. Professor Stolfo*  
Prerequisite and corequisite: COMS W4180. Network security. The state of threats against computers, and networked systems. An overview of computer security solutions and why they fail, including vulnerability assessment, firewalls, vpn's. Provides a detailed treatment for network and host-based intrusion detection and intrusion prevention systems and the classes of attacks each covers. Considerable depth is provided on anomaly detection systems to detect new, zero-day attacks. Covers issues and problems in e-mail (spam and viruses) and insider attacks (masquerading and impersonation). Science requirement: partial fulfillment.

#### **COMS E6204x or y Topics in graph theory**

*Lect: 2. 3 pts. Professor Gross.*  
Prerequisite: COMS W4203 or the instructor's permission. Content varies from year to year. This course may be repeated for credit. Concentration

on some aspect of graph theory, such as topological graph theory, algebraic graph theory, enumerative graph theory, graphical optimization problems, or matroids.

**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 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 W6732x 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-aided design, or the instructor's permission. Programming proficiency in C, C++, or Java. 3-D photography—the process of automatically creating 3-D, texture-mapped models of objects in detail. Applications include robotics, medicine, graphics, virtual reality, entertainment, and digital movies, etc. Topics include 3-D data acquisition devices, 3-D modeling systems, and algorithms to acquire, create, augment, manipulate, render, animate, and physically build such models. The course is divided into three parts. The first third is devoted to lectures introducing the concept of 3-D photography and advanced modeling. The second part will be student presentations of related papers in the field.

The third part will be a series of group projects centered around using 3-D photography to model objects (buildings, rooms, people, etc.).

**COMS E6831y Sequential logic circuits**

*Lect: 3. 3 pts. Professor Unger.*

Prerequisite: CSEE W3827 or any introduction to logic circuits. Generation and manipulation of flow table descriptions to asynchronous sequential functions. Coding of flow tables to satisfy various design criteria. Delays, races, hazards, metastability. Analysis of latches to determine key parameters. Bounds of input rates. Clocking schemes for synchronous systems. Synthesis of self-timed systems using 4-phase or 2-phase handshakes.

**COMS E6832x or y Topics in logic design theory**

*Lect: 3. 3 pts. Professor Unger.*

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 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 graduate-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 component behaviors. The course has a two-fold structure: the study of the enabling technologies (VLSI circuits, communication protocols, embedded 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 deployment 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.

**COMS E6900x and y Tutorial in computer science**

*1 to 3 pts. Instructor to be announced.*

Prerequisite: permission of the instructor. A reading course in an advanced topic for a small number of students, under faculty supervision.

**COMS E6901x and y Projects in computer science**

*1 to 12 pts. Instructor to be announced.*

Prerequisite: permission of the instructor. Software or hardware projects in computer science. Before registering, the student must submit a written proposal to the instructor for review. The proposal should give a brief outline of the project, estimated schedule of completion, and computer resources needed. Oral and written reports are 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 E6901 may be taken. Consult the department for section assignment.

**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



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DOHERTY SENIOR  
RESEARCH SCIENTIST  
Robin Bell

ADJUNCT SENIOR  
RESEARCH SCIENTIST  
Nada Assaf-Anid



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 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

## 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

**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 conse-

quences. 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/](http://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 SF<sub>6</sub>). 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 SF<sub>6</sub> in continental waters and CFCs and SF<sub>6</sub> in the atmosphere. GC/MS capability is being added to the spectrum of analytical capabilities. For more information: [www.ldeo.columbia.edu/~noblegas/](http://www.ldeo.columbia.edu/~noblegas/).

**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 catalysis mechanisms, membrane technology, novel separations of minerals, biocol-

loids, microbial surfaces, and interfacial spectroscopy.

**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 care products, soil decontamination, and waste treatment. For more information: <http://www.columbia.edu/cu/iucrc/>.

**International Research Institute for Climate Prediction (IRI).** The IRI ([iri.columbia.edu](http://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.

## 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 work-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. To provide students with the necessary tools (mathematics, chemistry, physics, Earth sciences, and engineering science) to understand and implement the underlying principles used in the engineering of processes and systems.
2. To prepare students for engineering 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 graduate studies in related disciplines.
3. To teach the basic concepts and skills needed for the practice of Earth and environmental engineering, including measurement and control of material flows through the environment; assessment of environmental impacts of past, present, and future industrial activi-

ties; analysis and design of processes for remediation, recycling, and disposal of used materials; and regional resource and environmental management.

4. To ensure that the technical training of our students is based on a strong liberal arts core, that professional ethics and responsibilities are well understood, and that written and oral communication skills are honed.

### THE CURRICULUM

The first two years of the program are nearly the same as those of other engineering programs. In addition to the basic sciences, students are provided with a strong liberal arts core. 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.

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 ELECTIVES

Students majoring in Earth and environmental engineering need to select at least one course from each of the five groups below. Additional technical electives can be selected by students in consultation with advisers from the courses below, other 3000- to 4000-level courses of any SEAS department, and courses listed in the section "Courses in Other Divisions" in this bulletin. If the SEAS requirement of 27 credits of nontechnical courses has been satisfied in the first and second year of studies, students can replace nontechnical with technical electives.

#### FIELD STUDIES

- EAAE E4006:** Field methods for environmental engineering (3)  
**EAAE E4007:** Field environmental geophysics (3)

- EESC W4076:** Geologic mapping (3)

#### ENVIRONMENTAL CHEMISTRY

- CHEE E4252:** Intro. to surface and colloidal chemistry (3)  
**EESC W4113:** Introduction to mineralogy (4)  
**CHEN E4410:** Environmental control technology (4)  
**CHEE E4050:** Principles of industrial electrochemistry (3)  
**CHEE E4530:** Corrosion of metals (3)

#### ENGINEERING FUNDAMENTALS

- EAAE E4009:** Geographic information systems (GIS) for resource, environment, and infrastructure management (3)  
**EAAE E4200:** Production of inorganic materials (3)  
**EAAE E4257:** Environmental data analysis and modeling (3)  
**CIEN E4163:** Environmental engineering: wastewater (3)  
**CIEN E4255:** Flow in porous media (3)  
**CIEN E4250:** Waste containment design and practice (3)  
**CIEE E4257:** Contaminant transport in subsurface systems (3)  
**EAAE E4150:** Air pollution prevention and control (3)  
**MECE E4211:** Energy: sources and conversion (3)

#### ECONOMICS AND DECISION MAKING

- EAIA E4200:** Alternative energy resources (3)  
**ECIA W4100:** Management and development of water systems (3)  
**EAAE E4361:** Economics of Earth resource industries (3)  
**ECON BC3039:** Natural resources and environmental economics (3)  
**ECON W4329:** Economics of sustainable development (3)

#### BIOLOGY

- EAAE E4901:** Environmental microbiology (3)  
**BIOLOGY BC2001:** Molecular biology (3)  
**BIOLOGY BC2002:** Physiology, ecology, evolution (3)  
**EEEB W2001:** Environmental biology I, Molecules to cells (4)  
**EEEB W2002:** Environmental biology II, Organisms to ecosystems (4)  
**EEEB W4200:** Ecotoxicology (3)  
**PUBH P6300:** Environmental health sciences (3)  
**PUBH P6309:** Biochemistry basic to environmental health (3)

## 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

## EARTH AND ENVIRONMENTAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b> (three tracks, choose one)	MATH V1101 (3) —→ Honors Math I (3) —→ Honors Math I (3) —→	MATH V1102 (3) —→ Honors Math II (3) —→ Honors Math II (3) —→	MATH V1201 (3) —→ MATH V2010 (3) —→ Honors Math III (4) —→	APMA E2101 (3) MATH E1210 (3) Honors Math IV (4) and MATH E1210 (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) —→ C1601 (3) —→ C2801 (4.5) —→	C1402 (3) —→ C1602 (3.5) —→ C2802 (4.5) —→	C1403 (3) or CHEM C3443 (3.5) BIOL C2005 (4) C2601 (3.5) or CHEM C3443 (3.5) BIOL C2005 (4)	
<b>CHEMISTRY</b> (three tracks, choose one)	C1403 (3.5) —→ and Lab C1500 (2) either semester C2407 (3) —→ C3045 (3.5) —→	C1404 (3.5) —→ C2507 (3) —→ C3046 (3.5), Lab C2507 (3)	C3443 (3.5) or PHYS C1403 (3.5) or C2601 (3.5) BIOL C2005 (4)	
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (3) —→ ALP0006 (0) —→	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101, or V2001 (4) HUMA C1121 or C1123 (3)	HUMA C1002, C1102, or V2002 (4) ECON W1105 (4) and W1155 recitation (0)
<b>REQUIRED PROF AND TECH ELECTIVES</b>	EAEE E1100 (3) or see page 16		EESC W4001 (4) or V2100 (4.5) or V2200 (4.5)	SIEO W3600 (4)
<b>COMPUTER SCIENCE</b>	Computer language: COMS W1003 (3) or W1004 (3) any semester			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

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:

## EARTH AND ENVIRONMENTAL ENGINEERING: THIRD AND FOURTH YEARS

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES</b>	MSAE E 3111 (3) <b>or</b> MECE E3301 (3) Thermodynamics  EAAE E3101 (3) Earth resources prod. sys.  MECE E3100 (3) Intro. to mech. of fluids <b>or</b> ENME E3161 (4) Fluid mechanics  CIEE E3255 (3) Environm. control & pollution reduction sys.	CIEE E4252 (3) Environm. eng.  CIEE E3250 (3) Hydrosystems eng.  EAAE E3103 (3) Energy & materials systems	EAAE E3998 (2) Undergrad. design project  EAAE E4003 (3) Aquatic chem.  EAAE E3801 (3) Water qual. anal.  EAAE E4001 (3) Indust. ecol. of Earth resources	EAAE E3999 (2) Undergrad. design project  EAAE E4160 (3) Solid & hazardous waste mgmt.
<b>ELECTIVES</b>		Any departmental or listed (see table) 3000- or 4000-level course 3 points	Any departmental or listed (see table) 3000- or 4000-level course 6 points	Any departmental or listed (see table) 3000- or 4000-level course 9 points
<b>TECH</b>				
<b>NONTECH</b>	3 points	3 points		3 points
<b>TOTAL POINTS</b>	15–16	15	17	17

- 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 colloidal 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 co-generation, 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.

Graduates of the MS-ERE program can continue for a Master in Public Administration (M.P.A.) and have some of their engineering courses credited toward this degree. The same applies to M.P.A. students who plan for careers in environmental management. Interested persons should contact Professor Themelis at 212-854-2138 or by e-mail at njt1@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 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."

### EAAE E1100y A better planet by design

*Lect.: 3. 3 pts. Professor Lall.*

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 E3101y Earth resource production systems

*Lect.: 3. 3 pts. Professor Yegulalp.*

Technologies and equipment common to a wide range of surface and subsurface engineering

activities: mine reclamation, hazardous waste remediation, discovering and operating surface and underground mines, detection and removal of hidden underground objects, waste disposal, dredging and harbor rehabilitation, and tunneling for transportation or water distribution systems. These methods and equipment are examined as they apply across the spectrum from mining to environmental engineering projects. The aim is to provide a broad background for earth and environmental engineers in careers involving minerals and industrial, large-scale environmental projects.

### EAAE E3103y Energy and materials systems

*Lect.: 3. 3 pts. Professor Lackner.*

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 metallurgical 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.

### EAAE E3112y Introduction to rock mechanics

*Lect.: 3. 3 pts. Not given in 2005–2006.*

Prerequisites: EAAE 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.

### EAAE 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.

**EAAE 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 Hydrosystems engineering**  
*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, and air, water, soil, and noise pollution. Life cycle assessments and emerging technologies.

**EAAE E3801y Water quality analysis**  
*Lect: 1.5. Lab: 3. 3 pts. Professor Duby.*

Principles underlying water analysis for organic, inorganic, and bacterial contaminants. Applications illustrated by means of laboratory experiments that include the study of impurity effects on physical properties of water, analysis of aggregate organic constituents, and analysis of inorganic constituents of waters of a wide range of quality, including drinking water, surface water, and wastewater. Determination of public health quality by means of current microbiological tests for the detection and enumeration of indicator organisms in various waters. Ten 3-hour laboratory sessions. Lab required.

**EAAE E3900x and y, and s Undergraduate research in Earth and environmental engineering**  
*Directed study. 0-3 pts. The faculty.*

This course may be repeated for credit, but no more than 3 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 Earth and environmental engineering, or carry out a special

project under the supervision of EAAE faculty. Credit for the course is contingent on the submission of an acceptable thesis or final report. This course cannot substitute for the undergraduate design project (E3999x-E3999y).

**EAAE E3998x-E3999y Undergraduate design project**

*Lect: 1. Lab: 2. 2 pts (each semester).*  
*Professors Castaldi, Duby, Gong, Lackner, Lall, Schlosser, Somasundaran, Yegulalp.*  
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.

**EAAE 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.

**EAAE E4001x Industrial ecology of Earth resources**

*Lect: 3. 3 pts. Professor Themelis.*  
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.

**EAAE 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**

*Lect: 3. 3 pts. Not given in 2005-2006.*  
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 process. 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**

*Lect: 3. 3 pts. Not given in 2005-2006.*  
Geophysical methods as applicable to engineering problems. Principles of geophysics and non-invasive 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, environment, 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**

*Lect: 3. 3 pts. Not given in 2005-2006.*  
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. 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.

**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 E4101y Introduction to particle technology**

*Lect: 2. Lab: 3. 3 pts. Not given in 2005–2006.*  
Prerequisite: the instructor's permission. Size reduction, theory of comminution. Small particle statistics, particle size measurement, properties of particle aggregates, behavior of particles in fluids, flow and retention of fluids in packings.

**EAAE E4150y Air pollution prevention and control**

*Lect: 3. 3 pts. Professor Fthenakis.*  
Adverse effects of air pollution, sources and transport media, monitoring and modeling of air quality, collection and treatment techniques, pollution prevention through waste minimalization and clean technologies, laws, regulations, standards, and guidelines.

**EAAE E4160y Solid and hazardous waste management**

*Lect: 3. 3 pts. Professor Somasundaran.*  
Generation, composition, collection, transport, storage, and disposal of solid and hazardous waste. Impact on the environment and public health. Government regulations. Recycling and resource recovery.

**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.

**EAIA W4200y Alternative energy resources**

*Lect: 3. 3 pts. Professor 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 disposal as a means of sustaining the fossil fuel option.

**EAAE E4241x Solids handling and transport systems**

*Lect: 3. 3 pts. Not given in 2005–2006.*  
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.

**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 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 E4900x Applied transport and chemical rate phenomena**

*Lect: 3. 3 pts. Professor Lackner.*  
Introduction to fluid dynamics, heat and mass transfer, and some applications in heterogeneous reaction systems. Effect of velocity, temperature, and concentration gradients and material properties on fluid flow, heat and mass transfer, and rate of chemical reactions; differential and overall balance; engineering concepts and semi-empirical correlations; application to chemical and materials processing and environmental problems.

**EAAE E4901y Environmental microbiology**

*Lect: 3. 3 pts. Instructor to be announced.*  
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.

**EEAE E4980 Urban environmental technology and policy**

*Lect: 3. 3 pts. Not given in 2005–2006.*  
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**

*Lect: 3. 3 pts. Not given in 2005–2006.*  
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**

*Lect: 3. 3 pts. Not given in 2005–2006.*  
Potential field data, prospecting, wave equations. Huygens' principle, Green's functions, Kirchoff equation, WKB approximation, ray tracing. Wave propagation, parameters. Computer applications. Wavelet processing, filters and seismic data. Stratified Earth model, seismic processing and profiling. Radon transform and Fourier migration. Multidimensional geological interpretation.

**EAAE E6200y Theory and applications of extreme value statistics in engineering and Earth sciences**

*Lect: 3. 3 pts. Professor Yegulalp.*  
Prerequisite: STAT G4107 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 rainfalls.

**EAAE E6208y Combustion chemistry and processes**

*Lect: 3. 3 pts. Professor Castaldi.*  
Prerequisite: EAAE 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 fueled combustion, fuel cells and plasma combustion.

**EAAE E6210x Quantitative environmental risk analysis**

*Lect: 3. 3 pts. Professor Yegulalp.*  
Prerequisite: EAAE 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.

**EAAE E6212x Carbon sequestration**

*Lect: 3. 3 pts. Professor Lackner.*  
Prerequisite: EAAE 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.

**EAAE E6220x Remedial and corrective action**

*Lect: 3. 3 pts. Not given in 2005–2006.*  
Prerequisite: EAAE 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 EAAE E4003. Detailed examination of chemical equilibria in hydrometallurgical systems. Kinetics and mechanisms of homogeneous and heterogeneous reactions in aqueous solutions.

**EAAE E6228y Theory of flotation**

*Lect: 3. 3 pts. Professor Not given in 2005–2006.*  
Prerequisite: CHEE E4252 or the instructor's permission. A detailed study of the physicochemical principles of the flotation process.

**EAAE E6240x or y Physical hydrology**

*Lect: 3. 3 pts. Professor Lall.*  
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.

**EAAE E6255x-E6256y Methods and applications of analytical decision making in mineral industries**

*Lect: 3. 3 pts. Not given in 2005–2006.*  
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.

**EAAE E8229x Selected topics in processing minerals and waste**

*Lect: 2. Lab: 3. 3 pts. Professors Somasundaran and Nagaraj.*  
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.

**EAAE E8231y Selected topics in hydro- and electrometallurgy**

*Lect: 3. 3 pts. Not given in 2005–2006.*  
Prerequisite: EAAE 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.

**EAAE 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.

**EAAE E8273x-E8274y Mining engineering reports**

*0 to 4 pts. Professor Yegulalp.*  
May be substituted for formal thesis, EAAE E9271, upon recommendation of the student's adviser.

**EAAE 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.

**EAAE E9273x-E9274y Earth and environmental engineering reports**

*0 to 4 pts. The staff.*  
May be substituted for the formal thesis, EAAE E9271, upon recommendation of the department.

**EAAE E9281x-E9282y Earth and environmental engineering seminar, I and II**

*Lect: 1.5. 0 or 1 pt. Instructor to be announced.*  
Verbal presentation and discussion of current findings and related literature, preferably related to thesis research project. Lectures will be given by Columbia scientists and representatives from state and city agencies on the chosen topic. Students will have to write several papers and assignments on a variety of problems and solutions appropriate to the topic.

**EAAE E9302x and y Mining engineering research**

*0 to 4 pts. Professor Yegulalp.*  
Graduate research directed toward solution of technoscientific problems in mining.

**EAAE E9305x and y, and s Earth and environmental engineering research**  
0 to 4 pts. *The staff.*

Graduate research directed toward solution of a problem in mineral processing or chemical metallurgy.

**EAAE 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 mineral engineering must register for 12 points of doctoral research instruction. Registration in EAAE E9800 may not be used to satisfy the minimum residence requirement for the degree.

**EAAE E9900x and y, and s Doctoral dissertation**  
0 pts. *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 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 Duby.*

**MSAE E3111x Thermodynamics, kinetic theory, and statistical mechanics**

*Lect: 3. 3 pts. Professor Marshall.*

**MSAE E3141y Processing of metals and semiconductors**

*Lect: 3. 3 pts. Professor Duby.*

**MSAE E3142y Processing of ceramics and polymers**

*Lect: 3. 3 pts. Professor O'Brien.*

**MSAE E3156x and y Design project**  
3 pts. *The staff.*

**MSAE E3900x and y Undergraduate research in materials science**

0 to 4 pts. *Members of the faculty.*

**MSAE E4101x Structural analysis of materials**

*Lect: 3. 3 pts. Professor Chan.*

**MSAE E4132y Fundamentals of polymers and ceramics**

*Lect: 3. 3 pts. Professor O'Brien.*

**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. Not given in 2005–2006.*

**MSAE E4301x and y Materials science laboratory**

1 to 3 pts. *Instructor to be announced.*

**MSAE E6020y Electronic ceramics**

*Lect: 3. 3 pts. Not given in 2005–2006.*

**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 E6090x Nanotechnology**

*Lect: 3. 3 pts. Offered in alternate years. Professor O'Brien.*

**MSAE E6091y Magnetism and magnetic materials**

*Lect: 3. 3 pts. Offered in alternate years. Not given in 2005–2006.*

**MSAE E6120x Grain boundaries and interfaces**

*Lect: 2. 3 pts. Offered in alternate years. Not given in 2005–2006.*

**MSAE E6220x Crystal physics**

*Lect: 3. 3 pts. Not given in 2005–2006.*

**MSAE E6221x Introduction to dislocation theory**

*Lect: 3. 3 pts. Not given in 2005–2006.*

**MSAE E6225y Techniques in x-ray and neutron diffraction**

*Lect: 3. 3 pts. Not given in 2005–2006.*

**MSAE E6229x Energy and particle beam processing of materials**

*Lect: 3. 3 pts. Not given in 2005–2006.*

**MSAE E6230x Kinetics of phase transformations**

*Lect: 3. 3 pts. Not given in 2005–2006.*

**MSAE E6240x Impurities and defects in semiconductor materials**

*Lect: 2. 3 pts. Not given in 2005–2006.*

**MSAE E6241y Theory of solids**

*Lect: 2. 3 pts. Not given in 2005–2006.*

**MSAE E6251y Thin films and layers**

*Lect: 2. 3 pts. Instructor to be announced.*

**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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

**MSAE E9000x and y Materials science and engineering colloquium**

0 pts. *Professor Im.*

**MSAE E9259x-E9260y, and s Research topics in materials science and metallurgical engineering**

*Lect: 1. 1pt. 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 E9800x 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.*

# Electrical Engineering

1312 S. W. Mudd, MC 4712, 212-854-3105  
<http://www.ee.columbia.edu>



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 1306 S. W. Mudd



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SENIOR LECTURER  
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 Robert Melville

ADJUNCT PROFESSORS  
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 Inder Gopal  
 Mark Hybertsen  
 Irving Kalet  
 Norton Lang  
 Ta-Hsin Li  
 James Misewich  
 Michael Picheny  
 Stephen Weinstein

Philip Whitting  
 Shalom Wind  
 James Yardley

ADJUNCT ASSOCIATE  
 PROFESSORS  
 Andrew Campbell  
 Vittorio Castelli  
 Abe Elfadel  
 Constantinos Papadias  
 Kudva Prabhakar  
 Emina Soljanin

ADJUNCT ASSISTANT  
 PROFESSORS  
 Alexei Ashikhmin  
 Yves Baryens  
 Nagendra Krishnapura  
 Ching-Yung Lin  
 Ramachandran Ramjee

SENIOR RESEARCH  
 SCIENTIST  
 Robert Laibowitz

ASSOCIATE RESEARCH  
 SCIENTISTS  
 Vladimir Sokolov  
 Shangheng Xin

VISITING RESEARCH  
 SCIENTISTS  
 Jeng-Shyan Feng  
 Chiu-Ting Hsu  
 Takaaki Ishigure  
 David Lang  
 Emiliano Miluuzo  
 Cerda Pons  
 Luca Venturino

POSTDOCTORAL  
 RESEARCH SCIENTIST  
 Nicolae Panoiu



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, transmis-

sion, 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. Undergraduates have an opportunity to learn firsthand about current research activities by participating in a program of undergraduate research projects with the faculty.

A master's level program in electrical engineering permits the graduate student to further specialize her/his knowledge and skills within a wide range of disciplines. For those who are interested in pursuing a career in teaching or research, our Ph.D. program offers the opportunity to conduct research under faculty supervision at the leading edge of technology and applied science. Research seminars are offered in a wide range of areas, including telecommunications, very large scale integrated circuits, photonics, and microelectronics.

The Electrical Engineering Department, along with the Computer Science Department, also offers B.S. and M.S. programs in computer engineering. Details on those programs can be found in the Computer Engineering section in this bulletin.

#### **GRADUATE RESEARCH ACTIVITIES**

The research interests of the faculty encompass a number of rapidly growing areas, vital to the development of future technology, that will affect almost every aspect of society: communications and information processing; solid-state devices; ultrafast optics and photonics; microelectronic circuits, integrated systems and computer-aided design; systems biology; and electromagnetics and plasmas. Details on all of these areas can be found at <http://www.ee.columbia.edu/research/>.

Communications research focuses on wireless communication, multimedia networking, real-time Internet, lightwave (fiber optic) communication networks, optical signal processing and switching, service architectures, network management and control, the processing of image and video information, and media engineering. Current studies include wireless and mobile computing environments, broadband kernels, object-oriented network management, real-time monitoring and

control, lightwave network architectures, lightweight protocol design, resource allocation and networking games, real-time Internet services, future all-digital HDTV systems, coding and modulation.

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, photodiodes, 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**

Every phase of current research activities is fully supported and carried out in one of 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, and VLSI Design Laboratory.

## **Undergraduate Program**

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

**ELECTRICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS  
EARLY-STARTING STUDENTS**

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3) <sup>3</sup>
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) —————→ C1601 (3.5) —————→ C2801 (4.5) —————→	C1402 (3) C1602 (3.5) C2802 (4.5)		
<b>CHEMISTRY</b>	one-semester lecture (3–4) C1403 or C1404 or C3045 or C2407			
<b>CORE REQUIRED COURSES</b>		ELEN E1201 (3.5) Introduction to electrical engineering	ELEN E3201 (3.5) Circuit analysis  ELEN E3801 (3.5) Signals & systems	ELEN E3331 (3) Electronic circuits  CSEE W3827 (3) Fund. of computer sys.
<b>REQUIRED LABS</b>			ELEN E3081 (1) <sup>2</sup> Circuit analysis lab  ELEN E3084 (1) <sup>2</sup> Signals & systems lab	ELEN E3083 (1) <sup>2</sup> Electronic circuits lab  ELEN E3082 (1) <sup>2</sup> Digital systems lab
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) —————→ ALP0006 (0) —————→	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>	HUMA C1001, C1101, or V2001 (4); HUMA C1121 or C1123 (3); HUMA C1002, C1102, or V2002 (4); ECON W1105 (4) and W1155 recitation (0); some of these courses can be postponed to the junior or senior year, to make room for taking the above electrical engineering courses.			
<b>COMPUTER SCIENCE</b>	COMS W1007 (3) either semester <sup>1</sup>			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>COMS W1007 may be replaced by COMS W1003, W1004, or W1009, but impact on later options should be considered (see <http://www.ee.columbia.edu/academics/undergrad>).

<sup>2</sup>If possible, these labs should be taken along with their corresponding lecture courses.

<sup>3</sup>APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2010.

**ELECTRICAL ENGINEERING: THIRD AND FOURTH YEARS  
EARLY-STARTING STUDENTS**

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>PHYSICS</b> (tracks continued)	C1403 (3) —————> C2601 (3.5) —————> Lab W3081 (2)	Lab C1494 (3) <sup>1</sup> Lab C2699 (3)		
<b>EE CORE REQUIRED COURSES</b>	ELEN E3106 (3.5) Solid-state devices & materials	ELEN E3401 (4) Electromagnetics  ELEN E3701 (3) <sup>2</sup> Intro. to communication systems <b>or</b> ELEN E4710 (3) <sup>2</sup> Intro. to network engineering		
<b>EE REQUIRED LABS</b>			ELEN E3043 (2) Solid state, microwave, & fiber optics lab	One capstone design course <sup>3</sup> (ELEN E3390, ELEN E4332, EECS E4340, <b>or</b> CSEE W4840)
<b>OTHER REQUIRED COURSES</b>	SIEO W3658 <b>or</b> W4105 <sup>4</sup> ; <b>and</b> COMS W3137 ( <b>or</b> W3133, W3134, or W3139) (Some of these courses are <i>not</i> offered both semesters. Students with an adequate background can take some of these courses in the sophomore year.)			
<b>ELECTIVES</b>	<b>EE DEPTH TECH</b>	At least two technical electives in one depth area, in addition to those in the core; at least one of these electives must have as a prerequisite another course in the same area, or a related course in the core. 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.		
	<b>BREADTH TECH</b>	At least two technical electives outside the depth area, in addition to those in the core; one or both of these electives can be from other departments. See checklist at <a href="http://www.ee.columbia.edu/academics/undergrad/">http://www.ee.columbia.edu/academics/undergrad/</a> .		
	<b>OTHER TECH</b>	From checklist available at <a href="http://www.ee.columbia.edu/academics/undergrad/">http://www.ee.columbia.edu/academics/undergrad/</a> , as required to bring the total points of technical electives to 18. <sup>5</sup>		
	<b>NONTECH</b>	Complete 27-point requirement; see page 14 or <a href="http://www.seas.columbia.edu">http://www.seas.columbia.edu</a> for details (administered by the Class Dean)		
<b>TOTAL POINTS</b>	16	15	18	16

<sup>1</sup>Chemistry lab (CHEM 1500) may be substituted for physics lab, although this is not generally recommended.

<sup>2</sup>These courses can be taken in the sophomore year if the prerequisites/corequisites are satisfied.

<sup>3</sup>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.

<sup>4</sup>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 the 2-point SIEO W3602 to obtain the required statistics material.

<sup>5</sup>The total points of technical electives can be reduced to 15 if APMA E2101 has been replaced by MATH E1210 and either APMA E3101 or MATH V2010.

**ELECTRICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS  
LATE-STARTING STUDENTS**

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101(3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3) <sup>3</sup>
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) ————— C1601 (3.5) ————— C2801 (4.5) —————	C1402 (3) ————— C1602 (3.5) ————— C2802 (4.5) —————	C1403 (3) ————— C2601 (3.5) ————— → Lab W3081 (2)	→ Lab C1494 (3) <sup>4</sup> → Lab C2699 (3)
<b>CHEMISTRY</b>	one-semester lecture (3–4) C1403 or C1404 or C3045 or C2407			
<b>ELECTRICAL ENGINEERING</b>		ELEN E1201 (3.5) <sup>1</sup>		
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ————— ALP0006 (0) —————	→ C1010 (3) → Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101, or V2001 (4) HUMA C1121 or C1123 (3)	HUMA C1002, C1102, or V2002 (4) ECON W1105 (4) and W1155 recitation (0)
<b>COMPUTER SCIENCE</b>	COMS W1007 (3) either semester <sup>2</sup>			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>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.

<sup>2</sup>COMS W1007 may be replaced by COMS W1003, W1004, or W1009, but impact on later options should be considered (see <http://www.ee.columbia.edu/academics/undergrad>).

<sup>3</sup>APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2010.

<sup>4</sup>Chemistry lab (CHEM C1500) may be substituted for physics lab, although this is not generally recommended.

**ELECTRICAL ENGINEERING: THIRD AND FOURTH YEARS<sup>1</sup>  
LATE-STARTING STUDENTS**

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>EE CORE REQUIRED COURSES</b>	ELEN E3106 (3.5) Solid-state devices & materials  ELEN E3201 (3.5) Circuit analysis  ELEN E3801 (3.5) Signals & systems	CSEE W3827(3) Fund. of computer sys.  ELEN E3331 (3.5) Electronic circuits  ELEN E3401 (4) Electromagnetics  ELEN E3701 (3) Intro. to communication systems <b>or</b> ELEN E4710 (3) Intro. to network engineering		
<b>EE REQUIRED LABS</b>	ELEN E3081 (1) <sup>2</sup> Circuit analysis lab  ELEN E3084 (1) <sup>2</sup> Signal & systems lab	ELEN E3083 (1) <sup>2</sup> Electronic circuits lab  ELEN E3082 (1) <sup>2</sup> Digital systems lab	ELEN E3043 (2) Solid state, microwave, & fiber optics lab	One capstone design course <sup>3</sup> ( ELEN E3390, ELEN E4332, EECS E4340, <b>or</b> CSEE W4840)
<b>OTHER REQUIRED COURSES</b>	SIEO W3658 <b>or</b> W4105 <sup>4</sup> ; <b>and</b> COMS W3137 ( <b>or</b> W3133, W3134, or W3139) (Some of these courses are <i>not</i> offered both semesters.)			
<b>ELECTIVES</b>	<b>EE DEPTH TECH</b>	At least two technical electives in one depth area, in addition to those in the core; at least one of these electives must have as a prerequisite another course in the same area, or a related course in the core. 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.		
	<b>BREADTH TECH</b>	At least two technical electives outside the depth area, in addition to those in the core; one or both of these electives can be from other departments. See checklist at <a href="http://www.ee.columbia.edu/academics/undergrad/">http://www.ee.columbia.edu/academics/undergrad/</a> .		
	<b>OTHER TECH</b>	From checklist available at <a href="http://www.ee.columbia.edu/academics/undergrad/">http://www.ee.columbia.edu/academics/undergrad/</a> , as required to bring the total points of technical electives to 18. <sup>5</sup>		
	<b>NONTECH</b>	Complete 27-point requirement; see page 14 or <a href="http://www.seas.columbia.edu">http://www.seas.columbia.edu</a> for details (administered by the Class Dean)		
<b>TOTAL POINTS</b>	16	15	18	16

<sup>1</sup>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.

<sup>2</sup>If possible, these labs should be taken along with their corresponding lecture courses.

<sup>3</sup>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.

<sup>4</sup>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 the 2-point SIEO W3602 to obtain the required statistics material.

<sup>5</sup>The total points of technical electives can be reduced to 15 if APMA E2101 has been replaced by MATH E1210 and either APMA E3101 or MATH V2010.

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 non-technical 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 <http://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.

### TECHNICAL ELECTIVES

The 18-point technical elective requirement must satisfy both depth and breadth requirements, as shown on the charts.

The *depth* requirement provides an opportunity to the student to pursue his/her interests, and exposes the student to the process of exploring a discipline in depth—an essential process that the student can later carry over to other disciplines, if he or she chooses. Suitable electives that satisfy the depth requirement for any one of four areas are shown in <http://www.ee.columbia.edu/curriculum/>.

The *breadth* requirement ensures that the student does not overspecialize in only one area. Breadth is particularly important today, as innovation requires more and more an interdisciplinary approach, and exposure to other fields is known to help one's creativity in his/her own main field. Such exposure also reduces the chance of obsolescence as technology changes.

If the depth and breadth electives, taken together, are not at least 18

points, additional technical electives must be taken to bring the total to at least 18 points.

Specific courses that are acceptable in each of the above categories are shown on a curriculum checklist available at <http://www.ee.columbia.edu/academics/undergrad/>. If a student wants to take a technical elective that is not on the checklist, adviser approval must be recorded on the checklist and submitted to the department.

### 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 nontechnical 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; programs may vary depending on student preparation and interests.

### TRANSFER STUDENTS

Transfer students coming to Columbia as juniors 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 the spring semester of the 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 required 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 <http://www.ee.columbia.edu/curriculum/>.

## 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 Engineering 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 <http://www.ee.columbia.edu/curriculum/>.

### 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 <http://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 register 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 <http://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 concentrations, contact the Department of Electrical Engineering or visit the Electrical Engineering home page on the Internet at <http://www.ee.columbia.edu/>.

### Concentration in Multimedia Networking

Advisers: Prof. Henning Schulzrinne, Prof. Predrag Jelenkovic

1. Satisfy the basic M.S. degree requirement.
2. Both *ELEN E6711: Stochastic signals and noise* and *ELEN E6761: Computer communication networks*.
3. Either *COMS W4118: Operating systems* or *COMS W4111: Database systems*.
4. *COMS E6181: Advanced Internet services*.
5. Either *ELEN E6960: Multimedia networking* or *ELEN E6970: Resource allocation and networking games*.

With the adviser's approval, any of the courses above can be replaced by the following closely related subjects: *ELEN E4710: An introduction to network engineering*; *ELEN E4720: Networking laboratory*; *COMS W4119: Computer networks*; *COMS W4995: Network security*; *ELEN E6762: Broadband networks*; *ELEN E6850:*

*Visual information systems*; *ELEN E6940: Telecommunication networks control and management*; *ELEN E6950: Wireless and mobile networking*.

### Concentration in Telecommunications Engineering

Advisers: Prof. Henning Schulzrinne, Prof. Predrag Jelenkovic, Prof. Ed Coffman, Prof. Nicholas Maxemchuk, Prof. Dan Rubenstein

1. Satisfy the basic M.S. degree requirements.
2. One basic hardware or software course such as: *ELEN E4321: VLSI circuits*; *ELEN E4411: Fundamentals of photonics*; *COMS W4118: Operating systems, I*; *COMS W4111: Database systems*.
3. One basic systems course such as: *ELEN E4702: Communication theory*; *ELEN E4703: Wireless communications*; *ELEN E4710: An introduction to network engineering*; *COMS W4119: Computer networks*; *ELEN E6761: Computer communication networks*.
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. Alexandros Eleftheriadis, Prof. Dan Ellis, Prof. Xiaodong Wang

1. Satisfy the basic M.S. degree requirements.
2. Both *ELEN E4810: Digital signal processing* and *ELEN E4830: Digital image processing*.
3. Either *ELEN E6761: Computer communication networks* or *COMS W4119: Computer networks*.
4. At least two approved advanced courses such as: *ELEN E4890: Music signal processing*; *ELEN E6820: Speech and audio processing and recognition*; *ELEN E6850: Visual information systems*; *ELEN E6860: Advanced digital signal processing*; *ELEN E6880: Topics in signal processing*; *ELEN E6762: Broadband networks*; *ELEN E6960: Multimedia networking*; *COMS E6181: Advanced Internet services*; 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 basic M.S. degree requirements.
2. Take both *ELEN E4411: Fundamentals of photonics* and *ELEN E6403: Classical electromagnetic theory* or equivalent.
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 E4306: 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: TBA

1. Satisfy the basic M.S. degree requirements.
2. One basic circuits course such as: *ELEN E4303: Analog electric circuits*; *ELEN E4314: Communication circuits*; *ELEN E6314: RF ICs*; *ELEN E6312: Design of analog integrated circuits*.
3. Two communications courses such as: *ELEN E4702: Communication theory*; *ELEN E4703: Wireless communications*; *ELEN E6711: Stochastic signals and noise*; *ELEN E4810: Digital signal processing*; *ELEN E6950: Wireless and mobile networking*; *ELEN E6761: Computer communication networks*.
4. At least two approved courses in wireless communications or a related area.

### Concentration in Microelectronic Circuits

Advisers: Prof. Yannis Tsvividis, Prof. Charles Zukowski, Prof. Kenneth Shepard, Prof. Peter Kinget

1. Satisfy the basic M.S. degree requirements.

2. One digital course: *ELEN E4321: VLSI circuits.*
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 E6261: Computational methods of circuit analysis; ELEN E6304: Topics in electronic circuits.*
5. At least two additional approved courses in circuits or a related area.

### Concentration in Microelectronic Devices

Advisers: Prof. Wen Wang,  
Prof. Richard Osgood

1. Satisfy the basic 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 E4944: Principles of device microfabrication; ELEN E4503: Sensors, actuators, and electro-mechanical systems; ELEN E6151: Surface physics and analysis of electronic materials; ELEN E6331: Principles of semiconductor physics, I; ELEN E6332: Principles of semiconductor physics, II; ELEN E6333: Semiconductor device physics.*
4. At least two approved courses in devices or a related area.

### Concentration in Systems Biology

Advisers: Prof. Dimitris Anastassiou,  
Prof. Ed Coffman, Prof. Pedrag Jelenkovic, Prof. Aurel Lazar, Prof. Kenneth Shepard, Prof. Xiaodong Wang, Prof. Charles Zukowski

1. Satisfy the basic M.S. degree requirements.
2. Take both *ECBM E4060: Introduction to genomic information science and technology* and *BMEB W4011: Computational neuroscience, I: circuits in the brain*
3. Take at least one course from *CBMF W4761: Computational*

*genomics; BIOL W4037: Bioinformatics of gene regulation; Biomedical Informatics G4015: Computational biology, bioinformatics; APMA E4400: Introduction to biophysical modeling; BMEN E6480: Computational neuroscience, II: neural modeling and neuroengineering; CHEN E4700: Principles of genomic technologies.*

4. Take at least one course from *ELEN E608x: Topics in systems biology; ELEN E6717: Information theory; ELEN E6201: Linear systems theory; EEME E6601: Introduction to control theory; ELEN E6711: Stochastic models in information systems; ELEN E6860: Advanced digital signal processing.*

## Courses in Electrical Engineering

### ELEN E1201y Introduction to electrical engineering

*Lect: 3. Lab: 1. 3.5 pts. Professor Tsvividis.*  
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.

### ELEN E3000x Introduction to circuits, systems, and electronics

*Lect: 3. Recit: 1. 3.5 pts. Professor Laibowitz.*  
Introductory course in electrical circuits, systems, electronics, and digital information processing for non-electrical engineers.

### ELEN E3043x Solid state, microwave, and fiber optics laboratory

*Lab: 6. 2 pts. Professor W. Wang.*  
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. Instructor to be announced.*  
Corequisite: ELEN E3201. Prerequisite: ELEN E1201 or equivalent. 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; opamp 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. Instructor to be announced.*  
Prerequisite: ELEN E3081. Corequisite: ELEN E3331. Companion lab course for ELEN E3331. Experiments cover such topics as macromodeling of nonidealities of opamps using HSPICE; Schmitt triggers and astable multivibrations using opamps and diodes; logic inverters and amplifiers using bipolar junction transistors; logic inverters and ring oscillators using MOSFETs; filter design using opamps. The lab generally meets on alternate weeks.

### ELEN E3084x Signals and systems laboratory

*Lab: 3. 1 pt. Instructor to be announced.*  
Corequisite: ELEN E3801. Companion lab course for ELEN E3801. Experiments cover topics such 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 E3106x 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 Kinget.*  
Prerequisite: ELEN E1201 or the equivalent. Corequisite: MATH V1201. A course on analysis of linear and nonlinear circuits and their applications. Formulation of circuit equations. Network theorems. Transient response of first and second-order circuits. Sinusoidal steady-state analysis. Frequency response of linear circuits. Poles and zeros. Bode plots. Two port networks.

### ELEN E3331y Electronic circuits

*Lect: 3. 3 pts. Instructor to be announced.*  
(Formerly ELEN E3301.) Prerequisite: ELEN E3201. Operational amplifier circuits. Diodes and diode circuits. MOS and bipolar junction transistors. Biasing techniques. Small-signal models. Single-stage transistor amplifiers. Analysis and design of CMOS logic gates. A/D and D/A converters.

**ELEN E3390y Electronic circuit design laboratory**

*Lab: 6. 3 pts. Instructor to be announced.*  
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**

*Lect: 3. 4 pts. Professor Diamant.*  
Prerequisite: MATH V1201, PHYS C1402, or PHYS C1602, or equivalents. Basic field concepts. Interaction of time-varying electromagnetic fields. Field calculation of lumped circuit parameters. Transition from electrostatic to quasi-static and electromagnetic regimes. Transmission lines. Energy transfer, dissipation, and storage. Waveguides. Radiation.

**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/DPCM 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.

**ELEN E3801x Signals and systems**

*Lect: 3. 3.5 pts. Professor X. Wang.*  
Corequisite: Math V1201. Modeling, description, and classification of signals and systems. Continuous-time systems. Time domain analysis, convolution. Frequency domain analysis, transfer functions. Fourier series. Fourier and Laplace transforms. Discrete-time systems and the Z transform.

**CSEE W3827 x and y Fundamentals of computer systems**

*Lect: 3. 3 pts. x: Professor Unger; y: to be announced.*  
Prerequisite: An introductory programming course (COMS W1007 or W1009). Fundamentals of computer organization and digital logic. Boolean algebra, Karnaugh maps, basic gates and components, flipflops and latches, counters and state machines, basis of combinational and sequential digital design. Assembly language, instruction sets, ALUs, single-cycle and multicycle processor design, introduction to pipelined processors and caches.

**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. The course shares lectures with EEHS E4900, but the work requirements differ somewhat.

**ELEN E3998x and y Projects in electrical engineering**

*0 to 3 pts. Instructor to be announced.*  
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.

**BMEB W4011x Computational neuroscience, I: Circuits in the brain**

*Lect: 3. 3 pts. Professors Lazar and Yuste.*  
Prerequisite: ELEN E3801 or BIOL W3004. This course will use Dayan and Abbott's Introduction to Theoretical Neuroscience to provide a broad overview of current knowledge about computation carried out by different microcircuits present in mammalian CNS. The material covered by this course will concentrate on synaptic physiology neuroanatomy and circuit analysis. Students will present chapters from the book and discuss relevant papers.

**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.

**ELEN E4301y Introduction to semiconductor devices**

*Lect: 3. 3 pts. Instructor to be announced.*  
Prerequisite: ELEN E3106 or the equivalent. Semiconductor physics. Carrier injection and recombination. P-n junction and diodes: Schottky barrier and heterojunctions, solar cells and light-

emitting diodes. Junction and MOS field-effect transistors, bipolar transistors. Tunneling and charge-transfer devices.

**ELEN E4312x Analog electronic circuits**

*Lect: 3. 3 pts. Professor Tsvividis.*  
(Formerly ELEN E4305.) 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 Tsvividis.*  
(Formerly ELEN E4306.) 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**

*Lect: 3. 3 pts. Instructor to be announced.*  
Recommended preparation: ELEN E3331, CSEE W3827, and ELEN E3106. Design and analysis of high-speed logic and memory. Digital CMOS and BiCMOS device modeling. Integrated circuit fabrication and layout. Interconnect and parasitic elements. Static and dynamic techniques. Worst-case design. Heat removal and I/O. Yield and circuit reliability. Logic gates, pass logic, latches, PLAs, ROMs, RAMs, receivers, drivers, repeaters, sense amplifiers.

**EECS E4340y Computer hardware design**

*Lec: 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**

*Lect: 3. 3 pts. Professor Diamant.*  
Prerequisite: ELEN E3401 or the equivalent. Waves and Maxwell's equations. Field energetics, dispersion, complex power. Waves in dielectrics and in conductors. Reflection and refraction. Oblique incidence and total internal reflection. Transmission lines and conducting waveguides. Planar and circular dielectric waveguides; integrated optics and optical fibers. Hybrid and LP modes. Graded-index fibers. Mode coupling; wave launching.

**ELEN E4405x Classical nonlinear optics**

*Lect: 3. 3 pts. Instructor to be announced.*  
Prerequisite: ELEN E4401. Waves in anisotropic media. Maxwell's equations and constitutive relations. Fresnel equations. Optical waves in

anisotropic crystals. Birefringence. Waves in non-linear media. Plasma model. Electro-optic, Pockels, and Kerr effects. Second harmonic generation and phase matching. Parametric amplification. Backward-wave oscillator. Acousto-optic beam deflection and light modulation.

**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 heterostructure laser diodes. Semiconductor photon detectors: p-n, p-i-n, and heterostructure photo diodes; avalanche photodiodes.

**ELEN E4501x Electromagnetic devices and energy conversion**

*Lect: 3. 3 pts. Instructor to be announced.*  
Prerequisite: ELEN E3401. 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**

*Lect: 3. 3 pts. Instructor to be announced.*  
Prerequisites: ELEN E3201 and E3401, or the equivalents. Electromagnetic energy storage, loss, and transfer. Dynamics of electromechanical systems. Linearization of nonlinear coupled dynamical equations and equivalent circuits. Electromechanical actuators: acoustic, IC processed micromachines. Electromechanical sensors: acoustic, pressure, and acceleration. Thermal sensors: polysilicon thermopiles and bipolar transistor temperature sensors. Electro-optic sensors: visible light, infrared, and x-ray.

**EEME E4601y Digital control systems**

*Lect: 3. 3 pts. Professor Longman.*  
Prerequisite: ELEN E3801 or MECE E3601, or the equivalent. Real-time control using digital computers. Solving scalar and state-space difference equations. Discrete equivalents of continuous systems fed by holds. Z-transfer functions. Creating closed-loop difference equation models by Z-transform and state variable approaches. The Nyquist frequency and sample rate selection. Classical- and modern-based digital control laws. Digital system identification.

**ELEN E4702x Communication theory**

*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.*  
Prerequisite: ELEN E3701 or the equivalent. Wireless communication systems. System design fundamentals. Trunking theory. Mobile radio propagation. Reflection of radio waves. Fading and multipath. Modulation techniques; signal space; probability of error, spread spectrum. Diversity. Multiple access.

**ELEN E4710x An introduction to network engineering**

*Lect: 3. 3 pts. Instructor to be announced.*  
Prerequisites: SIEO E3658 or the equivalent; ELEN E3701 recommended but not required. Covers theoretical fundamentals of network engineering. Topics include theoretical underpinnings of the physical layer; design, protocols, and analysis of the data-link layer and medium access sublayer; design, routing algorithms, and prefix addressing for the network layer, and evaluation of congestion control and connection setup/teardown algorithms for the transport layer.

**ELEN E4720y Networking laboratory**

*Lab: 3. 3 pts. Instructor to be announced.*  
Prerequisites: Knowledge of computer programming plus ELEN E4710 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 E4810x Digital signal processing**

*Lect: 3. 3 pts. Instructor to be announced.*  
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 Nowick.*  
Prerequisites: CSEE W3827 or the equivalent. Introduction to modern computer architecture. Focuses on advanced topics, illustrated by recent case studies. Topics include fundamentals of quantitative analysis, basics of pipelining, advanced pipelining, caches, memories, storage systems, and multiprocessors.

**CSEE W4825y Digital systems design**

*Lect: 3. 3 pts. Professor Unger.*  
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.

**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.

**CSEE W4840 y Embedded systems**

*Lect: 3. 3 pts. Professor Edwards.*  
Prerequisite: CSEE W3827 or the equivalent. Embedded system architecture and programming. 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, 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.

**EEHS E4900y History of telecommunications: from the telegraph to the Internet**

*Lect: 3. 3 pts. Professor Schwartz*

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.

**EEJR E4901y Telecommunications networks and applications**

*Lect: 3. 3 pts. Instructor to be announced.*

Introductory graduate course on telecommunications and information technology for nonengineers. Introduction to packet switching, current and past. Local area networks. Qualitative overview of telecommunications technology: analog-to-digital conversion, with voice as an example; modems; T1 and SONET technology; TCP/IP as example of layered architecture. Current and future telecommunications: new, high-speed access technologies; ATM; IP vs ATM; IP over ATM; cellular wireless telephony; HDTV; satellite systems-LEOS, MEOS, GEOS. Applications: Internet and WWW; JPEG and MPEG video; multimedia communications; the Mobile Journalist Workstation.

**ELEN E4998x and y Intermediate projects in electrical engineering**

*0 to 3 pts. Instructor to be announced.*

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. Instructor to be announced.*

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 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. Numbers rotate as specific topic varies.

**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 contention problems, and modeling of program behaviors.

**ELEN E6201x Linear system theory**

*Lect: 3. 4.5 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 discrete-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.*

(Formerly ELEN E6303.) 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.*

(Formerly ELEN E6306.) 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 amplifiers. Typical applications include wireless transceivers 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 engineering and microwave circuit design. Review of transmission lines. Smith chart, S-parameters, microwave impedance matching, transformation and power combining networks, active and passive microwave devices, S-parameter-based design of RF and microwave amplifiers. A microwave circuit design project (using microwave CAD) is an integral part of the course.

**ELEN E6321y Advanced digital electronic circuits**

*Lect: 3. 3 pts. Instructor to be announced.*

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 interconnect. 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 statistics, Boltzmann transport equation, scattering processes, quantum effect in transport phenomena, 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 E6403y Classical electromagnetic theory**

*Lect: 3. 4.5 pts. Instructor to be announced.*

Prerequisite: one term of undergraduate electromagnetic theory. A mathematical physics approach to electromagnetic phenomena. Poisson, Laplace equations; Green's functions.

Theorems of electrostatics. Multipole expansions. Energy relations and stress tensor. Maxwell's equations in stationary and moving media. The wave equation, energy and momentum theorems, potentials, choice of gauge.

#### **ELEN E6412y Lightwave devices**

*Lect: 2. 3 pts. Instructor to be announced.*

Prerequisite: ELEN E4411. Electro-optics: principles; 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. Introduction to fiber-optic communications: components of the fiberoptic 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 preparation: ELEN E6412. Fiber optics. Guiding, dispersion, attenuation, and nonlinear properties of fibers. Optical modulation schemes. Photonic components, optical amplifiers. Semiconductor laser transmitters. Receiver design. Fiber optic telecommunication links. Nonregenerative transmission using erbium-doped fiber amplifier chains. Coherent detection. Local area networks. Advanced topics in light wave networks.

#### **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, observability. Luenberger observers, pole placement, and linear-quadratic cost controllers.

#### **EEME E6602y Modern control theory**

*Lect: 3. 3 pts. Instructor to be announced.*

Prerequisite: EEME E6601 or EEME 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,  $H_\infty$ , 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 E6610x Optimal control theory**

*Lect: 3. 4.5 pts. Instructor to be announced.*

Prerequisite: ELEN E6201 or EEME E6601. Objectives of optimal control. Continuous and discrete control problems. Calculus of variations: Mayer and Bolza; Pontryagin's maximum principle. Bang-bang and singular controls. Existence of optimal control. Hamilton-Jacobi theory and dynamic programming. Numerical methods. Optimal feedback control regulatory problems. Linear-quadratic-Gaussian estimation. Applications.

#### **EEME E6612x or y Control of nonlinear dynamic systems**

*Lect: 3. 3 pts. Professor Girard.*

Prerequisites: EEME E6601 or ELEN E6201 and an undergraduate controls course. Fundamental properties of nonlinear systems; qualitative analysis of nonlinear systems; nonlinear control-ability and observability; nonlinear stability; zero dynamics and inverse systems; feedback stabilization and linearization; sliding control theory; nonlinear observers; describing functions.

#### **ELEN-STAT W6612y Stochastic control and identification**

*Lect: 3. 4.5 pts. Instructor to be announced.*

Prerequisite: ELEN E6711 or SIEO W6501, or the equivalent. Recommended preparation: a background in linear system theory. State-space description of dynamical systems. Bellman's principle of optimality. Dynamic programming. Linear quadratic regulator with Gaussian noise. Control with partial observations. The controlled Kalman-Bucy filter; the separation principle of estimation and control. Adaptive control and identification. The self-tuning regulator.

#### **ELEN E6711x Stochastic models in information systems**

*Lect: 3. 4.5 pts. Instructor to be announced.*

Prerequisite: SIEO W3658. Foundations: probability 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: communications networks (queueing systems), biological networks (hidden markov models), Bayesian restoration of images (Gibbs fields), and electric networks (random walks).

#### **ELEN E6712x Communication theory, I**

*Lect: 3. 4.5 pts. Instructor to be announced.*

Prerequisite: ELEN E6711, E4702, or E4703, or the equivalent, or the instructor's permission. Channel Characterization detection and Estimation Theory for discrete and continuous time. Performance metrics (bit and symbol error rates, mean-square error) and bounds. Error control (block and convolution codes; Viterbi Algorithm). Baseband pulse transmission (Nyquist Criterion, eye pattern, Intersymbol Interference). Passband data transmission (one- and two-dimensional modulation: AQM, MSK, and DMT). The wireless channel (Rayleigh and Rician fading, coherence time, multipath). Multiple access (Spread Spectrum, CDMA, system capacity).

#### **ELEN E6713y Communication theory, II**

*Lect: 3. 4.5 pts. Instructor to be announced.*

Prerequisite: ELEN E6712. This second half of the two-semester sequence in communication theory continues the coverage of the foundation technologies of modern digital communication systems, including advanced coding techniques (convolutional, trellis, and turbo codes); timing and carrier synchronization (data-directed phase-locked loops); optimum detection (Viterbi algorithm and Volterra nonlinear receivers); adaptive equalization (linear and decision feedback structures, LMS and Kalman adjustment algorithms, blind equalization, combined equalization and

carrier recovery, and effects of limited precision); adaptive echo cancellation; and spatial domain processing (smart antennas). Applications to leading-edge communications systems such as digital wireless (2nd and 3G systems), xDSL, cable modems, Gigabit Ethernet, and advanced fiber optic transmission systems will be emphasized throughout the course.

#### **ELEN E6717x Information theory**

*Lect: 2. 3 pts. Instructor to be announced.*

Prerequisite: SIEO W3658 or a course in stochastic processes. Corequisite: ELEN E6711. Mutual information and entropy. The source coding theorem. The capacity of discrete memoryless channels 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 ELEN E4710, 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 protocols. Data link layer. Network layer: flow and congestion control routing. Transport layer. Typical Local and Metropolitan Area Network standards: Ethernet, DQDB, FDDI. Introduction to internetting. Review of relevant aspects of queueing theory to provide the necessary analytical background.

#### **ELEN E6762y Computer communications networks, II**

*Lect: 2. 3 pts. Professor Maxemchuk.*

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 queueing. Quality of service (QoS) concepts.

#### **ELEN E6768y Topics in telecommunication networks**

*Lect: 3. 4.5 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. Topics vary from year to year to reflect current developments in the field.

#### **ELEN W6781y Topics in modeling and analysis of random phenomena**

*Lect: 3. 4.5 pts. Instructor to be announced.*

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.

**ELEN E6820y Speech and audio processing and recognition**

*Lect: 3. 4.5 pts. Professor Ellis.*  
Prerequisite: ELEN E4810 or the instructor's permission. 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 techniques for speech and other sounds, including hidden Markov models.

**CSEE W6847x or y Distributed concurrent systems**

*Lect: 3. 3 pts. Professor Carloni.*  
Prerequisite: Any COMS W411x, CSEE W48xx, or ELEN W43xx course, or the instructor's permission. An interdisciplinary graduate-level seminar on the design of distributed embedded systems. System robustness in the presence of highly variable communication delays and heterogeneous component behaviors. The study of the enabling technologies (VLSI circuits, communication protocols, embedded processors, RTOSs), models of computation, and design methods. The analysis of modern domain-specific applications, including on-chip microworlds, multiprocessor systems, fault-tolerant architectures, and robust deployment of embedded software. Research challenges such as 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 permission. 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 placement, scheduling, and admission control), compressed video editing, and synchronization issues of stored video/audio signals. Programming projects 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 processing, 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 E6880–6889 x 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 signal processing, image feature extraction, image/video editing and indexing, advanced digital filter design, multirate signal processing, adaptive signal processing, and waveform coding of signals. Topics vary from year to year to reflect current developments in the field.

**ELEN E6900–6909 x 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. May be repeated for credit.

**ELEN E6940y Telecommunication networks control and management**

*Lect: 3. 4.5 pts.*  
Prerequisite: ELEN E6761. Recommended preparation: ELEN E6711. Modeling the architecture of integrated networks. The separation principle, the principle of communication transparency, the principle of asynchronous resource management. Knowledge-based traffic control architectures. Reliability and fault detection. Knowledge representation, entity/relationship models for data representation. Computational models for data abstraction. Knowledge-based monitoring and control. The complexity of resource-sharing algorithms. Performance modeling, traffic classes, network and user performance. Real-time scheduling, routing, flow control, and admission control. Distributed database management systems and expert systems for telecommunications. A programming project is required.

**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 patterning 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. 4.5 pts. Instructor to be announced.*  
Prerequisite: ELEN E4710, 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.

**ELEN E6960y Multimedia networking**

*Lect: 2. Lab: 1. 4.5 pts. Instructor to be announced.*  
Prerequisite: ELEN E6761 or the instructor's permission. Recommended preparation: ELEN E6830y and E6940y. The challenge of supporting multimedia applications and services. Architectural framework for multimedia networking. Modeling traffic and service classes, and quality of service. Qualitative models for resource control and management. Broadband networking and media processor abstractions with QOS guarantees. Binding architectures, resource control, and media synchronization. Media protocols. Managing multimedia services. A programming project using Java is required.

**ELEN E6970x or y Resource allocation and networking games**

*Lect: 3. 4.5 pts. Instructor to be announced.*  
Prerequisites: ELEN E6711 and E6761. Resource allocation in single-class networks: flow control, routing. Multiclass networks: classification of control algorithms, motivation of the game-theoretic formulation, the greedy algorithm. Virtual path bandwidth reservation in network control games. Network design and management applications. Motivation, Braess paradox, architecting network resources and user flows. Network pricing. Internet economics. Project in Java required.

**ELEN E6980x Distributed telecommunication systems: fundamentals and programming**

*Lect: 2. Lab: 1 4.5 pts. Instructor to be announced.*  
Prerequisite: ELEN E6761 or the instructor's permission. Recommended preparation: ELEN E6960 and E6950. Next generation network architectures. IP, open distributed computing, and CORBA. Programmable networks, service creation, and network kernels. Mobile networking and cellular IP protocols. Quality of service in distributed telecommunications systems. Hot topics in distributed systems. Socket, protocol CORBA, and software programming assignments. Term software programming project.

**EEME E8601x 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 to 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 to be approved by the department.*  
Open only to doctoral students who have passed the qualifying examinations. Prerequisite: sub-

mission of an outline of the proposed research for the approval of the faculty member who is to supervise the work of the student.

**ELEN E 9060x 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.

**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 E1101 The digital information age**  
*Lect: 3. 3 pts.*

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 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 E4302x or y Magnetic sensors and instruments for medical imaging**

*Lect: 2. 5, Lab: 0.5. 3 pts.*  
Prerequisite: ELEN E3106, ELEN E3401, or the instructor's permission. Physics of nuclear magnetic resonance (NMR) and superconducting quantum interference device (SQUID). Design and operation of superconducting DC magnet, RF receiver, Josephson junction, and integrated SQUID. Principles of biomedical sensing systems, including Magnetic Resonance Imaging (MRI), SQUID magnetometer, and NMR spectroscopy. Medical image formation and processing.

**ELEN E4332y VLSI design laboratory**  
*Lab: 3. 3 pts.*

Prerequisite: ELEN E4321 or E6316 or EECS E4340. Design of a large-scale deep submicron CMOS 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 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 (filamentary antennas, arrays, aperture radiation, system properties, pattern synthesis); electrodynamics (special relativity, radiation by charged particles, relativistic beams, free electron lasers).

**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; de Vries-Rose square-root law; Weber's law; relation of sensory and communication systems.

**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 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. Numbers rotate as specific topic varies.

**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: the instructor's permission. 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. 4.5 pts.*

Prerequisites: ELEN E3331 and E3801. An axiomatic development of circuit theory. Circuit theorems, circuit topology, general methods of circuit analysis. Normal form characterizations. Scattering characterization and sensitivity function. Basic network synthesis methods: impedance and transfer function realization, multiport realization, approximation techniques.

**ELEN E6261y Computational methods of circuit analysis**

*Lect: 3. 3 pts.*  
Prerequisites: ELEN E3331 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 E3106 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. 4.5 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.*  
(Formerly ELEN E4304.) 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 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.

**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 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 E6920x or y Topics in VLSI systems design**

*Lect: 2. 3 pts.*

Prerequisite: ELEN E4321. Design automation: layout, placement, and routing. Circuit simulation algorithms and optimization of performance and area. Multiprocessor computing systems. Verification of testing. Topics may change from year to year.

**ELEN E8701y Point processes in information and dynamical systems**

*Lect: 3. 4.5 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.

**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 various areas of photonics 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 and Operations Research

313 S. W. Mudd, MC 4704, 212-854-2941  
<http://www.ieor.columbia.edu>



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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.

## 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.

## INDUSTRIAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b> (three tracks, choose one; track jumping is prohibited)	MATH V1101 (3)  Honors math I Honors math I	MATH V1102 (3)  Honors math II Honors math II	MATH V1201 (3)  Linear algebra (3) <sup>2</sup> Honors math III	Linear algebra (3) <sup>2</sup> and ODE (3) ODE (3) Honors math IV and ODE (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) C1601 (3.5) C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	Chemistry or physics lab: PHYS C1493 (3) <b>or</b> PHYS W3081 (2) <b>or</b> CHEM C1500 (3) <b>or</b> CHEM C2507 (3) <b>or</b> CHEM C3085 (4) <b>or</b>	
<b>CHEMISTRY</b> (choose one course)	C1403 (3) <b>or</b> C1404 (3) <b>or</b> C2407 (3) <b>or</b> C3045 (3)			
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ALP0006 (0)	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>	ECON W1105 (4) <b>and</b> W1155 recitation (0) either semester		HUMA C1001, C1101 <b>or</b> V2001 (4)	HUMA C1002, C1102 <b>or</b> V2002 (4)
			HUMA C1121 <b>or</b> C1123 (3) either semester	
<b>FIRST- AND SECOND-YEAR DEPT. REQUIREMENTS</b>	Professional-level course (3) (see page 16)		ECON W2261 (4)	SIEO W3600 (4)
<b>COMPUTER SCIENCE</b>			Computer programming <sup>1</sup> in C <b>or</b> Java (3) either semester	
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>The computer programming requirement may be fulfilled by COMS W1003, W1004, W1007, or W1009.

<sup>2</sup>The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.

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 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

## INDUSTRIAL ENGINEERING: THIRD AND FOURTH YEARS

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES</b>	IEOE E3608 (4) Mathematical prog.  Data structures (3) <sup>1</sup>  IEOE E3106 (3) Stochastic models  IEOE E4409 (3) Industrial info. sys.	IEOE E3402 (4) Production planning  IEOE E4404 (4) Simulation	IEOE E3800 (3) Design project I  IEOE E4003 (3) Industrial econ.  IEOE E4207 (3) Human factors	IEOE E3801 (3) Design project II  IEOE E4405 (3) Prod. scheduling  IEOE E4412 (3) Quality control & mgmt.
<b>INDUSTRIAL ENGINEERING ELECTIVES</b>			Choose two (6 pts. total): IEOE E4210 (3) IEOE E4310 (3) IEOE E4418 (3)	
<b>TECHNICAL ELECTIVES</b>	Choose one (3 pts.): IEOE E4001, E4208, E4307, E4308, E4406, E4700, E4708, MECE E3018, MECE E4408, MECE E4608, or consult faculty adviser			
<b>NONTECH ELECTIVES</b>	Complete 27-point requirement. See page 14 or <a href="http://www.engineering.columbia.edu">http://www.engineering.columbia.edu</a> for details			

<sup>1</sup>The data structures requirement may be fulfilled by COMS W3133, W3134, W3137, or W3139.

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.

## Undergraduate 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 under-

standing 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).

### 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 PROGRAM: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b> (three tracks, choose one; track jumping is prohibited)	MATH V1101 (3)  Honors math I Honors math I	MATH V1102 (3)  Honors math II Honors math II	MATH V1201 (3)  Linear algebra (3) <sup>2</sup> Honors math III	Linear algebra (3) <sup>2</sup> and ODE (3) ODE (3) Honors math IV and ODE (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) C1601 (3.5) C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	Chemistry or physics lab: PHYS C1493 (3) <b>or</b> PHYS W3081 (2) <b>or</b> CHEM C1500 (3) <b>or</b> CHEM C2507 (3) <b>or</b> CHEM C3085 (4) <b>or</b>	
<b>CHEMISTRY</b> (choose one course)	C1403 (3) <b>or</b> C1404 (3) <b>or</b> C2407 (3) <b>or</b> C3045 (3)			
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ALP0006 (0)	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>	ECON W1105 (4) <b>and</b> W1155 recitation (0) either semester		HUMA C1001, C1101 <b>or</b> V2001 (4)	HUMA C1002, C1102 <b>or</b> V2002 (4)
<b>FIRST- AND SECOND- YEAR DEPT. REQUIREMENTS</b>	Professional-level course (3) (see page 16)		ECON W2261 (4)	SIEO W3600 (4)
<b>COMPUTER SCIENCE</b>			Computer programming <sup>1</sup> in C <b>or</b> Java (3) either semester	
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>The computer programming requirement may be fulfilled by COMS W1003, W1004, W1007, or W1009.

<sup>2</sup>The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.

### ENGINEERING AND 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 have no difficulty in adding a minor in economics or computer science to their standard course schedules.

### 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

## OPERATIONS RESEARCH: THIRD AND FOURTH YEARS

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES</b>	IEOR E3608 (4) Mathematical prog.  Data structures (3) <sup>1</sup>  IEOR E3106 (3) Stochastic models  IEOR E4409 (3) Industrial info. sys.	IEOR E3402 (4) Production planning  IEOR E4404 (4) Simulation  IEOR E4600 (3) Applied integer prog.	IEOR E4307 (3) Forecasting  IEOR E4003 (3) Industrial econ.  IEOR E4407 (3) Game theoretic models of operations	IEOR E4405 (3) Prod. scheduling
<b>TECHNICAL ELECTIVES</b>	Choose four electives (12 pts. total); complete list is available at <a href="http://www.ieor.columbia.edu/">http://www.ieor.columbia.edu/</a> . At least two technical electives must be chosen from IEOR			
<b>NONTECH ELECTIVES</b>	Complete 27-point requirement. See page 14 or <a href="http://www.engineering.columbia.edu">http://www.engineering.columbia.edu</a> for details			

<sup>1</sup>The data structures requirement may be fulfilled by COMS W3133, W3134, W3137, or W3139.

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 172 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.

### 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, 330 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

**one elective** in operations research or statistics.

**MATHEMATICS:** Choose one of three tracks.

- V1101, V1102, and V1201** (Calculus I, II, and III), **V2010** (Linear algebra), and **E1210** or **V3027** (Ordinary differential equations);

or

- V1105, V1106, and V1205** (Calculus I, II, and III), **V2010** (Linear algebra), and **E1210**

- or **V3027** (Ordinary differential equations);  
 or  
 3. **V1107, V1108, V1207, V1208, and E1210** or **V3027** (Ordinary differential equations).

#### COMPUTER SCIENCE

**W1003** 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 industrial engineering, operations research, and financial engineering 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.

## ENGINEERING AND MANAGEMENT SYSTEMS PROGRAM: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b> (three tracks, choose one; track jumping is prohibited)	MATH V1102 (3) Honors math I Honors math I	MATH V1102 (3) Honors math II Honors math II	MATH V1201 (3) Linear algebra (3) <sup>2</sup> Honors math III	Linear algebra (3) <sup>2</sup> and ODE (3) ODE (3) Honors math IV and ODE (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) C1601 (3.5) C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	Chemistry or physics lab: PHYS C1493 (3) or PHYS W3081 (2) or CHEM C1500 (3) or CHEM C2507 (3) or CHEM C3085 (4) or	
<b>CHEMISTRY</b>	C1403 (3) or C1404 (3) or C2407 (3) or C3045 (3)			
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ALP0006 (0)	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>	ECON W1105 (4) and W1155 recitation (0) either semester		HUMA C1001, C1101 or V2001 (4)	HUMA C1002, C1102 or V2002 (4)
			HUMA C1121 or C1123 (3) either semester	
<b>FIRST- AND SECOND-YEAR DEPT. REQUIREMENTS</b>	Professional-level course (3) (see page 16)		ECON W2261 (4)	SIEO W3600 (4)
<b>COMPUTER SCIENCE</b>			Computer programming <sup>1</sup> in C or Java (3) either semester	
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>The computer programming requirement may be fulfilled by COMS W1003, W1004, W1007, or W1009.

<sup>2</sup>The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.

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.

### 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

ENGINEERING AND MANAGEMENT SYSTEMS: THIRD AND FOURTH YEARS				
	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES</b>	IEOR E3608 (4) Mathematical prog.	IEOR E3402 (4) Production planning	BUSI F3001 (3) Intro. finance	BUSI F3010 (3) Managerial behavior
	Data structures (3) <sup>1</sup>	IEOR E4409 (3) Industrial info. sys.	IEOR E4003 (3) Industrial econ.	
	IEOR E3106 (3) Stochastic models	ECON W3213 (3) Macroeconomics	IEOR E4404 (4) Simulation	
	ECON W3211 (3) Microeconomics			
<b>ELECTIVES</b>	<b>TECH</b>	Technical and technology electives (12 pts. total) <sup>2</sup>		
	<b>MANAGEMENT</b>	Management electives (9 pts. total): Please consult lists posted on IEOB Web site: <a href="http://www.ieor.columbia.edu">http://www.ieor.columbia.edu</a>		
	<b>NONTECH</b>	Complete 27-point requirement; see page 14 or <a href="http://www.engineering.columbia.edu">http://www.engineering.columbia.edu</a> for details		

<sup>1</sup>The data structures requirement may be fulfilled by COMS W3133, W3134, W3137, or W3139.

<sup>2</sup>At least two technical electives must be chosen from IEOB; the complete list is available at <http://www.ieor.columbia.edu/>.

- 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.

The professional degree of Industrial Engineer requires a minimum of 60 points of graduate credit with at least 30 points beyond the M.S. degree in industrial engineering. The complete 60-point program includes (a) 30 points completed in ten core courses, (b) a concentration of at least four courses, (c) other electives and (possibly) deficiencies. A minimum of twelve courses, providing 36 points of credit, must be industrial engineering courses taken from departmental course offerings or at other institutions where advanced standing is given. A thesis is not required.

#### OPERATIONS RESEARCH

Graduate programs in this area are designed to enable students to concen-

trate 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 stochastic models, as well as substantive areas for application.

M.S. degree programs 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.

M.S. degree programs can be taken on a part-time basis or completed in one year of full-time study. Students planning to complete this program in one year 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.

#### FINANCIAL ENGINEERING

The department offers an 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 (12 courses), which can be taken over a twelve-month period of full-time studies, starting with a Part II six-week summer session (July 5–August 12) and ending with a Part I six-week summer session (June 30) the following year. The requirements include six required core courses and an additional six elective courses (totaling at least 18 points) 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: [http://www.ieor.columbia.edu/grad\\_fe.html](http://www.ieor.columbia.edu/grad_fe.html).

The six required core courses for the financial engineering program are *IEOR E4706*, *IEOR E4707*, *SIEO W4606*, *IEOR E4703*, *IEOR E4007*, and *IEOR E4403*. Electives are chosen with the approval of an adviser.

#### JOINT M.S./M.B.A. DEGREE PROGRAMS

The department and the Graduate School of Business offer joint master's programs in industrial engineering and operations research. Prospective students for these special programs must submit separate applications to the School of Engineering and Applied Science and the Graduate School of Business and be admitted to both schools for entrance into the joint program.

Admissions requirements are the same as those for the regular M.S. programs and for the M.B.A. These joint programs are coordinated so that both degrees can be obtained after five terms of full-time study (30 points in two terms while registered in SEAS and 45 points in three terms while registered in the Graduate School of Business).

Students in joint programs must complete certain courses by the end of their first year of study. Students in the IE or OR joint program should take *IEOR E4000*, *IEOR E4004*, and *SIEO W4150*. If a substantial equivalent has been completed during undergraduate studies, students should consult with a faculty adviser in order to obtain exemption from a required course.

#### 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/phd\\_ieor.html](http://www.ieor.columbia.edu/phd_ieor.html).

## Courses in Industrial Engineering and Operations Research

For up-to-date course offerings, please visit <http://www.ieor.columbia.edu/>.

#### **IEOR E3106y Introduction to operations research: stochastic models**

*Lect: 3. 3 pts. Professor Kou.*

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.

#### **SIEO W3600y Introduction to probability and statistics**

*Lect: 3. Rec: 1. 4 pts. Professor Kou.*

Prerequisite: calculus. Fundamentals of probability and statistics used in engineering and applied science. Probability: random variables, useful distributions, expectations, law of large numbers, central limit theorem. Statistics: point and confidence interval estimation, hypothesis tests, linear regression.

#### **SIEO W3602y Introduction to statistics**

*Lect: 3. Rec: 1. 2 pts. Professor Kou.*

Prerequisite: SIEO W3658 or the equivalent.

Statistics: point and confidence interval estimation, hypothesis tests, linear regression. Note: This course starts in week 8 of the term and is intended to serve the needs of undergraduate students who have completed a course in probability theory. Students registering for this course will join the SIEO W3600 class after the midterm examination period.

#### **IEOR E3608x Introduction to mathematical programming**

*Lect: 3. Rec: 1. 4 pts. Professor Stein.*

Prerequisite: Linear algebra (MATH V2010 or APMA E3101). Introduction to mathematical programming models and computational techniques. Linear programming and the simplex method, dynamic programming, production planning applications.

#### **SIEO W3658x Probability**

*Lect: 3. 3 pts. Professor Coffman.*

Prerequisite: a working knowledge of calculus. Fundamentals of probability theory. Distributions of one or more random variables. Moments. Generating functions. Law of large numbers and central limit theorem.

#### **IEOR E3800x-E3801y Industrial engineering design project, I and II**

*3 pts. Professor Norden.*

Senior industrial engineering group design project. Teams of three to five students formulate and solve current industrial engineering problems in cooperation with local production, service, or government organizations. Oral and written reports required.

#### **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. Professor Gallego.*

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 SIEO W4150) and IEOR E3608 (or IEOR E4001).

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, and s Introduction to operations research: deterministic models**

*Lect: 3. 3 pts. Professor Sethuraman.*

Prerequisite: 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 E4007s 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.

#### **SIEO W4105x and y Probability**

*Lect: 3. 3 pts. x: Professor Dolgoarshinnykh; y: Instructor to be announced.*

Prerequisite: a working knowledge of calculus. Fundamentals, random variables and distribution functions in one or more dimensions; moments, conditional probabilities, and densities; Laplace transforms and characteristic functions. Infinite sequences of random variables; weak and strong laws of large numbers; central limit theorem.

#### **IEOR E4106y Introduction to operations research: stochastic models**

*Lect: 3. 3 pts. Professor Whitt.*

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 and y, and s Introduction to probability and statistics**

*Lect: 3. 3 pts. x: Professor Vecer; y: Professor Gallego.*

Prerequisite: a working knowledge of calculus. Fundamentals of probability theory and statistical inference used in engineering and applied science. Probabilistic models, random variables, useful distributions, expectations, law of large numbers, central limit theorem. Statistical inference: point and confidence interval estimation, hypothesis tests, linear regression.

#### **IEOR E4201x The engineering of management, I**

*Lect: 3. 3 pts. Professor 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.

#### **IEOR E4202y The engineering of management, II**

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

#### **IEOR E4210y Supply chain management**

*Lect: 3. 3 pts. Professor Huh.*

Prerequisite: IEOR 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. Instructor to be announced.*

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.

#### **IEME E4310x The manufacturing enterprise**

*Lect: 3. 3 pts. 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.

#### **IEOR E4403x Advanced engineering and corporate economics**

*Lect: 3. 3 pts. Professor Kachani.*

Prerequisites: SIEO W3600 (or SIEO 4150) and IEOR E3608 (or IEOR 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 Shahabuddin; y: Professor Iyengar.*

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 IEOR E4703 may not register for this course.

#### **IEOR E4405y Production scheduling**

*Lect: 3. 3 pts. Professor Stein.*

Prerequisites: SIEO W3600 or W4150 and IEOR E3608 or W4004, 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: IEOR E3608 or IEOR 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 Huh.*

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-

ple-unit auctions, combinatorial auctions, incentives, and supply chain coordination with contracts. No previous knowledge of game theory is required.

#### **IEOR E4409x and y Industrial information systems**

*Lect: 3. 3 pts. x: Professor Mihaila; y: Professor Shapiro.*

This is a first course in database management systems, teaching database concepts, data modeling, and database design. Concepts and tools will be integrated in a small-group term project by designing and implementing an actual information system. After completing the course students will understand, and be able to use, database system capabilities. Students should be able to specify data requirements, evaluate possible data structures, and implement a working system prototype.

#### **IEOR E4412y Quality control and management**

*Lect: 3. 3 pts. Instructor to be announced.*

Prerequisite: SIEO W3600 or SIEO 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 instructor's permission. Introduces quantitative techniques and state-of-the-art practice of operations 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, including air, urban and highway traffic, rail, and maritime 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 integrated logistics and transportation systems and studies the underlying principles governing transportation planning, investment and operations.

#### **IEOR E4500y Applications programming for OR**

*Lect: 2.5. 3 pts. Professor Bienstock.*

Prerequisites: Programming in Java, C, or C++ and the instructor's approval. In this course we will take a hands-on approach to developing computer applications for OR and FE. Beginning with basic programs, we will work our way to full-blown systems with graphical interfaces that exercise important uses of operations research and financial engineering. Examples: simulation of stock price evolution, tracking and evaluation of a stock portfolio, simula-

tion of a transportation system, optimization of an inventory system. In the course of developing these applications, we will review topics of interest to OR/FE in a holistic fashion.

#### **IEOR E4600y Applied integer programming**

*Lect: 3. 3 pts. Professor Iyengar.*

Prerequisites: IEOR E3608 and E4004, linear algebra (MATH V2010 or APMA E3101), and a working knowledge of computer programming. Applications of mathematical programming techniques, especially integer programming, with emphasis on software implementation. Typical applications: capacity expansion, network design, and scheduling.

#### **SIEO W4606x and s Elementary stochastic processes**

*Lect: 3. 3 pts. s: Professor Whitt; x: Professor Yao.*

Prerequisite: IEOR E3106 or 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 E4700x Introduction to financial engineering**

*Lect: 3. 3 pts. Professor Sigman.*

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 E4703x Monte Carlo simulation**

*Lect: 3. 3 pts. Professor Shahabuddin.*

Prerequisite: SIEO W4606 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 IEOR E4404 may not register for this course.

#### **IEOR E4705x Studies in operations research**

*Lect: 3. 3 pts. Professor Riccio.*

Prerequisites: IEOR E3608 (or SIEO 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 Financial engineering: discrete-time asset pricing**

*Lect: 3. 3 pts. Professor Iyengar.*

Prerequisites: SIEO W4150 and linear algebra (MATH V2010 or APMA E3101). Corequisites: IEOR E4007 and SIEO 4606 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**

*Lect: 3. 3 pts. Professor Yao.*

Prerequisite: SIEO W4606. Corequisite: IEOR E4706. Modeling, analysis, and computation of derivative securities. Applications of stochastic calculus and stochastic differential equations. Numerical techniques: finite-difference, binomial method, and Monte Carlo.

#### **IEOR E4708y Financial engineering topics**

*Lect: 3. 3 pts. Professor Derman.*

Prerequisites: SIEO W4606 and IEOR E4706. Corequisite: IEOR E4703. 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 E4709x Data analysis for financial engineering**

*Lect: 3. 3 pts. Professor Kou.*

Prerequisite: SIEO W4606. Corequisite: IEOR E4706. Empirical analysis of asset prices: heavy tails, test of the predictability of stock returns. Financial time series: ARMA, stochastic volatility, and GARCH models. Regression models: linear regression and test of CAPM, nonlinear regression and fitting of term structures.

#### **IEOR E4718y Topics in derivatives pricing**

*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.

#### **SIEO W4801x Introduction to property-liability insurance models**

*Lect: 3. 3 pts. Professor Venter.*

Prerequisites: IEOR E4007 and SIEO W4606, or the instructor's permission. Positive-valued distributions used in property-liability insurance. Empirical approximations. Estimation by moment and percentile matching, minimum chi-square, and maximum likelihood. Interval estimates of parameters. Adjusting estimates for data restrictions. Integer-valued distributions: building families of and effects of parameters.

#### **SIEO W4802y Introduction to life insurance and aggregate loss models**

*Lect: 3. 3 pts. Professor Venter.*

Prerequisites: IEOR E4007 and SIEO W4606, 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 E4998y Managing technological innovation**

*Lect: 3. 3 pts. Instructor to be announced.*  
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. Instructor to be announced.*  
Prerequisite: IEOR E4004. Classification of deterministic scheduling models. Single machine, parallel machines, flow shops, and job shops. Makespan, flow time, sum of weighted tardinesses. Applications of dynamic programming and branch and bound.

**IEOR E6403y Routing**

*Lect: 2. 2 or 3 pts. Instructor to be announced.*  
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. Instructor to be announced.*  
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.

**MSIE W6410x Logistics and distribution management**

*Lect: 2. 3 pts. Instructor to be announced.*  
Prerequisite: IEOR E4004. Models are studied for problems arising in the planning of the logistics of multi-echelon systems. Focus on the following operational and strategic problems: (1) facility location, (2) vehicle routing, (3) inventory allocation, (4) capacity expansion. Emphasis on devices to integrate these areas. Case studies and applications.

**SIEO W6501x Stochastic processes and applications, I**

*Lect: 2.5. 3 pts. Professor Vecer.*  
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 W6502y Stochastic processes and applications, II**

*Lect: 2.5. 3 pts. Instructor to be announced.*

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. Instructor to be announced.*  
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**

*Lect: 2.5. 3 pts. Professor Beinstock.*  
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. Instructor to be announced.*  
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. Professor Bienstock.*  
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: SIEO W4606 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**

*Lect: 2. 3 pts. Professor Stein.*  
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.*  
Prerequisite: linear algebra. Theory and geometry of linear programming. The simplex method. Duality theory, sensitivity analysis, column generation and decomposition. Interior point methods. Introduction to nonlinear optimization: convexity, optimality conditions, steepest descent and Newton's method, active set and barrier methods.

**IEOR E6614y Optimization, II**

*Lect: 3. 4.5 pts. Professor Stein.*  
Prerequisite: linear algebra. An introduction to combinatorial optimization, network flows and discrete algorithms. Shortest path problems, maximum flow problems. Matching problems, bipartite and cardinality nonbipartite. Introduction to discrete algorithms and complexity theory: NP-completeness and approximation algorithms

**IEOR E6702x Reliability theory**

*Lect: 2. 3 pts. Instructor to be announced.*  
Prerequisites: SIEO W4606 or IEOR 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 E6703y Advanced financial engineering**

*Lect: 2. 3 pts. Professor Haugh.*  
Prerequisites: IEOR E4106 or SIEO W4606, and SIEO W4150. Review of basic mathematics, including renewal theory and stochastic calculus. Martingale approach to Black-Scholes formula. Optimal stopping and American options. Pricing of continuous and discrete exotic options. Term struc-

ture models and pricing of bond options. Jump diffusion models. Applications, including pricing of real and electricity options and hedging of real options.

**IEOR E6704y Queueing theory and applications**

*Lect: 2. 3 pts. Professor Sigman.*

Prerequisite: SIEO W4606 or IEOR E4106.

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 E4106 or SIEO W4606. 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's 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**

*Lect: 2. 3 pts. Professor Whitt.*

Prerequisites: IEOR E4004 and E4404, and SIEO W4606. 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: SIEO W4606 or the equivalent. 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 and discrete event simulation**

*Lect: 2. 3 pts. Instructor to be announced.*

Prerequisites: SIEO W4606 or IEOR E4106, 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 adviser'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.*

Before registering, the student must submit an outline of the proposed work for approval by the supervisor and the chair of the Department. Advanced study in a specialized field under the supervision of a member of the department staff. This course may be repeated for credit.

**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

<http://www.apam.columbia.edu>

<http://www.seas.columbia.edu/matsci>

IN CHARGE OF  
MATERIALS SCIENCE  
AND ENGINEERING  
Professor James S. Im  
1106 S. W. Mudd

IN CHARGE OF SOLID-  
STATE SCIENCE AND  
ENGINEERING  
Professor Siu-Wai Chan  
1136 S. W. Mudd  
Professor Irving P.  
Herman  
200 S. W. Mudd

COMMITTEE ON  
MATERIALS SCIENCE  
AND ENGINEERING/  
SOLID-STATE SCIENCE  
AND ENGINEERING  
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Science

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Engineering  
Yasutomo Uemura  
Professor of Physics  
Wen I. Wang  
Professor of Electrical  
Engineering

**M**aterials 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 (EAEE) 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, Durning, Flynn, Koberstein, O'Shaughnessy, and Turro from Chemical Engineering; Duby, Somasundaran, and Themelis from EAEE; 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 thin films to nanocrystals. This involves techniques such as deposition; 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.

MATERIALS SCIENCE AND ENGINEERING PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS<sup>1</sup></b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and ODE (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) C1601 (3.5) C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	C1403 (3) C2601 (3.5) Lab W3081 (2)	C1494 (3) Lab C2699 (3)
<b>CHEMISTRY</b> (three tracks, choose one)	C1403 (3.5) Lab C1500 (2) either semester C2407 (4) C3045 (3)	C1404 (3) C2507 (3) C3046 (3), Lab C2507 (3)	C3545 (3)	
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ALP0006 (0)	C1010 (3) Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101 or V2001 (4) HUMA C1121 (4) or C1123 (3)	HUMA C1002, C1102, or V2002 (4) ECON W1105 (4) and W1155 recitation (0)
<b>REQUIRED TECH ELECTIVES</b>	(3) Student's choice, see list of first-and second-year technical electives (professional-level courses; see page 16)			
<b>COMPUTER SCIENCE</b>	A computer language of the student's choice at the 1000 level or higher			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>Students with advanced standing may start the calculus sequence at a higher level.

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 technolo-

gies. 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; and deposition and characterization of magnetic thin films. 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

Among the facilities in materials science and engineering are an acoustical apparatus for studying internal friction (ultrasonic attenuation) over a very wide range of frequencies and cognate equipment for observing dielectric relaxations. A number of modern microscopes, including scanning surface probe optical, transmission electron, and scanning electron with energy dispersive analytical capability, together with a modernized sample preparation lab, facilitate observations at all scales of interest from the atomic to the bulk. Modern X-ray and mechanical testing equipment is also available. Materials are prepared and processed in a variety of ways, including mechanical working, induction melting, electron-beam evaporation,

## MATERIALS SCIENCE AND ENGINEERING: THIRD AND FOURTH YEARS

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES</b>	MSAE E3103 (3) Elements of mat. sci.  MSAE E 3111 (3) Thermodynamics, kinetic theory, and statistical mechanics  ENME E3113 (3) Mechanics of solids	MSAE E3104 (3) Laboratory in mat. sci.  MSAE E3141 (3) Processing of metals and semiconductors  MSAE E3142 (3) <sup>2</sup> Processing of ceramics and polymers	EAEE E4900 (3) Applied transport and chemical rate phenomena  MSAE E4101 (3) Structural analysis of materials  MSAE E4206 (3) Electronic and magnetic properties of solids	MSAE E3156 (3) Design project  MSAE E4202 (3) Thermodynamics and reactions in solids  MSAE E4215 (3) Mechanical behavior of materials
<b>ELECTIVES</b>	6 points <sup>1</sup>	6 points <sup>1</sup>	6 points <sup>1</sup>	6 points <sup>1</sup>
<b>TOTAL POINTS</b>	15	15	15	15

<sup>1</sup>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.

<sup>2</sup>Juniors substitute E4132 for E3142 when offered.

plasma sputtering, and laser ablation and recrystallization.

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; 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, *APCH E4252: Introduction to surface and colloidal chemistry* should also be considered by students interested in biomaterials and environmental materials.

#### Type A electives are:

**CHEE E4530:** Corrosion of metals

**CHEE E4252:** Introduction to surface and colloidal science

**BMEN E3310:** Solid biomechanics

**MSAE E4207:** Lattice vibrations and crystal defects

**MSAE E4250:** Ceramics and composites

**ELEN E4944:** Principles of device microfabrication

**Type B electives are:**

**BIOMATERIALS**

- BMEN E4301:** Structure, mechanics, and adaptation of bone
- BMEN E4501:** Tissue engineering, I: biological tissue substitutes
- BMEN E4502:** Tissue engineering, II: extracorporeal systems and implantable devices

**ELECTRONIC MATERIALS**

- APPH E3100:** Introduction to quantum mechanics
- ELEN E3000:** Introduction to circuits, systems, and electronics
- ELEN E3106:** Solid-state devices and materials
- ELEN E4301:** Introduction to semiconductor devices

**ENVIRONMENTAL MATERIALS**

- EAAE E4001:** Industrial ecology of Earth resources
- EAAE E4160:** Solid and hazardous waste management

**MECHANICAL PROPERTIES OF MATERIALS**

- ENME-MECE E3105:** Engineering mechanics
- 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 E4050:** Principles of industrial electrochemistry
- CHEE E4252:** Introduction to surface and colloidal chemistry
- APMA E4400:** Introduction to biophysical modeling
- 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 E6273*) 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 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 submit a written proposal within one to two years of passing the qualifying examination 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 thin films, oxide thin 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  $T_c$  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 regis-

tered. However, the bulk of the program for the specialty will be arranged in consultation with a member of the interdepartmental Committee on Materials Science and Engineering/Solid-State Science and Engineering. At the end of the first year of graduate study, doctoral candidates are required to take a comprehensive written examination concentrating on solid-state science and engineering.

The following are regarded as core courses of the specialty:

- 
- APPH E4100:** Quantum physics of matter  
**APPH E4112:** Laser physics  
**APPH-MSAE E6081-E6082:** Solid state physics, I and II
- 
- CHEM G4230:** Statistical thermodynamics
- 
- or
- 
- CHAP E4120:** Statistical mechanics  
**ELEN E4301:** Introduction to semiconductor devices  
**ELEN E4944:** Principles of device microfabrication  
**ELEN E6331-E6332:** Principles of semiconductor physics  
**ELEN E6403:** Classical electromagnetic theory
- 
- or
- 
- PHYS G6092:** Electromagnetic theory, I  
**MSAE E4206:** Electronic and magnetic properties of solids  
**MSAE E4207:** Lattice vibrations and crystal defects  
**MSAE E6220:** Crystal physics  
**MSAE E6240:** Impurities and defects in semiconductor materials  
**MSAE E6241:** Theory of solids  
**PHYS G6018:** Physics of the solid state  
**PHYS G6037:** Quantum mechanics
- 

## 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 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.

#### **MSAE E3103x Elements of materials science**

*Lect: 3. 3 pts. Professor Noyan.*

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 O'Brien.*

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 Marshall.*

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 Duby.*

Prerequisite: MSAE E3103 or the 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.

#### **MSAE E3142y Processing of ceramics and polymers**

*Lect: 3. 3 pts. Professor O'Brien.*

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 and y Design project**

*3 pts. Members of the faculty.*

Prerequisite: senior standing. May be repeated with the permission of the undergraduate adviser. A design problem in materials science or metal-

lurgical engineering selected jointly by the student and a professor in the department. The project requires research by the student, directed reading, regular conferences with the professor in charge, and a written report.

#### **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 submission of an acceptable thesis or final report.

#### **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 characterization and analysis of crystalline defects.

#### **MSAE E4132y Fundamentals of polymers and ceramics**

*Lect: 3. 3 pts. Professor O'Brien.*

Prerequisite: MSAE E3103 or the instructor's permission. The science and engineering of polymer, ceramic, and composite inorganic materials. Fundamental aspects of structure, processing, and properties. Polymers: classification, synthesis, elastomers, thermoplastics, thermosets. Ceramics: crystal structure, morphology, classification, oxides, nitrides, carbides, silicates. Electrical, mechanical, thermal, and optical properties. 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 compounds 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 electronic and magnetic properties of materials, oriented toward materials for solid-state devices. Dielectric and magnetic properties, ferroelectrics and ferromagnets. Conductivity and superconductivity. Electronic band theory of solids: classification of metals, insulators, and semiconductors. Materials in devices: examples from semiconductor 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 properties. Elastic waves in solids. Phonons and lattice 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 elastic-plastic concepts introduced to explain work hardening, various materials-strengthening mechanisms, ductility, and toughness. Macroscopic and microstructural aspects of brittle and ductile fracture mechanics, creep and fatigue phenomena. Case studies used throughout, 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 materials. Structure, composition, and classification. Preparation: synthesis and processing of ceramics; modern techniques; crystal growth and reaction kinetics. The properties of ceramics and composites: structure-property relations; electrical, mechanical, thermal, and optical properties. Common and advanced technological applications 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 so conducted as to fulfill particular needs of special students.

#### **MSAE E6020y Electronic ceramics**

*Lect: 3. 3 pts. Offered in alternate years.*

*Not given in 2005–2006.*

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: 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; 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. 3pts. Professor Aleiner.*

Prerequisite: MSAE E6081x 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.

**MSAE E6090x Nanotechnology**

*Lect. 3. 3 pts. Offered in alternate years.*

*Professor O'Brien.*

Prerequisites: APPH E3100 and CHEM C1404, or equivalent 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, properties of materials as a function of size, self-assembly, nanostructured materials. Nanoscale films and composites. Devices and applications. The "top down" manufacturing paradigm; prospects for the future. Molecular engineering, molecular electronics, nanofabrication, bionanotechnology. Imaging and manipulating at the atomic scale. Nanotechnology in industry.

**APPH E6091y Magnetism and magnetic materials**

*Lect: 3. 3 pts. Offered in alternate years.*

*Not given in 2005–2006.*

Prerequisite: MSAE E4206, APPH E6081, or the equivalent. Types of magnetism. Band theory of ferromagnetism. Magnetic metals, insulators, and semiconductors. Magnetic nanostructures: ultrathin films, superlattices, and particles. Surface magnetism and spectroscopies. High-speed magnetization dynamics. Spin electronics.

**MSAE E6120x Grain boundaries and interfaces**

*Lect: 2. 3 pts. Offered in alternate years.*

*Not given in 2005–2006.*

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.*

*Not given in 2005–2006.*

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.*

*Not given in 2005–2006.*

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.*

*Not given in 2005–2006.*

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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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 E6230x Kinetics of phase transformations**

*Lect: 3. 3 pts. Offered in alternate years.*

*Professor Im.*

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 E6240x Impurities and defects in semiconductor materials**

*Lect: 2. 3 pts. Offered in alternate years.*

*Professor Im.*

Prerequisite: MSAE E4206 or ELEN E4301. Recommended preparation: MSAE E4207.

Effects and characterization of impurities and defects in semiconductors, their implications for electrical and optical properties, and use of such properties for material characterization. Inclusion of interactions among impurities, defects, interfaces, carriers, and photons, and consequences of interactions such as compensation, pair luminescence, recombination-enhanced defect reactions, and modulation-doped heterostructures.

**MSAE E6241y Theory of solids**

*Lect: 3. 3 pts. Offered in alternate years. Not given in 2005–2006.*

Prerequisite: ELEN E4111 or MSAE E4206, or the instructor's permission. The theory of solids from a fundamental point of view. Topics include tight binding and band theories of electrons in metals and insulators, structure and cohesion of solids, electron scattering by phonons and defects, the quantum theory of superconductivity and of magnetism.

**MSAE E6251y Thin films and layers**

*Lect: 3. 3 pts. Instructor to be announced.*

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.*

*Not given in 2005–2006.*

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**

*0 to 15 pts. Members of the faculty.*

Prerequisite: the qualifying examination for the doctorate. Required of doctoral candidates.

**MSAE E9309x and y, and s Proposal of research for the doctorate**

*0 to 3 pts. Members of the faculty.*

A written report prepared by the prospective doctoral candidate defining the proposed research for the dissertation, and oral defense of the proposal at the time of the qualifying examinations.

**MSAE E9800x 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:**


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**CHEE E4050:** Principles of industrial electro-chemistry

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**CHEN E4201:** Engineering applications of electro chemistry

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**CHEE E4252:** Introduction to surface and colloid chemistry

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**CHEE E4530:** Corrosion of metals

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**CHEN E4620:** Introduction to polymer science

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**CHEN E4630:** Polymer laboratory

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**CIEN E4212:** Structural assessment

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**CIEN E4332:** Finite element analysis, I

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**CHEN E3110:** Transport phenomena, I: theory and methodology of rate phenomena

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**EAAE E4011:** Industrial ecology of manufacturing

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**EAAE E4160:** Solid and hazardous waste management

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**EAAE E4900:** Applied transport and chemical rate phenomena

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**EAAE E6228:** Theory of flotation

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**ENME E3113:** Mechanics of solids

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**ENME E6315:** Theory of elasticity

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# Mechanical Engineering

220 S. W. Mudd, MC 4703, 212-854-2965  
<http://www.columbia.edu/cu/mechanical>



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MANAGER OF  
INSTRUCTIONAL  
LABORATORIES  
Robert G. Stark



**M**echanical 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); microelectro-

mechanical 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 tech-

MECHANICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS STANDARD TRACK				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) ————— C1601 (3.5) ————— C2801 (4.5) —————	C1402 (3) ————— C1602 (3.5) ————— C2802 (4.5) —————	→ C1403 (3) <sup>3</sup> → C2601 (3.5) <sup>3</sup>	
<b>CHEMISTRY</b>	one semester lecture (3–4) C1403 or C1404 or C3045 or C2407	Lab C1500 (3) <sup>1</sup>		
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ————— ALP0006 (0) —————	→ C1010 (3) → Z1003 (4)		
<b>REQUIRED NONTECHNICAL ELECTIVES</b>			HUMA C1001, C1101, or V2001 (4) HUMA C1121 or C1123 (3)	HUMA C1002, C1102, or V2002 (4) ECON W1105 (4) and W1155 recitation (0)
<b>REQUIRED TECHNICAL COURSES</b>	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see page 16) <sup>2</sup>		ENME-MECE E3105 (4) either semester	
<b>COMPUTER SCIENCE</b>	Computer language: W1003 (3) or W1004 (3) any semester			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>May substitute Physics Lab C1493 (3), C1494 (3), or W3081 (2).

<sup>2</sup>ELEN E1201 (see semester VI) satisfies this requirement. However, MECE E1001 is strongly encouraged.

<sup>3</sup>May substitute BIOL W2001 or higher.

nical 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 constraints, 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 are in the areas of controls and robotics, energy and micro-power 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 meso-length scales. 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

## MECHANICAL ENGINEERING: THIRD AND FOURTH YEARS STANDARD TRACK

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES</b>	MECE E3018 (3) <sup>1</sup> Lab I	MECE E3028 (3) <sup>1</sup> Lab II	MECE E3038 (3) <sup>1</sup> Lab III	MECE E3410 (4) Engineering design
	MECE E3100 (3) Fluids I	MECE E3408 (3) Graphics & design	MECE E3409 (3) CAD	
	MECE E 3301 (3) Thermodynamics	MECE E3311 (3) Heat transfer	MECE E3601 (3) Classical control sys.	
	ENME E3105 (4) <sup>2</sup> Mechanics	MECE E4608 (3) Manufacturing proc.		
	ENME E3133 (3) Mechanics of solids	ELEN E1201 (3.5) Intro. elec. eng.		
<b>TECHNICAL ELECTIVES</b>			6 points	6 points
<b>NONTECHNICAL ELECTIVES</b>	3 points		3 points	6 points
<b>TOTAL POINTS</b>	15	15.5	18	16

<sup>1</sup>In 2005–2006 this lab sequence starts in Semester VI.

<sup>2</sup>Strongly recommended to be taken in Semester III or IV.

power-law hardening. In addition, the role that the constitutive relations play in the fracture and failure of materials is emphasized. (Kysar)

### Control, Robotics, 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)

Systems engineering research is also being conducted with applications to intelligent systems, hybrid/distributed/embedded systems, autonomous vehicles, mobile robots, air and ocean robots with supervisory control, nonlinear and sliding mode control, biocontrols, and artificial intelligence. (Girard)

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 and environmentally conscious manufacturing. Investigations are being carried out in laser micromachining; laser forming of sheet metal; microscale laser shock-peening, material processing using improved laser-beam quality; cryogenic lubrication; micro-temperature manipulation of metal-cutting processes; development of new economical and ecological cryogenic machining and milling systems; and such other nontraditional manufacturing methods as controlled fire polishing for glass scratchitti removal. Both numerical and experimental work is conducted using state-of-the-art equipment, instruments,

MECHANICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS EARLY DECISION TRACK				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3)
<b>PHYSICS</b> (three tracks, choose one)	C1401 (3) ————— C1601 (3.5) ————— C2801 (4.5) —————	C1402 (3) ————— C1602 (3.5) ————— C2802 (4.5) —————	—————> C1403 (3) <sup>3</sup> —————> C2601 (3.5) <sup>3</sup>	
<b>CHEMISTRY</b>	one semester lecture (3–4) C1403 or C1404 or C3045 or C2407	Lab C1500 (3) <sup>2</sup>		
<b>ENGLISH COMPOSITION</b> (three tracks, choose one)	C1010 (3) Z1003 (4) ————— ALP0006 (4.5) —————	—————> C1010 (3) —————> Z1003 (4)		
<b>REQUIRED NONTECHNICAL COURSES</b>			HUMA C1001, C1101 or V2001 (4)	HUMA C1002, C1102, or V2002 (4)
<b>REQUIRED TECHNICAL COURSES</b>	(3) Student's choice, see list of first- and second- year technical electives (professional-level courses; see page 16) <sup>1</sup>	ENME E3105 (4) Mechanics	ENME E3113 (3) Mechanics of solids	ELEN E1201 (3.5) Intro. elec. eng.  MECE E3408 (3) Graphics & design
<b>COMPUTER SCIENCE</b>	Computer language: W1003 (3) or W1004 (3) any semester			
<b>PHYSICAL EDUCATION</b>	C1001 (1)	C1002 (1)		
<b>GATEWAY LAB</b>	E1102 (4) either semester			

<sup>1</sup>ELEN E1201 (see semester VI) satisfies this requirement. However, MECE E1001 is strongly encouraged.

<sup>2</sup>May substitute Physics Lab C1493 (3), C1494 (3), or W3081 (2).

<sup>3</sup>May substitute BIOL W2001 or higher.

and computing facilities. Close ties with industry have been established for collaborative efforts. (Yao)

Some of the work in the area of design deals with analytical, experimental, and computational mechanics of machines, vibration analysis of rotating machines, and new automatic transmission principles.

**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 micro-siting and performance evaluation of energy and environmental systems. The design and testing of components

and systems for micro-power 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 interest are concerned with the investigation fluid mechanics of inkjet printing, drop on demand, and the suppression of satellite droplets, shock wave propagation, and remediation in high-frequency printing systems. (Chevray, Modi)

**MEMS and Nanotechnology.** In these areas research activities focus on power generation systems, nanostructures for

photonics, fuel cells and photovoltaics; 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. (Hone, Wong, Modi)

Research in the area of nanotechnology focuses on nanomaterials such as nanotubes and nanowires and their applications, especially in nanoelectromechanical systems (NEMS). A laboratory 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 is available. This effort will seek to optimize the fabrication, readout, and sen-

## MECHANICAL ENGINEERING: THIRD AND FOURTH YEARS EARLY DECISION TRACK

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
<b>REQUIRED COURSES</b>	MECE E3018 (3) <sup>1</sup> Lab I  MECE E3100 (3) Fluids I  MECE E 3301 (3) Thermodynamics	MECE E3028 (3) <sup>1</sup> Lab II  MECE E3311 (3) Heat transfer  MECE E4608 (3) Manufacturing proc.	MECE E3038 (3) <sup>1</sup> Lab III  MECE E3409 (3) CAD  MECE E3601 (3) Classical control sys.	MECE E3410 (4) Engineering design
<b>REQUIRED NONTECHNICAL COURSES</b>	HUMA C1121 or C1123 (3)	ECON W1105 (4) and W1155 recitation (0)		
<b>TECHNICAL ELECTIVES</b>		3 points	3 points	6 points
<b>NONTECHNICAL ELECTIVES</b>	3 points		3 points	6 points
<b>TOTAL POINTS</b>	15	16	15	16

<sup>1</sup>In 2005–2006 this lab sequence starts in Semester VI.

sitivity of these devices for numerous applications, such as sensitive detection of mass, charge, and magnetic resonance. (Hone, Wong, Modi)

In the area of photonic structures, the effort focuses on photonic band gap microcavities, NEMS, nanoscale optical physics, integrated photonics, and derived applications toward single biomolecular experiments. (Wong)

### 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 servohy-

draulic 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 center (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 cir-

uits 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 protoboard 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 (<http://www.columbia.edu/cu/mechanical/research.htm>). 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 (<http://www.columbia.edu/cu/lweb>). E-mail and computing services are maintained by Academic Information Systems (AcIS) (<http://www.columbia.edu/acis>).

## Undergraduate Program

The objectives of the undergraduate program in mechanical engineering are as follows:

1. To prepare our students for a career in mechanical engineering and simultaneously to provide a basis for a wide range of other career paths, such as business, management, medicine, law, or education.
2. To provide our students with the necessary tools (e.g., mathematics, science, and engineering) to understand the basic underlying principles of engineering devices and systems.
3. To teach our students the basic concepts and skills needed for creative design and to provide exposure to modern experimental techniques and tools of engineering design, analysis, and manufacturing.
4. To place the technical education within the wider context of a liberal

arts education; to instill in our students an understanding of ethical issues and professional responsibilities; and to prepare them for effective oral and written communication.

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.

## 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 mini-

mum 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.
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 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 require-

ment 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 3 pts. Professor Kysar and the staff.*  
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 E2400x 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 undergraduate students only. A laboratory fee of \$50 is collected.

**MECE E3018x 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 \$25 is collected.

**MECE E3028x and y Mechanical engineering laboratory, II**

*Lect: 1. Lab: 5. 3 pts. Professor Hone.*  
Selected intermediate experiments in power and energy conversion, heat transfer, and solid and fluid mechanics. A lab fee of \$25 is collected.

**MECE E3038y Mechanical engineering laboratory, III**

*Lect: 1. Lab: 5. 3 pts. Professor Wong.*  
Selected advanced experiments in fluid mechanics, heat transfer, and energy conversion. A lab fee of \$25 is collected.

**MECE E3100x Introduction to mechanics of fluids**

*Lect: 3. 3 pts. Professor Chevray.*  
Prerequisite: ENME E3105. Basic continuum concepts. Liquids and gases in static equilibrium. Continuity equation. Twodimensional kinematics. Equation of motion. Bernoulli's equation and applications. Equations of energy and angular momentum. Dimensional analysis. Two-dimensional laminar flow. Pipe flow, laminar, and turbulent. Elements of compressible flow.

**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 Wong.*  
Steady and unsteady heat conduction. Radiative heat transfer. Internal and external forced and free convective heat transfer. Change of phase. Heat exchangers.

**MECE E3401x Mechanics of machines**

*Lect: 3. 3 pts. Professor Simaan.*  
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. Professor Simaan.*  
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 Ateshian.*  
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 Girard.*  
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.

**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 mechanical engineering**

*3 pts. Professors Ateshian, Chevray, Girard, Hone, Kysar, Longman, Modi, Simaan, Wong, and Yao. Hours individually arranged.*  
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 E3998 x and y Projects in mechanical engineering**

*1 to 3 pts. Professors Ateshian, Chevray, Girard, Hone, Kysar, Longman, Modi, Simaan, 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 \$25 is collected.

**MECE E4100y Mechanics of fluids**

*Lect: 3. 3 pts. Instructor to be announced.*  
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 E4302y Advanced thermodynamics**

*Lect: 3. 3 pts. Professor Tiliakos.*  
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**

*Lect: 3. 3 pts. Not given in 2005–2006.*  
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.

**MECE E4312y Design of thermal systems**

*Lect: 3. 3 pts. Professor Naraghi.*  
Prerequisite: MECE E3311. Fundamentals of convection, boiling, condensation, melting, solidification. Extended surfaces of arbitrary and specific shapes. Heat exchangers: basic methods of thermal design, flow arrangements, effects of

variable conditions. Shell-and-tube. Plate heat exchangers. Design procedures for process heat exchangers. Rating and sizing of compact heat exchangers. Applications to HVAC systems design, indoor air quality control, electronics packaging, and solar thermal energy systems design.

**MECE E4314y Energy dynamics of green buildings**

*Lect: 3. 3 pts. Not given in 2005–2006.*

Prerequisites: MECE E3301 and MECE E3311. Introduction to analysis and design of heating, ventilating, and air-conditioning systems. Heating and cooling loads. Humidity control. Solar gain and passive solar design. Global energy implications. Green buildings. Building-integrated photovoltaics. Roof-mounted gardens and greenhouses. Financial assessment tools and case studies. Open to mechanical engineering graduate students only.

**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.*

Prerequisite: MECE E3100. Fluid friction. The hydrodynamic and hydrostatic theories of lubrication. Plane surfaces and thrust bearing design. Journal bearings; load-carrying capacity and temperature rise. Principles of bearing design for efficient lubrication. Oil flow in bearings. Bearings with semi-fluid lubrication. Fluid and nonfluid lubricants. Bearing materials.

**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 E4601y Digital control systems**

*Lect: 3. 3 pts. Instructor to be announced.*

Prerequisite: MECE E3601 or ELEN E3202. Real-time control using digital computers.

Solving scalar and state-space difference equations. Discrete equivalents of continuous systems fed by holds. Z-transform functions. Creating closed-loop difference equation models by Z-transform and state variable approaches. The Nyquist frequency and sample rate selection. Classical- and modern-based digital control laws. Digital system identification.

**MECE E4602y Introduction to robotics**

*Lect: 3. 3 pts. Professor Longman.*

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. Not given in 2005–2006.*

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 Yao.*

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, rapid 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. Not given in 2005–2006.*

Advanced analysis and modeling of the muscu-

loskeletal 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 E4999x and y (sect. 001) Curricular practical training**

*1 pt. Professor Modi.*

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. Instructor to be announced.*

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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

Prerequisites: MECE E3100 and E3311; FORTRAN. Mathematical description of pertinent physical phenomena. Basics of finite-difference methods of discretization, explicit and implicit schemes, grid sizes, stability, and convergence. Solution of algebraic equations, relaxation. Heat conduction. Incompressible fluid flow, stream function-vorticity formulation. Forced and natural convection. Use of primitive variables, turbulence modeling, and coordinate transformations.

**MECE E6104y Case studies in computational fluid dynamics**

*Lect: 3. 3 pts. Professor Modi and 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 E6200y Turbulence**

*Lect: 3. 3 pts. Not given in 2005–2006.*

Prerequisite: MECE E6100. Introductory concepts and statistical description. Kinematics of random velocity fields, dynamics of vorticity, and scalar quantities. Transport processes in a turbulent medium. Turbulent shear flows: deterministic and random structures. Experimental techniques, prediction methods, and simulation.

**MEBM E6310x–E6311y Mixture theories for biological tissues, I and II**

*Lect: 3. 3 pts. Professor Ateshian.*

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 or 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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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 gyro-dynamics.

#### **MECE E6422x-E6423x or y Introduction to the theory of elasticity, I and II**

*Lect: 3. 3 pts. Professor Ateshian.*

Corequisite: APMA E4200. Analysis of stress and strain. Formulation of the problem of elastic equilibrium. Torsion and flexure of prismatic bars. Problems in stress concentration, rotating disks, shrink fits, and curved beams; pressure vessels, contact and impact of elastic bodies, thermal stresses, propagation of elastic waves.

#### **EEME E6601x Introduction to control theory**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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**

*Lect: 3. 3 pts. Not given in 2005–2006.*

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,  $H_\infty$ , 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. Not given in 2005–2006.*

Prerequisite: EEME E6601 or EEME E4601 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.

#### **EEME E6612x Control of nonlinear dynamic systems**

*Lect: 3. 3 pts. Professor Girard.*

Prerequisites: EEME E6601 or ELEN E6201 and an undergraduate controls course. Fundamental properties of nonlinear systems; qualitative analysis of nonlinear systems; nonlinear control-stability and observability; nonlinear stability; zero dynamics and inverse systems; feedback stabilization and linearization; sliding control theory; nonlinear observers; describing functions.

#### **EEME E6620x or y Applied signal recognition and classification**

*Lect: 3. 3 pts. Professor Beigi.*

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**

*Lect: 3. 3 pts. Professor Hone.*

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.

#### **MECE E8020x-E8021y Master's thesis**

*1 to 3 pts. Professors Ateshian, Chevray, Girard, Hone, Kysar, Longman, Modi, Simaan, Wong, and Yao.*

Interpretive research in graduate areas in mechanical engineering and engineering science.

#### **MECE E8100y Advanced topics in fluid mechanics**

*Lect: 2. 3 pts. Not given in 2005–2006.*

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**

*Lect: 2. 3 pts. Not given in 2005–2006.*

Prerequisite: A previous control-related course including some state variable formulation and preferably some digital control concepts, e.g. EEME E6601 or E4601, or ELEN E6201, or the instructor's permission. Iterative learning control (ILC) and repetitive control (RC) are new fields that increase the performance of feedback control systems simply by iteratively adjusting the command. In the course, examples are given of improving the RMS tracking accuracy of a robot by a factor of 1000 when performing a high-speed maneuver. This error level is reached after 12 iterations for learning. Note that this level is actually below the repeatability level of the robot when measured on a day-to-day basis rather than a minute-to-minute basis, which means that in order to maintain such high tracking accuracy one needs to keep the learning control on—so that it adjusts for the small changes in robot behavior from day to day. Repetitive control does the same kind of learning for systems with periodic commands or periodic disturbances, for example for canceling vibrations. This large improvement in feedback control system performance is obtained purely in software, and hence can be very attractive in industry applications. Industry is currently starting to use the methods, for example some robots are now being delivered with learning control built in, and repetitive control ideas are being used to increase the storage density on computer disk drives. The course develops the mathematical background needed to use these methods, putting the emphasis on the most practical approaches for applications.

#### **MECE E9000x and E9001y, and s Graduate research and study**

*1 to 3 pts. Professors Ateshian, Chevray, Hone, Kysar, Longman, Modi, Wong, and Yao.*

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**

*3, 6, 9, or 12 pts. Professors Ateshian, Chevray, Girard, Hone, Kysar, Longman, Modi, Simaan, Wong, and Yao.*

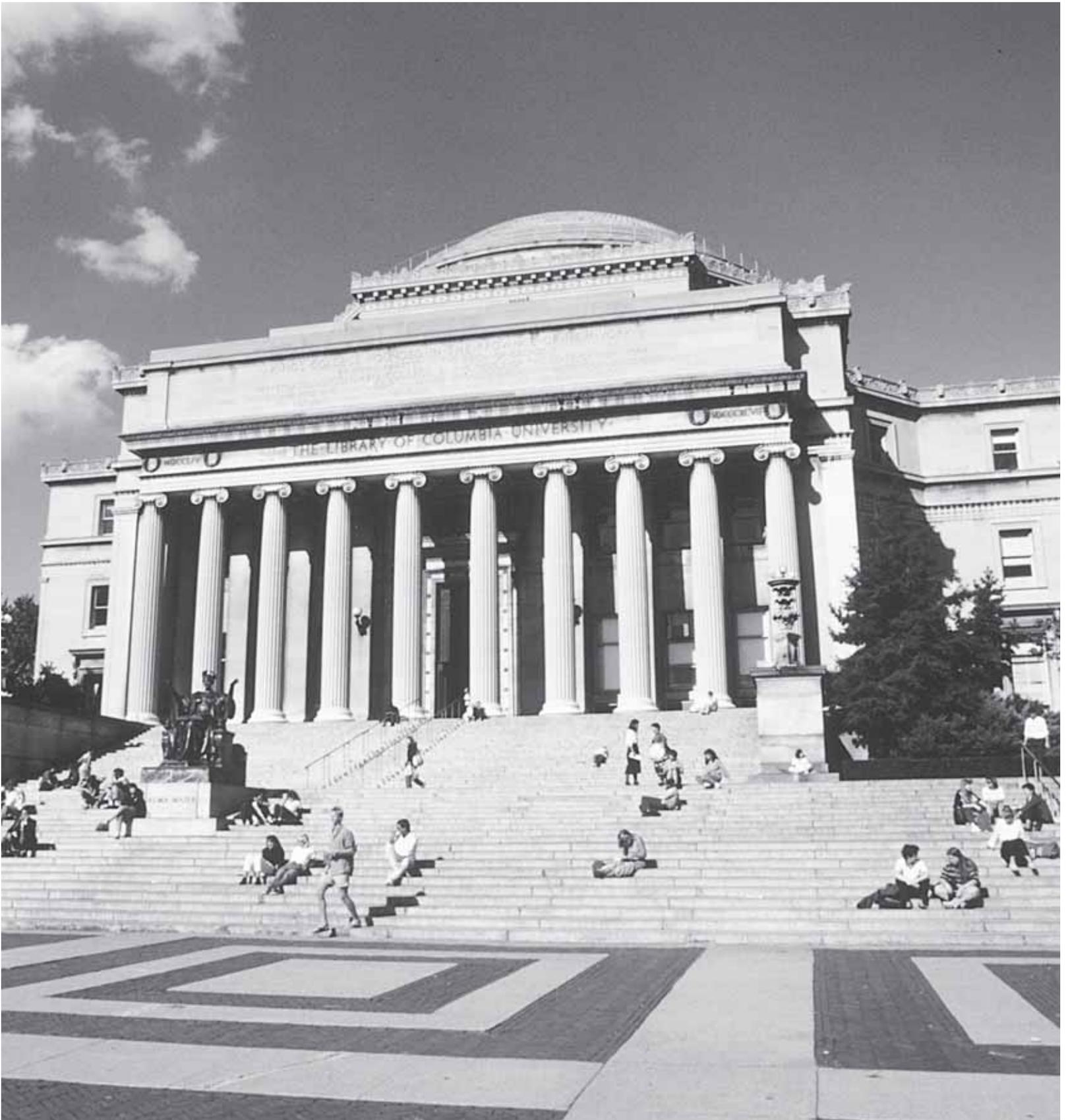
A candidate for the Eng.Sc.D. degree in mechanical engineering must register for 12 points of doctoral research instruction. Registration in MECE E9800 may not be used to satisfy the minimum residence requirement for the degree.

#### **MECE E9900x and y Doctoral dissertation**

*0 pts. Professors Ateshian, Chevray, Girard, Hone, Kysar, Longman, Modi, Simaan, Wong, and Yao.*

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

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 credits that must be taken at Columbia. 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 nonengineering minors offered by SEAS.

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.

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1. **AMST W101:** Introduction to American studies 3.0 points

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2–6. Five additional courses in American Studies with no distribution or seminar requirements.

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## 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.

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1. **APMA E4901:** Seminar: problems in applied mathematics 1.0 points

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2. **APMA E3101:** Applied mathematics, I: linear algebra 3.0 points  
or  
**MATH V2010:** Linear algebra 3.0 points

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3. **APMA E3102:** Applied mathematics, II: partial differential equations 3.0 points  
or  
**MATH V3028:** Partial differential equations 3.0 points

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4–6. Any three of the following courses:  
**APMA E4300:** Computational mathematics, I: introduction to numerical methods 3.0 points  
**APMA E4204:** Functions of a complex variable 3.0 points  
**APMA E4101:** Applied mathematics, III: 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

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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.

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1. **APPH E4901:** Seminar: problems in applied physics 1.0 points

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2. **PHYS W3003:** Mechanics 3.0 points

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3. **APPH E3100:** Introduction to quantum mechanics 3.0 points

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4. **APPH E3300:** Applied electromagnetism 3.0 points

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5. **MSAE E3111:** Thermodynamics, kinetic theory, and statistical mechanics 3.0 points

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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

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## Minor in Architecture

<b>1-2. Two of the following courses:</b>	
<b>ARCH V1020:</b> Introduction to architectural design and visual culture	3.0 points
<b>AHIS C3001:</b> Introduction to architecture	3.0 points
<b>ARCH V3117:</b> Perception of architecture	3.0 points
<b>ARCH A4220:</b> Enclosures and environments, I	3.0 points
<b>3-5. Three of the following courses:</b>	
<b>ARCH A4221:</b> Enclosures and environments, II	3.0 points
<b>ARCH A4125:</b> Building systems, I	3.0 points
<b>ARCH A4610:</b> Building systems, II	3.0 points
<b>ARCH A4627:</b> Materials and methods in architecture	3.0 points
<b>ARCH A4629:</b> Architectural acoustics/architecture lighting	3.0 points
<b>ARCH A4634:</b> Advanced curtain walls	3.0 points
<b>ARCH A4684:</b> Sustainable design	3.0 points
<b>ARCH A4151:</b> Foundations of urban economic analysis	3.0 points
<b>ARCH A4208:</b> Quantitative techniques	3.0 points

## Minor in Art History

<b>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.</b>
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## 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

<b>1. BIOL C2005:</b> Introduction to molecular and cellular biology	4.0 points
<b>2. BMEN E4001:</b> Quantitative physiology, I	3.0 points
or	
<b>BMEN E4002:</b> Quantitative physiology, II	3.0 points

### I. CELL AND TISSUE ENGINEERING TRACK

<b>3. CHEN E3010:</b> Chemical engineering thermodynamics	4.0 points
<b>4. BMEN E4501:</b> Tissue engineering, I	3.0 points
<b>5. BMEN E4502:</b> Tissue engineering, II	3.0 points
<b>6. One of the following courses:</b>	
<b>BMEN E3320:</b> Fluid biomechanics	3.0 points
<b>BMEN E4570:</b> Science and engineering of body fluids, I	3.0 points
or	
<b>BMEN E4580:</b> Science and engineering of body fluids, II	3.0 points
<b>ECBM E3060:</b> Introduction to genomic information	3.0 points
<b>CHEN E3110:</b> Transport phenomena, I	4.0 points
<b>CHEN E4700:</b> Principles of genomic technologies	3.0 points
<b>MSAE E3103:</b> Elements of materials science	3.0 points

### II. BIOMECHANICS TRACK

<b>3. BMEN E4300:</b> Solid biomechanics	3.0 points
<b>4. BMEN E3320:</b> Fluid biomechanics	3.0 points
<b>5-6. Two of the following courses:</b>	
<b>ENME E3113:</b> Mechanics of solids	3.0 points
<b>ENME E3161:</b> Fluid mechanics	4.0 points
or	
<b>MECE E3100:</b> Introduction to mechanics of fluids	3.0 points
<b>MECE E3301:</b> Thermodynamics	3.0 points
or	
<b>MSAE E3111:</b> Thermodynamics, kinetic theory, and statistical mechanics	3.0 points

### III. BIOMEDICAL IMAGING TRACK

<b>3. BMEN E4894:</b> Biomedical imaging	3.0 points
<b>4-5. Two of the following courses:</b>	
<b>BMEN E4430:</b> Principles of magnetic resonance imaging	3.0 points
<b>BMEN E4400:</b> Wavelet applications in biomedical image and signal processing	3.0 points
<b>BMEN E4898:</b> Phototonics	3.0 points
<b>BMEN E4410:</b> Ultrasound in diagnostic imaging	3.0 points
<b>6. One of the following courses:</b>	
<b>ELEN E3801:</b> Signals and systems	3.0 points
<b>ELEN E4810:</b> Digital signal processing	3.0 points
<b>ELEN E4830:</b> 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:

<b>1. CHEN E3100:</b> Material and energy balances	4.0 points
<b>2. CHEN E3010:</b> Principles of chemical engineering thermodynamics	
4.0 points	
or	
<b>MSAE E3111:</b> Thermodynamics, kinetic theory, and statistical mechanics	3.0 points
or	
<b>MECE E3301:</b> Thermodynamics	3.0 points
<b>3. CHEN E3110:</b> Transport phenomena, I	
4.0 points	
or one of the following:	
<b>EAAE E4900:</b> Applied transport and chemical rate phenomena	3.0 points
<b>MECE E3100:</b> Introduction to mechanics of fluids	3.0 points
<b>ENME E3161:</b> Fluid mechanics	4.0 points
<b>4. CHEN E4230:</b> Reactor design and control	
4.0 points	
<b>5-6. Two courses from the following:</b>	
Any 3000-level or higher <i>CHEN</i> , <i>CHAP</i> , or <i>CHEE</i> course	
<b>APMA E3101:</b> Applied mathematics, I	3.0 points
<b>APMA E3102:</b> Applied mathematics, II	3.0 points
<b>BMEN E3320:</b> Fluid biomechanics	3.0 points
<b>BMEN E4001:</b> Quantitative physiology, I	3.0 points
<b>BMEN E4002:</b> Quantitative physiology, II	3.0 points
<b>ELEN E3201:</b> Circuit analysis	3.5 points
<b>ELEN E3301:</b> Electronic circuits	
3.0 points	
<b>SIEO W3600:</b> Introduction to probability and statistics	4.0 points
<b>IEOR W4105:</b> Probability	3.0 points
<b>IEOR W4106:</b> Stochastic models	3.0 points
<b>MSAE E3103:</b> Elements of materials science	3.0 points
<b>MSAE E3142:</b> Processing of ceramics and polymers	3.0 points

## Minor in Civil Engineering

1. **CIEN E3121:** Structural analysis 3.0 points  
or  
**ENME E3161:** Fluid mechanics 4.0 points  
or  
**MECE E3100:** Introduction to mechanics of fluids 3.0 points
2. **ENME E3105:** Mechanics 4.0 points
3. **ENME E3113:** Mechanics of solids 3.0 points
- 4–6. **Electives (any two)**
  - CIEN E1201:** Design of buildings, bridges, and spacecraft 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
  - CIEE E3250:** Hydrosystems engineering 3.0 points
  - CIEN E4163:** Environmental engineering: wastewater 3.0 points
  - CIEN E4129:** Managing engineering and construction process 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 credits 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.

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 of the following history/criticism courses:**
  - DNCE BC 2565/2566:** History of dance, I and/or II
  - DNCE BC 2560:** Exploring dance
  - DNCE BC2570:** Dance in New York City
  - 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
- 3–4. **Two of the following performance/choreography courses:**
  - DNCE BC 2555:** Ensemble repertory: modern
  - DNCE BC 2556:** Ensemble repertory: ballet
  - 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 2558:** 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 Earth and Environmental Engineering

- 1–3. **Three courses from the following:**
  - EAAE E3101:** Earth resource production systems 3.0 points
  - EAAE E3103:** Energy and materials systems 3.0 points
  - EAAE E3221:** Environmental geophysics 3.0 points
  - EAAE E3255:** Environmental control and pollution reduction systems 3.0 points
  - EAAE E4003:** Introduction to aquatic chemistry 3.0 points
  - EAAE E4004:** Physical processing and recovery of solids 3.0 points
  - EAAE E4006:** Field methods for environmental engineering 3.0 points
  - EAAE E4001:** Industrial ecology of earth resources 3.0 points
  - EAAE E4160:** Solids and hazardous waste management 3.0 points
  - EAAE E4257:** Environmental data analysis and modeling 3.0 points
  - EAAE E4361:** Economics of Earth resource industries 3.0 points
  - EAAE E4150:** Air pollution prevention and control 3.0 points
  - EAAE E4200:** Production of inorganic materials 3.0 points
  - EAAE E4009:** GIS for resource, environment and infrastructure management 3.0 points
- 4–6. **Three courses from the following (other environmentally related courses may also be approved):**
  - ECIA W4100:** Management and development of water systems 3.0 points
  - CIEN E3141:** Soil mechanics 3.0 points
  - CIEE E3250:** Hydrosystems engineering 3.0 points
  - MECE E4211:** Energy: sources and conversion 3.0 points
  - EAIA E4200:** Alternative energy sources 3.0 points
  - CIEN E4250:** Waste containment design and practice 3.0 points
  - CIEE E4252:** Environmental engineering 3.0 points
  - CIEE E4260:** Urban ecology studios 3.0 points
  - CHEE E4252:** Intro to surface and colloid chemistry 3.0 points
  - CIEN E4257:** Contaminant transport in subsurface systems 3.0 points
  - CIEN E4163:** Environmental engineering: wastewater 3.0 points
  - CHEN E4410:** Environmental control technology 3.0 points



<b>CHEN E3010:</b> Principles of chemical engineering thermodynamics	3.0 points
<b>CHEN E3110:</b> Transport phenomena, I	4.0 points
<b>SIEO W3600:</b> Introduction to probability and statistics	4.0 points

## Minor in East Asian Languages and Cultures

1–2. Any two of the survey courses on Chinese, Japanese, or Korean civilization (ASCE V2359, V2361, V2363).

3–6. Three elective courses dealing with East Asia.

*Note:* The elective courses may be taken in departments outside of East Asian Languages and Cultures.

## Minor in Economics

- ECON W1105:** Principles of economics
- ECON W3211:** Intermediate microeconomics
- ECON W3213:** Intermediate macroeconomics
- 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 W2257:** Global economy
- ECON W2261:** Intro to accounting and finance
- ECON W3003:** Corporate finance or
- ECON W4280:** Corporate finance
- ECON V3025:** Financial economics
- ECON W3265:** Economics of money and banking
- ECON W4020:** Economics of uncertainty and information
- ECON W4080:** Globalization, incomes and inequality
- ECON W4213:** Advanced macroeconomics
- ECON W4228:** Urban economics
- ECON G4235:** Historical foundations of modern economics
- ECON W4251:** Industrial organization
- ECON W4321:** Economic development
- ECON W4329:** Economics of sustainable development
- ECON W4345:** World economic problems
- ECON W4370:** Political economy
- ECON W4400:** Labor economics
- ECON W4415:** Game theory
- ECON W4438:** Economics of race in the United States

- ECON W4457:** Industrial organization of art, entertainment and communications
- ECON W4465:** Public economics
- ECON W4490:** Economics of the Internet
- ECON W4500:** International trade
- ECON W4505:** International monetary theory and policy
- ECON W4615:** Law and economics
- ECON W4625:** Economics of the environment
- ECON W4750:** Globalization and its risks

*Note:* Electives may be taken only after the completion of both *ECON W3211* and *W3213*, with the exception of *ECON W2261*, which may be taken after completing *ECON W1105*. See the Columbia College course bulletin for complete course descriptions of the classes.

7. One of the following statistics courses (or sequence of courses):

- STAT W1211:** Introduction to statistics
- SIEO W3600:** Introduction to probability and statistics
- SIEO W3658:** Probability and
- SIEO W3602:** Introduction to 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 *ECON W2261: 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.

- Students with AP credit for economics and an exemption for *ECON W1105* may use the credit toward the minor.

## Minor in Electrical Engineering

- ELEN E1201:** Introduction to electrical engineering 3.5 points  
(May be replaced by a similar course or roughly equivalent experience)
- ELEN E3201:** Circuit analysis 3.5 points
- CSEE W3827:** Fundamentals of computer systems 3.0 points
- ELEN E3081 and ELEN E3082:** Electrical engineering labs 2.0 points
- ELEN E3801:** Signals and systems 3.5 points
- ELEN E3106:** Solid-state devices and materials 3.5 points  
or  
**ELEN E3401:** Electromagnetics 4.0 points

*Notes:*

- Not available to computer engineering majors.
- The old signals and systems course, *ELEN E3202*, has been replaced by *ELEN E3801*; either will satisfy requirement 5.

## Minor in Engineering Mechanics

- ENME E3105:** Mechanics 4.0 points
- ENME E3113:** Mechanics of solids 3.0 points
- ENME E3161:** Fluid mechanics 4.0 points  
or  
**MECE E3100:** Mechanics of fluids 3.0 points

### 4–6. Electives (any two):

- |  |            |
|--|------------|
| <b>ENME E3106:</b><br>Dynamics and vibrations          | 3.0 points |
| <b>ENME E3114:</b> Experimental mechanics of materials | 4.0 points |
| or   |            |
| <b>MECE E3414:</b> Advanced strength of materials      | 3.0 points |
| <b>CIEN E3121:</b> Structural analysis                 | 3.0 points |
| <b>ENME E4202:</b> Advanced mechanics                  | 3.0 points |
| <b>ENME E4113:</b> Advanced mechanics of solids        | 3.0 points |
| <b>ENME E4114:</b> Mechanics of fracture and fatigue   | 3.0 points |
| <b>ENME E4214:</b> Theory of plates and shells         | 3.0 points |
| <b>ENME E4215:</b> Theory of vibrations                | 3.0 points |
| <b>MECE E3301:</b> Thermodynamics                      | 3.0 points |

*Note:* At least three of the courses must be courses that are not required in the student's major.

## 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

- 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 German

Required: 15 points beyond second-year German.

- GERM V3001 or V3002:** Advanced German, I or II 3.0 points
- 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 ComplLit-German courses taught in German or English.

## 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 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

- SIEO W3600:** Introduction to probability and statistics 4.0 points
- IEOR E3608:** Introduction to mathematical programming 4.0 points
- IEOR E3402:** Production-inventory planning and control 3.0 points
- IEOR E4003:** Industrial economics 3.0 points
- 5–6. Electives: Two IEOR courses of interest and approved by a faculty adviser.

*Note:* In addition to the required courses, students majoring in operations research or engineering and management systems minoring in industrial engineering must take three industrial engineering courses that are not used to satisfy the requirements of their major.

## Minor in Materials Science and Engineering

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<b>1. MSAE E3103:</b>	
Elements of materials science	3.0 points

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<b>2–3. Two of the following courses:</b>	
<b>MSAE E3111:</b>	
Thermodynamics, kinetic theory, and statistical mechanics	3.0 points
<b>or</b>	
<b>CHEN E3010:</b> Principles of chemical engineering thermodynamics	3.0 points
<b>MSAE E3141:</b> Processing of metals and semiconductors	3.0 points
<b>MSAE E3142:</b> Processing of ceramics and polymers	3.0 points
<b>MSAE E4206:</b> Electronic and magnetic properties of solids	3.0 points
<b>MSAE E4101:</b> Structural analysis of materials	3.0 points

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<b>4–6. Three of the following courses (other materials-related courses may be acceptable):</b>	
<b>APPH E4100:</b>	
Quantum physics of matter	3.0 points
<b>CHEE E4050:</b>	
Industrial and environmental electro-chemistry	3.0 points
<b>CHEE E4252:</b> Introduction to surface and colloid chemistry	3.0 points
<b>CHEE E4530:</b>	
Corrosion of metals	3.0 points
<b>CHEE E4620:</b> Introduction to polymer science	3.0 points
<b>CHEN E4630:</b>	
Polymer laboratory	3.0 points
<b>CHEM C3443-C3444:</b>	
Organic chemistry	3.5 points
<b>EAEE E4900:</b> Applied transport and chemical rate phenomena	3.0 points
<b>ELEN E3106:</b> Solid-state devices and materials	3.5 points
<b>ELEN E4411:</b>	
Fundamentals of photonics	3.0 points
<b>ELEN E4301:</b> Introduction to semiconductor devices	3.0 points
<b>ELEN E4944:</b> Principles of device microfabrication	3.0 points
<b>ENME E4113:</b>	
Advanced mechanics of solids	3.0 points
<b>ENME E4114:</b> Mechanics of fracture and fatigue	3.0 points
<b>MECE E4608:</b>	
Manufacturing processes	3.0 points
<b>MECE E4701:</b>	
Introductory biomechanics	3.0 points

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## Minor in Mechanical Engineering

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<b>1–4. Any four courses from the following (equivalent substitution courses require the approval of the mechanical engineering program adviser):</b>	
<b>MECE E3100:</b> Introduction to mechanics of fluids	3.0 points
<b>or one of the following:</b>	
<b>ENME E3161:</b>	
Fluid mechanics	4.0 points
<b>CHEN E3110:</b>	
Transport phenomena, I	4.0 points
<b>EAEE E4900:</b> Applied transport and chemical rate phenomena	3.0 points
<b>ENME E3105:</b> Mechanics	4.0 points
<b>MECE E3301:</b>	
Thermodynamics	3.0 points
<b>or one of the following:</b>	
<b>CHEN E3010:</b> Principles of chemical engineering thermodynamics	4.0 points
<b>MSAE E3111:</b>	
Thermodynamics, kinetic theory, and statistical mechanics	3.0 points
<b>ENME E3113:</b>	
Mechanics of solids	3.0 points
<b>MECE E3408:</b> Computer graphics and design	3.0 points
<b>MECE E3311:</b> Heat transfer	3.0 points
<b>MECE E4608:</b>	
Manufacturing processes	3.0 points
<b>MECE E3409:</b>	
Computer-aided design	3.0 points
<b>EEME E3601:</b>	
Classical control systems	3.0 points

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<b>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):</b>	
<b>MECE E3200:</b> Computer-aided product design	3.0 points
<b>MECE E3401:</b>	
Mechanics of machines	3.0 points
<b>MECE E3601:</b>	
Classical control systems	3.0 points
<b>MECE E4058:</b>	
Mechatronics and embedded microcomputer control	3.0 points
<b>MECE E4100:</b>	
Mechanics of fluids	3.0 points
<b>MECE E4211:</b> Energy: sources and conversion	3.0 points
<b>MECE E4302:</b>	
Advanced thermodynamics	3.0 points
<b>MECE E4501:</b>	
Geometrical modeling	3.0 points
<b>MECE E4502:</b> Computational geometry for CAD/CAM	3.0 points
<b>EEME E4601:</b>	
Digital control systems	3.0 points
<b>MECE E4603:</b>	
Analysis, modeling, and control of manufacturing systems	3.0 points
<b>MECE E4604:</b> Product design for manufacturability	3.0 points
<b>MECE E4609:</b>	
Principles of metal cutting	3.0 points

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## Minor in Middle East and Asian Languages and Cultures

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<b>1–5. Five courses, to be chosen with the approval of the MEALAC Director of Undergraduate Studies; no elementary or intermediate language courses may be taken.</b>
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## Minor in Music

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<b>1. MUSI V2318-V2319:</b> Diatonic harmony and counterpoint	6.0 points
<b>2. MUSI V1312-V1313:</b> Introductory ear training	2.0 points
<b>3. One course from the following:</b>	
<b>MUSI V3128:</b> History of Western music I: Middle Ages to baroque	3.0 points
<b>MUSI V3129:</b> History of Western music II: classical to 20th century	3.0 points
<b>4–5. Any two electives at the 3000 or 4000 level. See also the SEAS-approved non-technical electives in music (page 15).</b>	

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### Note:

- 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 Operations Research

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<b>1. IEOR E3106:</b> Stochastic models	3.0 points
<b>2. SIEO W3600:</b> Introduction to probability and statistics	4.0 points
<b>3. IEOR E3608:</b> Introduction to mathematical programming	4.0 points
<b>4. IEOR E4404:</b> Simulation	3.0 points
<b>5–6. Electives: Two IEOR courses of interest and approved by a faculty adviser. IEOR E3402: Production-inventory planning and control (3.0 points) is strongly recommended.</b>	

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*Note:* In addition to the required courses, students majoring in industrial engineering or engineering management systems must take three operations research courses that are not used to satisfy the requirements of their major.

## 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 of 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.

## Minor in Religion

- 1–5. Five courses (total 15 points), one of which must be:
- V2800:** Religions and the modern world 3.0 points

## 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 Spanish

1. **SPAN V3200:** Spanish grammar and composition 3.0 points
2. **SPAN V3332:** Reading and writing about 20th-century Hispanic literature 3.0 points
3. One of the following courses from the series **Texts and Contexts:**
- SPAN V3351:** Literature and culture of Latin America: colonial period through "modernismo" 3.0 points
  - SPAN V3552:** Literature and culture of Spain: Enlightenment to Generation '98 3.0 points
  - SPAN V3353:** Literature and culture of Spain: medieval through Golden Age 3.0 points
- 4.–5. Two additional courses in Spanish beyond satisfaction of the language requirement, numbered above 3200.

*Note:* Please see the Director of Undergraduate Studies for more information. The department offers a three-track program. In addition to the Spanish language and literature track listed above, students can choose the Hispanic studies track and the Latin American studies track.

# Interdisciplinary Courses and Courses in Other Divisions of the University



# Interdisciplinary Engineering Courses

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.

## **SCNC W1005x and y Science, technology, and society**

*Lect: 3. 3pts. J. McGourty*

Survey of the history of technology, innovation, and entrepreneurialism in the modern industrial Western world. Investigation of evolution and diffusion of technological innovations: how they developed and how they are related to social forces, cultural values, economic possibilities, and political influences. Technological innovation within the conceptual, social, and historical framework. Specific case studies focusing on major innovations and resulting industries, including transportation, power, medical, and information. Current evolution of emerging technologies and the societal implications for the future.

## **ENGI E1102x and y Design fundamentals using advanced computer technologies**

*Lect: 4. 4 pts. J. McGourty and J. Sanchez.*

Basic engineering design processes and complementary professional skills for future engineers and applied scientists in the state-of-the-art multimedia Botwinick Gateway Laboratory; advanced three-dimensional graphical and Web applications in the service of design as a crucial engineering tool; students develop skills in collaboration, communication, problem solving, and project management. Lab fee: \$175.

## **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 prerequi-

sites, 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.

# Courses in Other Divisions of the University

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**

*Lect: 3. Recit: 2. 4 pts. L. Chasin and D. Mowshowitz.*

Prerequisite: one year of college chemistry, or a strong high school chemistry background.

Recommended introductory biology course for biology and related majors and for premedical students. Fundamental principles of biochemistry, molecular biology, and genetics.

### **BIOL C2006y Introduction to molecular and cellular biology, II**

*Lect: 3. Recit: 2. 4 pts. D. Mowshowitz.*

Prerequisite: ENVB W2001 or BIOL C2005 or the instructor's permission. The recommended second term of biology for biology and related majors and for premedical students. Cellular biology and development; physiology of cells and organisms.

### **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. Emphasis on experimental techniques and data analysis in a variety of biological disciplines.

### **BIOC C3501 Biochemistry: structure and metabolism**

*Lect: 3. Recit: 1. 4 pts. G. Zubay and L. Tong.*

Prerequisite: BIOL C2005 or ENVB W2001 and

one year of organic chemistry. Students wishing to cover the full range of modern biochemistry should take both BIOC C3501 and C3512.

Protein structure, protein folding, enzyme kinetics, allostery, membrane transport, biological membranes, and protein targeting. Chemistry and metabolism of amino acids, carbohydrates, lipids, purines, pyrimidines. Note: BIOC C3512 may be taken without C3501.

## Business

School of Continuing Education

Contact: Lucas Rubin,  
303 Lewisoohn, 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: <http://www.ce.columbia.edu/bci/courseAvailability.cfm>.

### **BUSI W3001x and y Introductory finance**

*3 pts. x: J. Martinez; y: 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 adminis-

tered 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 Miler-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 (ECON W2261 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.

**BUSI W3020x and y Introduction to marketing and marketing management**

3 pts. x: K. Jedidi; y: A. Ansari.

No previous background in marketing is required for the course. Introduction to the basic concepts of marketing. Students develop an understanding of, and the decision-making capabilities for, formulating marketing strategies for the complex situations that characterize real-life marketing problems.

## Chemistry

### COURSES OF INSTRUCTION

Pre-engineering students should refer to the First Year–Sophomore Program to determine the chemistry requirements for admission to particular Junior-Senior Programs. Special attention should be given to the requirements for admission to chemical engineering, biomedical engineering,

materials science and metallurgical engineering, and other related fields.

### LABORATORY FEE

The laboratory fee covers the cost of nonreturnable items, chemicals, and reasonable breakage. In addition, students may be charged for lab handouts and excessive breakage, for cleaning of equipment returned dirty, and for checking out late.

**CHEM C1403x-C1404y General chemistry**

Lect: 3.5 pts. and a 1-hour recitation section. L. Fine, N. Turro, A. McDermott, J. Norton, G. Flynn, and R. Friesner.

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. 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, introduction to organic and biological chemistry, solid-state and materials science, polymer science and macromolecular structures, chemical kinetics, coordination chemistry, and electrochemistry. Although C1403 and C1404 are sepa-

rate 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. L. Fine.

Prerequisite or corequisite: CHEM C1403. Fee: \$125. An introduction to basic techniques and practices of modern experimental chemistry, including quantitative procedures and chemical analysis.

**CHEM C2407x Intensive general chemistry**

Lect: 3.5 pts. and a 1-hour recitation section. B. Berne.

Students who register for CHEM 2407 are required to enroll in C2507y. Prerequisite: entrance physics, chemistry, and trigonometry, and acceptable performance on the chemistry Advanced Placement Examination and/or the qualifying examination given during orientation week. Corequisite: elementary calculus. A knowledge of chemistry beyond that of the usual one-year high school chemistry course is assumed. Topics include the nature of the chemical bond, chemical equilibrium and the laws of thermodynamics, the dynamics and mechanisms of chemical reactions, the chemistry of materials, and topics in environmental chemistry.

**CHEM C2507y Intensive general chemistry laboratory**

Lab: 3 pts. L. Fine.

Prerequisite: CHEM C2407 or C3045 and the instructor's permission. Fee: \$125. An introduction to basic techniques and practices of modern

experimental chemistry, including qualitative procedures and chemical analysis. This course differs from CHEM C1500 in its emphasis on instrumentation and methods.

**CHEM C3045x-C3046y Intensive organic chemistry for first-year students (lecture)**

*Lect: 3.5 pts. and a 1-hour recitation section. N. Breslow and D. Sames.*

Prerequisite: grade of 4 or 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 C3079x-C3080y Physical chemistry, I and II**

*Lect: 3 pts. D. Adams and K. Eisenhal.*

Prerequisite: CHEM C1403-C1404 or C3045-C3046; PHYS C1406-C1407, or the equivalent; first-year calculus. Recommended parallel: CHEM C3085-C3086, a detailed examination of physical laws governing the behavior of the molecular systems encountered in chemistry; C3079, an introduction to the principles of quantum mechanics, chemical bonding, and atomic and molecular spectroscopy; C3080, equilibrium thermodynamics with applications to gases, nonelectrolyte and electrolyte solutions, and thermochemistry; dynamics of chemical reactions in gas and liquid phase systems.

**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.

**CHEM C3098x 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. T. Katz, V. Cornish, J. Leighton, and C. Nuckolls.*

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 Kelemen.*

Students who wish to take only the lectures should register for EESC V1411. Fee: \$15. 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 W3018y Weapons of mass destruction**

*3 pts. Professor Richards.*

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 W4001x Advanced general geology**

*3 pts. Lab: 3. 4 pts. Professors Scholz and Anders.*

Prerequisite: One semester of college-level calculus, physics, and chemistry. Fee: \$35. A concentrated introduction to the solid Earth, its interior, and near-surface geology. Intended for students with good backgrounds in the physical sciences but none in geology. Laboratory and field trips.

**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 W4009x. Chemical geology**

*4 pts. Offered in alternate years. Not given in 2005-2006.*

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. C. Small and J. Weissel.*

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. Not given in 2005–2006.  
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. 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; earthquake processes; ductile deformation; large-scale crustal contractional and extensional events.

**EESC W4300y The Earth's deep interior**

3 pts. Professor Richards.  
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 W4501x Mineral deposits and the environment**

3 pts. Offered in alternate years. Not given in 2005–2006.  
Prerequisites: Introductory Earth sciences and mineralogy courses or their equivalents, or the instructor's permission. A broad survey suitable for students majoring in Earth and environmental sciences or Earth and environmental engineering. Topics include economic minerals, the formation of mineral deposits, and environmental impacts of mining waste products.

**EESC W4701y. Introduction to igneous petrology**

4 pts. Professor Kelemen.  
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 labo-

ratory 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 W4885y The chemistry of continental waters**

3 pts. Offered in alternate years. Professors Anderson and Simpson.  
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 W4886y Isotope hydrology**

3 pts. Offered in alternate years. Not given in 2005–2006.  
Prerequisite: basic knowledge of physics, math, and chemistry. Trace substances in groundwater systems with the potential for investigations of groundwater flow and paleoclimate. The principal methods of isotope hydrology (e.g., tracers as dyes or radioactive clocks) and the geochemistry and sources/sinks of the individual tracers in the groundwater system are discussed. Observed distributions are presented and interpreted in terms of groundwater flow dynamics and paleoclimate.

**EESC W4924y Introduction to atmospheric chemistry**

3 pts. Offered in alternate years. Not given in 2005–2006.  
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. Not offered in 2005–2006.  
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 radioisotope 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. Professor Hayes.  
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. W. Pitman and W. Ryan.  
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.

**EESC W4950x Mathematical methods in the Earth sciences**

3 pts. Professor Richards.  
Prerequisites: college-level physics and calculus. A set of basic mathematical skills is essential for understanding sophisticated methods of analysis. This course will develop and improve these skills and give a sense of the key analytical methods and challenges in different subdisciplines within the Earth sciences.

## 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**  
4 pts.

A study in their historical context of major contributions to the intellectual tradition of the West from Plato to Freud and beyond. Emphasis on the history of political, social, and philosophical thought. Students are expected to write at least three papers and examinations and to 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.

**ECON W2261x and y Introduction to accounting and finance**  
4 pts.

Prerequisite: ECON W1115. The concepts and methods underlying the financial statements of business corporations, with particular 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. Strategies and analytical methods for evaluation of capital projects. Analysis of capital structure and leverage.

**ECON W4261x and y Introduction to accounting and finance**  
4 pts.

This is the same course as W2261 above, but

is open only to engineering graduate students. Students must register at 331 S. W. Mudd.

**ENGL C1010x or y University writing**

3 pts. *The staff.*

Teaches general techniques and strategies for academic reading and writing. Students read and discuss essays from a number of fields, 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 "Lit Hum," this course considers works by over twenty authors, ranging in time, theme, and genre from Homer to Virginia Woolf. Students are expected to write at least two papers and two examinations and to participate actively in class discussions.

**HUMA W1121x or y Masterpieces of Western art**  
3 pts.

Discussion and analysis of the artistic qualities and significance of selected works of painting, sculpture, and architecture from the Parthenon in Athens to works of the twentieth century.

**HUMA W1123x or y Masterpieces of Western music**

3 pts.

Analysis and discussion of representative works from the Middle Ages to the present.

## Mathematics

### COURSES FOR FIRST-YEAR STUDENTS

Completion of Calculus IV satisfies the basic mathematics requirement of the degree program. Normally students who have taken an AP Calculus course begin with either Calculus II or Calculus III. 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 Academic Advising Center 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. 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 E1210x or y Ordinary differential equations**

*Lect: 3 pts. M. Sirbu.*

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. S. Paul.*

Prerequisites: MATH V1102 and V1201 or the equivalent, and MATH V2010. Mathematical methods for economics. Quadratic forms, Hessian, implicit functions. Convex sets, convex functions. Optimization, constrained optimization, Kuhn-Tucker conditions. Elements of the calculus of variations and optimal control.

**MATH V3007y Complex variables**

*Lect: 3 pts. P. Gallagher.*

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. M. Sirbu.*

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. S. Paul.*

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-W4642y Introduction to modern algebra**

*Lect: 3 pts. R. Friedman.*

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. I. Kartzas.*

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.

## Physics

The general four-term pre-engineering physics sequence consists of *PHYS C1401, C1402, C1403, and C1494 (laboratory)*; or *PHYS C1601, C1602, C2601, and C2699 (laboratory)*.

**PHYS C1401x Introduction to mechanics and thermodynamics**

*Lect: 3 pts. Professor Westerhoff.*

Corequisite: MATH V1101 or the equivalent. 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 C1402y Introduction to electricity, magnetism, and optics**

*Lect: 3 pts. Professor Westerhoff.*

Prerequisite: PHYS C1401. Corequisite: MATH V1102 or the equivalent. Electric fields, direct currents, magnetic fields, alternating currents, electromagnetic waves, polarization, geometrical optics, interference and diffraction.

**PHYS C1403x Introduction to classical and quantum waves**

*Lect: 3 pts. Professor Mawhinney.*

Prerequisite: PHYS C1402. Corequisite: MATH V1201 or the equivalent. 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 C1493x Introduction to experimental physics**

*Lab and lecture: 3 pts. Lect: 1 hour weekly to be arranged. Lab: 3 hours weekly to be arranged.*

*Mr. BenZvi.*

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 C1494y Introduction to experimental physics**

*Lab and lecture: 3 pts. Lect: 1 hour weekly to be arranged. Lab: 3 hours weekly to be arranged.*

*Mr. BenZvi.*

Prerequisites: PHYS C1401, C1402, and C1403. 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 C1601x Physics I: mechanics and relativity**

*Lect: 3.5 pts. Rec: 1 hour weekly to be arranged.*

*Professor Brooijmans (Sec 1); Professor Miller (Sec 2).*

Corequisite: MATH V1102 or the equivalent.

Fundamental laws of mechanics, kinematics and dynamics, work and energy, rotational dynamics, oscillations, gravitation, fluids, introduction to special relativity and relativistic kinematics.

The course is preparatory for advanced work in physics and related fields.

**PHYS C1602y Physics II: thermodynamics, electricity, and magnetism**

*Lect: 3.5 pts. Rec: 1 hour weekly to be arranged.*

*Professor Marka (Sec 1); instructor to be announced (Sec 2).*

Prerequisite: PHYS C1601. Corequisite: MATH V1201 or the equivalent. Temperature and heat, gas laws, the first and second 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 C2601x Physics III: classical and quantum waves**

*Lect: 3.5 pts. Rec: 1 hour weekly to be arranged.*

*Professor Cole.*

Prerequisite: PHYS C1602 or C1402.

Corequisite: MATH V1202 or the equivalent.

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 C2699y Experiments in classical and modern physics**

*Lab and lecture: 3 pts. Lect: 1 hour weekly to be arranged. Lab: 3 hours weekly to be arranged.*

*Mr. BenZvi.*

Prerequisites: PHYS C1601 (or C1401), C1602 (or C1402), and C2601. Laboratory work associated with the three prerequisite lecture courses. Experiments in mechanics, thermodynamics, electricity, magnetism, optics, wave motion, atomic and nuclear physics.

**PHYS C2801x-C2802y Accelerated physics, I and II**

*Lect: 4.5 pts. Rec: 1 hour weekly to be arranged. Professor Christ.*

Prerequisite: advanced placement in physics and

mathematics, or the equivalent, and the instructor's permission. (A special placement meeting is held during Orientation.) This accelerated two-semester sequence covers the subject matter of PHYS C1601, C1602, and C2601 and is intended for students who have an exceptionally strong background in both physics and mathematics. The course is preparatory for advanced work in physics and related fields. There is no accompanying laboratory; however, students are encouraged to take the intermediate laboratory, PHYS W3081, in the following year.

**PHYS W3001y Physical phenomena**

*Lect: 3.5 pts. Rec: 1 hour weekly to be arranged. Not given in 2005–2006.*

Prerequisite: PHYS C2601 or C2802. A variety of physical phenomena in classical and modern physics are described and analyzed. The course provides a brief introduction to atomic physics, solid-state physics, nuclear physics, astrophysics, nonlinear systems and chaos, numerical methods, and computer programming. The course is preparatory for advanced work in physics and related fields.

**PHYS W3002y From quarks to the cosmos: applications of modern physics**

*Lect: 3.5 pts. Rec: 1 hour weekly to be arranged. Professor Hui.*

Prerequisites: PHYS C2601 or C2802. 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 W3003x Mechanics**

*Lect: 3 pts. Professor Ponton.*

Prerequisite: general physics; differential and integral calculus. Newtonian mechanics, oscillations and resonance, conservative forces and potential energy, central forces, noninertial frames of reference, rigid body motion, an introduction to Lagrange's formulation of mechanics, coupled oscillators, and normal modes.

**PHYS W3007y Electricity and magnetism**

*Lect: 3 pts. Professor Brooijmans.*

Prerequisite: general physics; differential and integral calculus. Electrostatics and magnetostatics, Laplace's equation and boundary-value problems, multipole expansions, dielectric and magnetic materials, Faraday's law, AC circuits, Maxwell's equations, Lorentz covariance, and special relativity.

**PHYS W3008x Electromagnetic waves and optics**

*Lect: 3 pts. Professor Marka.*

Prerequisite: PHYS W3007. Maxwell's equations and electromagnetic potentials, the wave equation, propagation of plane waves, reflection and refraction, geometrical optics, transmission lines, wave guides, resonant cavities, radiation, interference of waves, and diffraction.

**PHYS W3081x or y Intermediate laboratory work**

*Lab: 2 pts. Professors May 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 W3083x Electronics laboratory**

*Lab: 2 pts. Professor Parsons.*

Prerequisite or corequisite: PHYS W3003 or W3007. Registration is limited to the capacity of the laboratory. A sequence of experiments in solid-state electronics, with introductory lectures.

**PHYS G4003y Advanced mechanics**

*Lect: 3 pts. Professor Cole.*

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 Beloborodov.*

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 Kim.*

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 Zajc.*

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.

## Statistics

For descriptions of the following courses offered jointly by the Departments of Statistics and Industrial Engineering and Operations Research, see "Industrial Engineering and Operations Research":

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**SIEO W3600:** Introduction to probability and statistics

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**SIEO W3658:** Probability

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**SIEO W4105:** Probability

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**SIEO W4150:** Introduction to probability and statistics

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**SIEO W4606:** Elementary stochastic processes

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**SIEO W6501:** Stochastic processes and applications, I

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**STAT W3000y Introduction to statistics: probability models**

*3 pts. Professor V. de la Peña.*

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 SIEO W4015. 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. Examples are drawn from finance, insurance, biology, genetics, physics, meteorology, engineering, and medical studies.

**STAT W3659/W4107x and y Statistical inference**

*3 pts. Instructor to be announced.*

Prerequisite: STAT W3000, or SIEO W3658 or W4105, or the equivalent. Principles of statistical inference. Population parameters, sufficient statistics. Basic distribution theory. Point and interval estimation. Method of maximum likelihood. Method of least squares, regression. Introduction to the theory of hypothesis testing. Likelihood ratio tests. Nonparametric procedures. Statistical design theory. Applications to engineering, medicine, natural and social sciences.

**STAT W3701/W4201x and y Advanced data analysis**

*3 pts. D. Alemayehu.*

Prerequisite: STAT W4315. Data analysis using a computer statistical package and selected exploratory data analysis subroutines. Topics include editing of data for errors, exploratory and standard techniques for one-way analysis of variance, linear regression, and two-way analysis of variance. Material is presented in case-study format.



**STAT W4109x Probability and statistical inference**

6 pts. Instructor to be announced.  
Combines STAT W4105 and W4107.

**STAT W4315x and y Linear regression models**

3 pts. Instructor to be announced.  
This course is identical to PUBH P8111.  
Prerequisite: Probability and statistics at the level of SIEO W4150 or STAT W3000, or SIEO W4105 and W4107 taken concurrently, linear algebra and calculus. Simple and multiple regression including testing, estimation and confidence procedures, modelling, regression diagnostics and plots, polynomial regression, fixed effects anova and ancova models, nonlinear regression, multiple comparisons, colinearity and confounding, model selection. Geometric approach to the theory and use of the computer to analyze data will both be emphasized.

**STAT W4330x Regression and multilevel models**

3 pts. A. Gelman.  
Prerequisite: STAT W4315 or the equivalent.

Setup, inference, and checking the fit of multi-level models (also called hierarchical, random-effects, and mixed-effects models). Computation using various software packages and applications in social science and elsewhere.

**STAT W4413x Nonparametric statistics**

3 pts. Given in alternate years.  
This course is identical to PUBH P8117.  
Prerequisite: STAT W4107. Statistical inference without parametric model assumption. Hypothesis testing using ranks, permutations, and order statistics. Nonparametric analogs of analysis of variance. Tolerance limits. Robust estimation. Introduction to sequential statistical procedures. Applications to quality control and clinical trials.

**STAT W4437x and y Time series analysis**

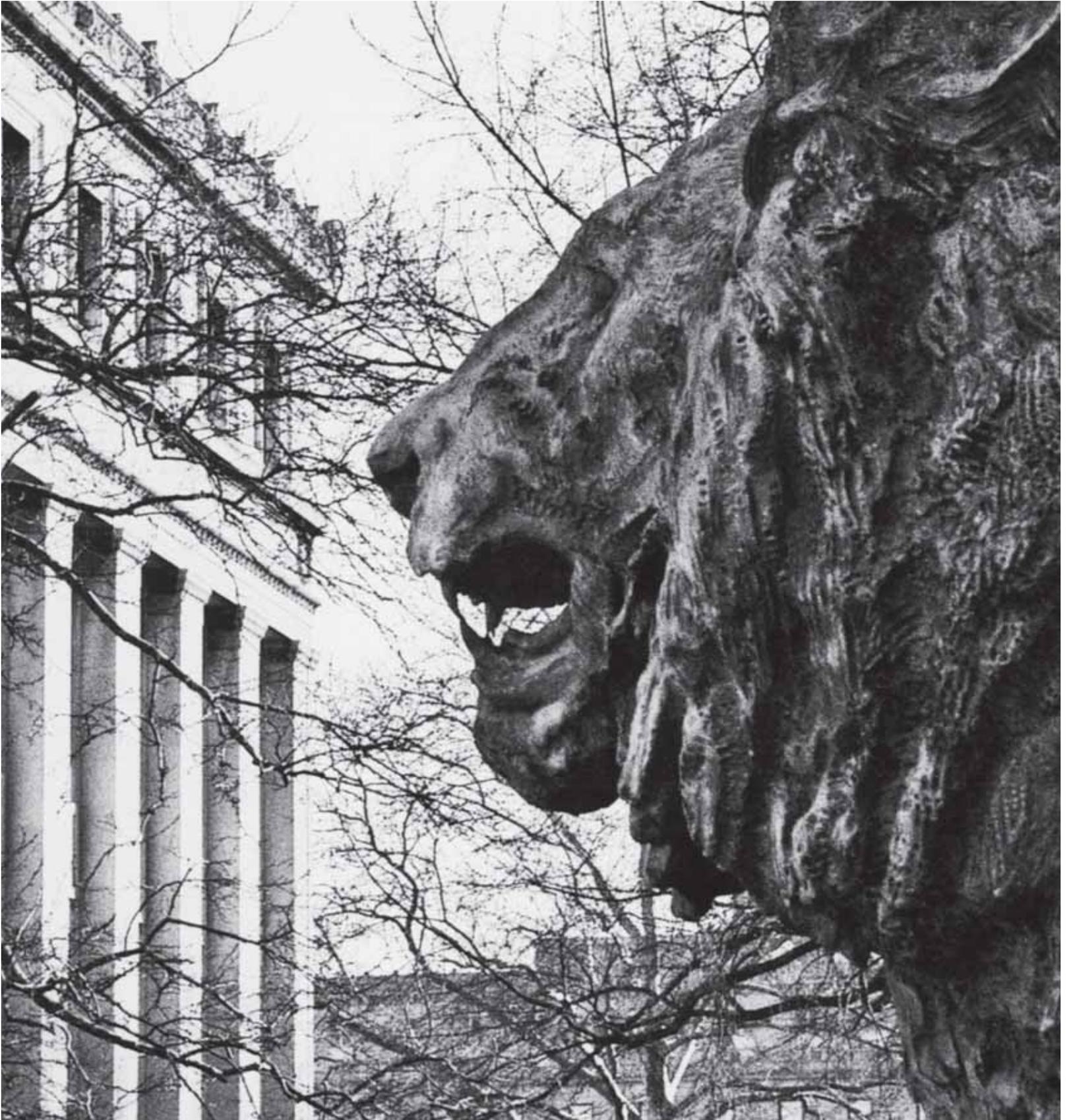
3 pts. H. Xing.  
Prerequisite: STAT W4315 or the equivalent.  
Least-squares smoothing and prediction, linear systems, Fourier analysis and spectral estimation. Discussions of the impulse response and transfer function. Fourier series, the fast Fourier

transform algorithm, autocorrelation function, and spectral density. Univariate Box-Jenkins modeling and forecasting. Emphasis is on practical applications in examples from the physical sciences, social sciences, and business. Sample output from an interactive graphical-statistical system is an integral part of the lectures.

**STAT W4543x Survival analysis**

3 pts. D. Rabinowitz.  
Prerequisite: STAT W3659/W4107 or the equivalent. Survival distributions, types of censored data, estimation for various survival models, nonparametric estimation of survival distributions, the proportional hazard and accelerated lifetime models for covariate data, actuarial models.

# Campus Life and Student Services



# Campus Life

**T**he 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 95 percent of 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 across the hall from 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.

## Dean 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 Dean of Student Affairs Office is the hub of undergraduate student life. Admissions, Financial Aid and Educational Financing, Advising and Academic Resources, Residential Programs, Office of Multicultural Affairs, Family Programs, Special Events, Student Development and Activities, and Academic Success Programs 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 Dean 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.

## Academic Advising

The unit of Advising and Academic Resources is a complimentary, multi-functional unit that serves to enhance student experience both in and out of the classroom. Through our programs and services, we reach every student at The Fu Foundation School of Engineering and Applied Science and serve a significant number of alumni seeking admission to medical school, law school, or graduate school and those applying for postbaccalaureate fellowships. Advising duties include

counseling students about academic policies, options, and opportunities, and assisting students in the development of meaningful educational plans by helping them to identify and assess alternatives and the impact of their decisions. The essence of the unit is to be a vital and creative organization that works to strengthen and enrich the student experience and support students' academic goals. Advising and Academic Resources is committed to helping all students reach their highest potential. The programs and opportunities supported by the unit assist students in developing the ability to integrate academic knowledge with experiences that extend the boundaries of the classroom.

## ADVISING CENTERS

Collectively, the Advising Centers reflect 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 pre-professional 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 a dean in the First Year Sophomore Academic Advising Center (FYSAAC) to work with him or her during the first two years. When a student declares a major, a faculty member is appointed to guide him or her for the next two years. Students are also assigned a dean in the Junior Senior Academic Advising Center (JSAAC) who will continue to support them in their academic endeavors to graduation.

### **ACADEMIC SUCCESS PROGRAMS**

Academic Success Programs (ASP) provides a holistic approach to student development through an array of retention-based opportunities, transitional programming, tutoring, skill-building seminars, educational and personal advising, and mentoring programs. Participants receive supportive services throughout their college experience. The unit operates the McNair Fellows Program, the CC/SEAS Tutoring Services and the Opportunity Programs and Undergraduate Services. Columbia has participated in the Higher Education and Opportunity Program (HEOP) since 1970. In 1986 the University created the National Opportunity Program (NOP) and made a commitment to provide academic and financial services similar to HEOP to students from the entire United States. The mission of the McNair Fellows Program is to encourage and prepare interested and eligible undergraduates for doctoral studies and to increase the diversity of college and university faculty.

### **CC/SEAS TUTORING SERVICE**

Academic Success Programs (ASP) coordinates the CC/SEAS Tutoring Service, which provides group and individual tutoring for all undergraduate students and is free to any student receiving financial aid. Students not receiving financial aid may request and

receive free group tutoring; for individual tutoring, payment arrangements must be made with the tutor.

Tutoring is offered in a broad range of courses, including introductory sciences, languages, Core classes, and engineering subjects. Highly qualified and trained peer tutors assist students with mastering their course content, sharpening their testing skills, and maximizing their potential for academic achievement. Students can request a tutor in any subject, up until the midpoint of the semester, by filling out a tutor request form in the ASP office, 103 Furnald Hall. The last day to request a tutor is the third Friday in October for the fall term, and the first Friday in March for the spring term. Groups are formed on a first-come, first-serve basis.

### **SCHOLARS OFFICE**

The Scholars Office offers scholars enhanced academic and cultural opportunities unique to a major research university in an international city.

The Scholars Program promotes intellectual growth, the development of leadership skills, and a sense of global awareness among C. P. Davis, John Jay, Global, and Kluge Scholars through a series of events and activities that marshal the resources of Columbia University and New York City at large.

### **PRE-PROFESSIONAL ADVISING**

The Office of Pre-professional Advising works closely with the Advising Centers 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 Pre-professional Advising. Students will work with their class deans as primary pre-professional advisers; these advisers will be instrumental in writing committee evaluations for some professional schools.

## **Student Development and Activities**

Knowing that student 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 address 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.

### **ORIENTATION**

All new students are required to participate in an Orientation program that is designed to acquaint them with the University, the administration and faculty of The Fu Foundation School of Engineering and Applied Science, upper-class students, and New York City. The New Student Orientation Program for new undergraduate students begins the week prior to the start of the fall semester. Orientation is intended to assist all new students with the transition to college life. 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.

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, students will be introduced to faculty members, deans, resident advisers, and other students. Orientation includes walking tours of New York City, social events, and information sessions on University services and co-curricular opportunities. During Orientation, new students have the campus to themselves, providing a unique opportunity to make friends and settle into life at Columbia before classes begin.

## **STUDENT ORGANIZATIONS**

Programs and activities at Columbia are primarily shaped by students who assume leadership and volunteer positions in hundreds of organizations across the campus. The Engineering Student Council is the schoolwide elected representative body of The Fu Foundation School of Engineering and Applied Science. Its members represent 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) oversees the management and funding of student groups. The ABC provides information for students on campus organizations and events and offers office support to the over 150 student groups that operate directly under the ABC. Another 100 student-run organizations operate from other parts of the campus—including the Inter-Greek Council, club sports, and the Earl Hall Center. Of special interest to engineering students are the preprofessional societies, recognizing the various academic disciplines. These societies, which include the Asian-American Society of Engineers, National Society of Black Engineers, Society of Hispanic Professional Engineers, and the Society of Women Engineers, provide many networking opportunities for students.

Graduate students can participate in University-affiliated organizations and activities. As a Columbia University student, you can participate in and enjoy hundreds of diverse 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 help build a sense of community, support responsible student governance and cocurricular activities, and further students' leadership development and personal growth.

Student Development and Activities staff members advise all ABC/SDA-recognized organizations and serve 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. In addition, the Office administers the Urban New York Program, the New Student Orientation Program, and the various Columbia Outdoor Orientation programs.

## **RESIDENTIAL PROGRAMS AND FACULTY-IN-RESIDENCE PROGRAM**

The commitment to student life at Columbia has been strengthened in recent years by refocusing on the Residential Life System. The Residential Programs staff, supervised by the Assistant Dean/Director of Residential Programs and consisting of professional staff and graduate 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 Residence Life and the Faculty-in-Residence programs provide a powerful and unique synergy in Columbia's residence halls. They offer students intellectual stimulation, social interaction, and cultural awareness—all important parts of a rewarding

undergraduate experience. The success of these programs will continue to strengthen not only the sense of residential community that students enjoy, but also the academic and intellectual atmosphere of one of the world's pre-eminent educational institutions.

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 relationships and friendships 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.

## **FRATERNITIES AND SORORITIES**

Columbia has a diverse Greek system that includes fourteen men's fraternities, four coed fraternities, and five sororities. A majority 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 Fraternity and Sorority Affairs Director.

## **Multicultural Affairs**

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.

## The Office of the University Chaplain

The Office of the University Chaplain is located in the Earl Hall Center and includes the Music at St. Paul's program, the Earl Hall Annex, and Community Impact. 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. It is home to over eighty student groups that are recognized by the Student Governing Board. Additionally, 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.

## Lerner 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 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, in the pool and games room, 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 and Student Services offices. These offices include the Dean of Student Affairs Office, Student Development and Activities; the Double Discovery Center; Columbia TV; WKCR studies; 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.

## 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, crew (heavyweight and lightweight), cross-country, fencing, football, golf, 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, crew, cross-country, fencing, field hockey, golf, lacrosse, 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 a "state of the art" Astroplay practice 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-sized gymnasiums for basketball, volleyball, and badminton; twelve 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; two fully equipped saunas; and two full-size tennis courts.

### ELIGIBILITY FOR INTERCOLLEGIATE ATHLETICS

Any student in the Engineering School who is pursuing the undergraduate program or a 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 Committee on Athletic Eligibility 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 compliance office in the Department of Physical Education and Intercollegiate Athletics.

### PHYSICAL EDUCATION PROGRAMS

In addition to the activity courses (see page 17), the Physical Education Department offers a comprehensive

Intramural and Sports Club 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, <http://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 in *FACETS*, the University student handbook (<http://www.columbia.edu/cu/facets>); or at the Web site for the United States Department of Education (<http://ope.ed.gov/Security/search.asp>); or 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.

# Student Services

## 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 waiting list upon their return and are on the waiting list for each subsequent year.

A variety of residence hall accommodations are available to Columbia students. Carman, John Jay, Wien, Furnald, McBain, Schapiro, and the new Broadway residence hall are traditional corridor-style residence halls, and all but Wien 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; more than 75 percent of undergraduates live in singles. Single and double rooms are available in all halls except Carman, which has only doubles.

The residence halls are also home to a variety of Special Interest Suites. These suites, founded by students, 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 suites include 3/2 House, Casa Latina, China House, Korean Culture House, Queer House, and Pan Africa House. First-year students are not eligible to live in Special Interest Suites 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 lottery, which takes place each spring.

### 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 <http://www.columbia.edu/cu/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 <http://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 <http://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:

<http://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.

UAH-approved students can begin viewing apartments and moving in during the last week of August for the fall term, and early January for the spring term. Students will be properly notified of Graduate Orientation and Registration, which are generally held the week before the first day of class. If a student needs to move in earlier, proper documentation from the department in support of the request is necessary.

## Dining Services

### FIRST-YEAR STUDENTS

All first-year students in residence are required to enroll in one of four meal plans, each of which offers a combination of meals and Columbia Points. The meal 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 meal plan enables you to help yourself to unlimited servings of food served buffet-style in John Jay Dining Hall. With meals, you may purchase brunch and dinner, Monday through Sunday in John Jay.

### POINTS

In addition to meals, Columbia Points comprise the other portion of your first-year meal plan. Each Columbia Point is equal to one dollar and operates as a declining balance account, much like a debit card. Columbia Points roll over from the fall term to the spring, but will expire at the end of the spring.

### DINING DOLLARS

Columbia Dining Services maintains twelve dining facilities conveniently located on campus. Each of the locations 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.

### UPPER-CLASS AND GRADUATE STUDENTS

Many upper-class and graduate students who dine on campus open a Dining Dollars account; however, some choose to enroll in an upper class/graduate student meal 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.

### LOCATIONS/MENUS/HOURS

**John Jay Dining Hall:** John Jay Dining Hall, located on the first floor of John Jay Hall, serves brunch and dinner in an "all you care to eat" buffet style.

Brunch offerings include pancakes, waffles, eggs, and omelets, along with a salad bar and other lunch items.

Dinner includes hot entrees, with low-fat vegetarian and vegan choices, pasta, salads, and homemade soups. Weekend brunch offers the best of breakfast and lunch.

Monday–Sunday: 10:30 a.m.–1:30 p.m.

(brunch) and 5:00 p.m.–8:00 p.m. (dinner)

**Ferris Booth Commons:** Ferris Booth Commons is a European-style marketplace located on the third and fourth floors of Alfred Lerner Hall. The emphasis here is on an abundance of fresh, distinctive foods prepared right in front of you. Options include a sushi bar, fresh homemade pasta, New York-style pizza, Asian stir-fry, and an Indian curry station.

Monday–Thursday: 10:00 a.m.–9:00 p.m.  
Friday: 11:00 a.m.–5:00 p.m.  
Saturday and Sunday: Closed

**Café 212:** Also located in Alfred Lerner Hall, Café 212 serves fresh salads, deli sandwiches, and carryout snacks and beverages, making it a quick and convenient stop for students on the move.

Monday–Thursday: 8:00 a.m.–2:00 a.m.  
Friday: 8:00 a.m.–9:00 p.m.  
Saturday: 9:00 a.m.–9:00 p.m.  
Sunday: 9:00 a.m.–2:00 a.m.

**The Food Court at Wien Hall:** You are likely to recognize the restaurants in Wien's Food Court. Pizza Hut Express serves pizza, bread sticks, and chicken wings; Sandella's presents delicious wraps and salads; and Odyssey Café offers gourmet Greek food. In addition, two local favorites, Mill Korean and Golden Garden, bring their neighborhood Korean and Chinese menus, respectively, right to campus. Also available are a variety of grab-n-go items, including frozen entrees, pastries, beverages, desserts, and snacks.

Monday–Thursday: 11:00 a.m.–7:30 p.m.  
Friday: 11:00 a.m.–6:30 p.m.  
Saturday and Sunday: Closed

**Uris Deli:** Located directly in the center of campus on the main floor of the Business School's Uris Hall, Uris Deli brings true Manhattan deli-style fare right into the heart of Columbia University. The deli serves continental breakfast, gourmet soups, grab-n-go salads, and a variety of snacks, but their trademark is the traditional New

York-style deli sandwiches made with the finest meats on a variety of fresh breads.

Monday–Wednesday: 7:30 a.m.–7:00 p.m.  
Thursday and Friday: 7:30 a.m.–5:00 p.m.  
Saturday and Sunday: Closed

**Lenfest Café:** Lenfest Café is a compact grill, deli, and sushi bar located in the Law School on the second floor of Jerome Greene Hall. Stop by for a veggie burger, handmade sushi, or a quick snack on your way to class on the east side of campus.

Monday–Friday: 8:30 a.m.–4:00 p.m.  
Saturday and Sunday: Closed

**Carleton Lounge:** Located on the first floor of the Mudd Building, Carleton Lounge is an ideal stop for students taking classes in Columbia’s Fu Foundation School of Engineering and Applied Science. Enjoy hot entrees and prepared salads, along with gourmet soups and deli sandwiches.

Monday–Friday: 10:00 a.m.–4:00 p.m.  
Saturday and Sunday: Closed

**JJ’s Place:** Located in the basement of John Jay Hall, JJ’s Place is a combination convenience store, grill, and snack bar. While enjoying a fresh fruit smoothie, you can also pick up chips and salsa, laundry detergent, and a prepackaged sandwich for later. And JJ’s is open “after hours,” making it a favorite for students with the late-night munchies.

Monday–Thursday: 8:00 p.m.–4:00 a.m. (late night)  
Sunday: 3:00 p.m.–4:00 a.m.

**Hartley Kosher Deli:** Offering a variety of kosher sandwiches, salads, and snacks, Hartley Kosher Deli is located on the first floor of Hartley Hall. In addition to its on-site offerings, prepackaged kosher sandwiches are available for purchase at Ferris Booth Commons and Uris Deli Monday through Friday.

Monday–Thursday: 11:00 a.m.–3:00 p.m.  
Friday, Saturday and Sunday: Closed

Please note:

- All Columbia Dining Services accept Columbia Points, Dining Dollars, Flex, and cash.
- Hours are subject to change.

For further information, please feel free to write to us at Columbia University Dining Services, 2960 Broadway, MC 3003, New York, NY 10027. You may also call us at 212-854-4076 or e-mail [eats@columbia.edu](mailto:eats@columbia.edu).

#### COFFEE BAR LOCATIONS

Blue Java is a gourmet coffee bar with three convenient locations on campus that offers students a wide variety of cappuccino and espresso drinks, regular and herbal teas, hot chocolate, and a selection of grab-n-go food items. Blue Java accepts Columbia Points, Dining Dollars, Flex, and cash.

- Dodge Hall—campus level
- Butler Library—campus level
- John Jay lobby—express location

## Health Services and Insurance

#### HEALTH SERVICES AT COLUMBIA (HSC)

Health Services at Columbia (HSC) on the Morningside Campus 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 are comprised of more than 100 individuals: medical providers, dietitians, disability specialists, health educators, therapists, psychiatrists, peer counselors, student personnel, support staff, and administrative professionals. HSC is made up of the following departments:

**Alice!, Columbia University’s Health Promotion Program** seeks to make the campus healthier by connecting students with information and resources, cultivating healthy attitudes and behaviors, and fostering a culture that values and supports a healthy community. Alice! coordinates Stressbusters, the 100

m.i.l.e. Club, and the Go Ask Alice! internet Q&A service. Alfred Lerner Hall, 7th floor, 212-854-2878.

**Counseling and Psychological Services (CPS)**, supports the psychological and emotional well-being of the campus community by providing counseling, couples counseling for students and their partners, student life support groups, and medication consultations to Columbia University students who have paid the health service fee. Emergency consultations and trainings are available to the entire University community. Alfred Lerner Hall, 8th floor, 212-854-2878.

**Office of Disability Services (ODS)** facilitates equal access for students with disabilities by coordinating reasonable accommodations and support services. Reasonable accommodations are adjustments to policy, practice, and programs that “level the playing field” for students with disabilities and provide equal access to Columbia’s programs and activities. Examples include the administration of exams, services such as note-taking, sign language interpreters, assistive technology, and coordination of accessible housing needs. Accommodation plans and services are custom designed to match the disability-related needs of each student and are determined according to documented needs and the student’s program requirements. Registration includes submission of both the Application for Accommodations and Services and disability documentation. The application and disability documentation guidelines are available online (<http://www.health.columbia.edu>) and at the ODS office. Students are encouraged to register within the first two weeks of the semester to ensure that reasonable accommodations can be made. Please note that students are not eligible to receive reasonable accommodations until the registration process is complete. Alfred Lerner Hall, Room 801, 212-854-2388.

**Primary Care Medical Services (PCMS)** provides comprehensive care for routine, urgent, and chronic medical needs for students, and well-woman services,

GLBTQ health care, immunizations, and referrals. There are three practice groups: Amsterdam, Broadway, and Morningside. Also part of PCMS is the multidisciplinary Eating Disorders Team, CU on the Road Travel Medicine Program, CU Emergency Medical Services, and the Gay Health Advocacy Project (GHAP). John Jay Hall, 3rd and 4th floors, 212-854-2284.

**Sexual Violence Prevention and Response Program (SVPRP)** educates students and administrators about consent and coercion, and promotes community standards for a respectful and safe campus. Through its programs and services, SVPRP fosters individual and collective action to end sexual and relationship violence. The Rape Crisis/Anti-Violence Support Center provides peer counseling, advocacy, and education to survivors and co-survivors of sexual assault, relationship violence, childhood sexual abuse, and other forms of violence. The Men's Peer Education Program provides educational events, prevention strategies, and leadership training programs to engage men to end sexual and relationship violence. Alfred Lerner Hall, Room 301, 212-854-3500.

For information on how to report sexual misconduct, or for the University's policy on sexual misconduct, please check the Web site for *FACETS*, the University student handbook (<http://www.columbia.edu/cu/facets>).

**The Sexual Violence Prevention and Response Program**, located on the third floor of Lerner Hall, provides comprehensive and integrated education, support, and advocacy about sexual and relationship violence. The program includes the **Rape Crisis/Anti-Violence Support Center** (100 Brooks Hall on the Barnard campus), which offers peer counseling, advocacy, and education to survivors and community members.

All programs and services provided by Health Services at Columbia adhere to strict standards of confidentiality in compliance with state and federal laws. <http://www.health.columbia.edu>

#### **ON-CAMPUS EMERGENCY RESOURCES**

CU Emergency Medical Services: 212-854-5555

Clinician-on-call & General Information: 212-854-2284

Rape Crisis/Anti-Violence Support Center: 212-854-HELP; 212-85-WALK

Security: x99, 212-854-5555

#### **OFF-CAMPUS EMERGENCY RESOURCES**

St. Luke's-Roosevelt Emergency Room 212-523-3335

St. Luke's-Roosevelt Psychiatric Emergency 212-523-3347

#### **HEALTH SERVICE FEE**

Services and programs offered by Health Services at Columbia are supported by the Health Service Fee. Students who have paid the Health Service Fee pay no additional charges when using services provided on campus, except for nominal charges for immunizations and travel assessments. By University policy, all registered full-time and residential students must have acceptable health insurance coverage and pay the Health Service Fee. In addition to the services available on campus, Health Services at Columbia arranges for students who have paid the Health Service Fee to obtain coverage for certain important services from off-campus providers when necessary. Coverage is provided for accidental injury or medical emergencies, emergency room care, emergency in-patient hospital care, physician services related to the treatment of accidental injury or medical emergencies, elective termination of pregnancy, off-campus mental health services,\* out-patient treatment for chemical abuse.\* There are limits and restrictions on this coverage. Please review the full program descriptions and directions for utilizing the benefits at <http://www.health.columbia.edu/>.

#### **STUDENT MEDICAL INSURANCE PLAN**

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. Part-time students may elect enrollment in the Health Services Program and in the medical insurance plan. Visit <http://www.health.columbia.edu> for detailed information about medical insurance coverage options and directions for making confirmation, enrollment, or waiver requests.

#### **MENINGOCOCCAL MENINGITIS VACCINATION DECISION**

New York State law requires that all college and university students receive information from their institutions about meningococcal meningitis and the vaccine that protects against most strains of the disease that occur on university campuses. Columbia University students must certify their meningitis vaccination decision at <http://www.health.columbia.edu>. Students must use their individual University Network ID (UNI) and password to complete this certification.

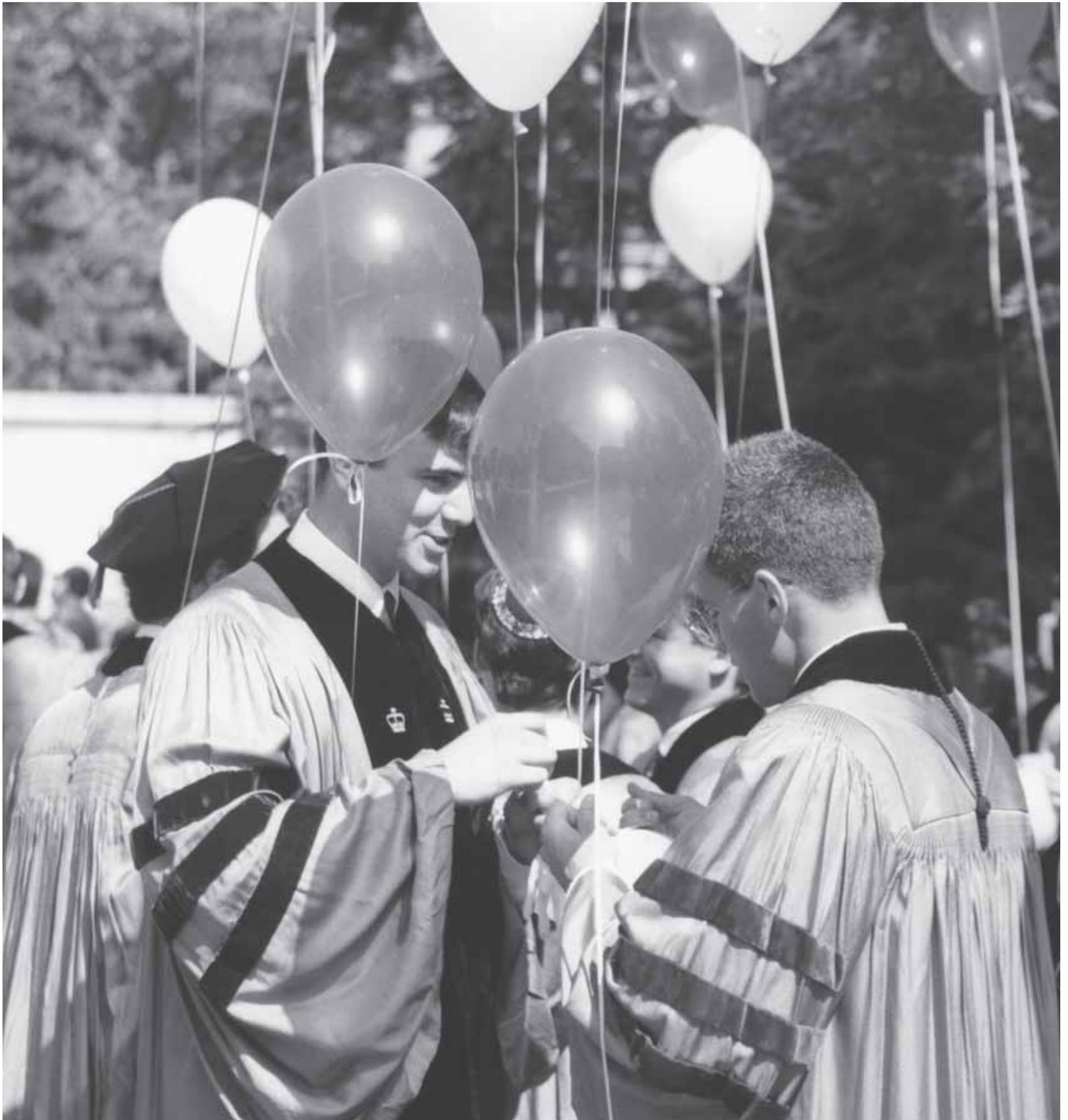
#### **MEASLES, MUMPS, AND RUBELLA (MMR)**

New York State law requires all college and university students enrolled for 6 or more credits to be adequately protected against measles, mumps, and rubella (MMR) prior to enrollment at the University. If a student cannot provide evidence of immunity to MMR, s/he will not be permitted to register for classes. Visit <http://www.health.columbia.edu> for documentation instructions and to download the MMR form.

If you have any questions about these requirements, please e-mail us at [hs-enrollment@columbia.edu](mailto:hs-enrollment@columbia.edu) (please allow one business day for questions to be answered).

\*Referral by a clinician in Counseling and Psychological Services is required.

# Scholarships, Fellowships, Awards, and Prizes



# 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.

### **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.

### **William Campbell Fellowships for Encouraging Scientific Research**

Four or five fellowships awarded annually for research in the general field of metals.

### **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.

### **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.

### **Quincy Ward Boese Fellowships**

Predocctoral 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.

### **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.

### **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 depart-

ment 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.

**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.

**Nichoplas 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.

**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.

**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.

**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**

Gift of Theodore T. Tsung (1982). Awarded for graduate study in the Department of Electrical Engineering.

**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

**Czi 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.

**Nathaniel Arbiter Scholarship (1985)**

Gift of various donors in honor of Professor Nathaniel Arbiter 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)**

For needy and deserving students in the Fu Foundation School of Engineering and Applied Science. Gift of Michael J. Attardo (1963).

**Jee Yin and Choi Heung Au Scholarship Fund (2002)**

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)**  
For a student continuing in The Fu Foundation School of Engineering and Applied Science. Preference given to United States citizens. Gift of Lauren P. Breakiron (1956).

**Samuel J. Clarke Scholarship (1960)**  
Bequest of Agnes Robertson Clarke.

**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.

**Burns and Roe, Arthur J. Fiehn Scholarship (1989)**  
Gifts from various donors in memory of Arthur J. Fiehn (1946).

**Byron Fellowship (1980)**  
Bequest of Verna and Oscar Byron (1914).

**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 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.

**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).

**Jack Dicker Endowed Scholarship (2003)**  
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.

**Everard A. Elledge Memorial Scholarship (1985)**  
Gift of Carol G. Elledge, in memory of Everard A. Elledge (1942).

**John M. Erickson Memorial Scholarship (1986)**  
Preference is given to students of Scandinavian heritage.

**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.

**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).

**Robert Gross Fund (1999)**  
Gifts of friends of Robert Gross. For an applied physics student.

**Wallace K. Grubman Scholarship (1998)**  
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.

**James T. Horn Scholarship (1938)**  
Gift of Sarah L. and Mary T. Horn, in memory of their brother, James T. Horn (1884).

**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)**  
Bequest of Belinda Hearn Jouet, in memory of C. H. Jouet (1882).

**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.

**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).

**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.

**Donald D. MacLaren Scholarship (1995)**

For an undergraduate student who is studying biochemical engineering. Established by Donald D. MacLaren (1945).

**Manelski Family Scholarship (2004)**

Gift of Darren E. Manelski (1991) to support needy and deserving students of The Fu Foundation School of Engineering and Applied Science.

**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.

**Stuart Miller Endowed Scholarship in Engineering (2003)**

Gift of Stuart Miller, to be used to provide support for an undergraduate engineering student.

**Frank C. Mock and Family Scholarship (1987)**

Bequest of Frank C. Mock (1913). For students in electrical engineering with financial need.

**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.

**Louis Morin Scholars and Fellows (2000)**

Gift of the Louis Morin Charitable Trust. Designated for Jewish undergraduates, Ph.D.s, and postdocs.

**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).

**Robert I. Pearlman Scholarship (1989)**

Gift of Robert I. Pearlman (1955). Awarded in alternate years to students in the School of Engineering and Applied Science and in Columbia College. Preference is given to students who are from one-parent families.

**Robert Peele 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.

**Roy Howard Pollack Scholarship (1998)**

Bequest of Roy Howard Pollack to be used for scholarships for junior or senior 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.

**The Frederick Roeser 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 Roeser 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.

**Ralph J. Schwarz Scholarship (1993)**

Gift of the Class of 1943 and other donors in honor 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).

**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).

**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.

### **Dean's Scholarships**

One or more scholarships awarded annually to students of exceptional promise. A stipulation of this special fund is that financial need is not a requirement. Annual renewal is dependent upon continued superior achievement.

### **DuPont Fellowship**

In chemical engineering.

### **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.

### **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.

### **School of Engineering and Applied Science Fellowships**

Varying in number; provided annually by the Trustees of Columbia University.

### **The Weing 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.

**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.

**Stephen D. Guarino Memorial Award in Industrial Engineering and Operations Research (2003)**

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 \$100 cash prize presented annually 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 geotechnical/geoenvironmental 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 M. 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 outstand-

ing promise of personal development leading to a career in construction engineering and management.

**The James F. Parker Memorial Award (Mechanical Engineering Design Award)**

**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 graduate senior in the department.

**Richard Skalak Memorial Prize**

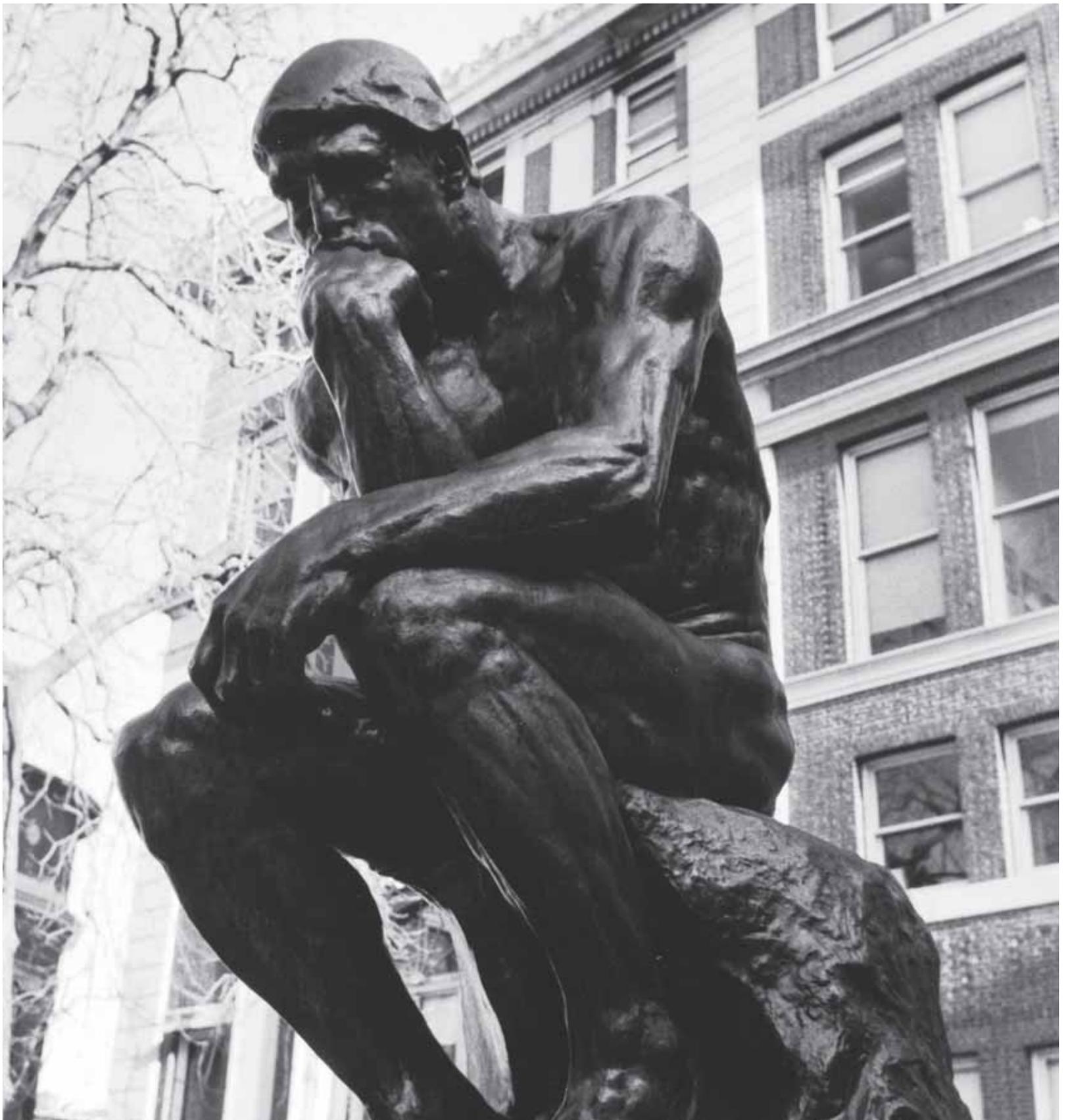
The Richard Skalak Memorial Prize was founded in recognition of the pioneering contributions of Richard Skalak to the development of the biomedical engineering program at Columbia University. Dr. Skalak was an inspirational teacher and scholar who taught students and colleagues to appreciate the value 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



# Academic Procedures and Standards

## 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 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. *Note:* Auditing is available to graduate students only.

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 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.

### REGISTRATION FOR LIMITED-ENROLLMENT CLASSES

There are two categories of limited-enrollment classes. The enrollment limits in the first category are controlled directly by instructors or their departments. To register for these classes, students must first obtain the approval of the person indicated in the registration instructions and their adviser's approval of the entire program. Students who have completed these steps may then register on the dates provided by the Office of the Registrar.

## 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 their adviser.

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, 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 (D.E.S.) 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 (D.E.S.) 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 published deadlines must obtain the signature of his or her adviser on an add/drop form. 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; a maximum of 12 credits may be taken per 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 the approval of their adviser and the Department before taking such courses. 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 may obtain academic credit toward the Ph.D. or D.E.S. only. No academic credit is awarded from other institutions toward the M.S. degree; students must complete the entire M.S. degree (minimum of 30 points) at Columbia. Advanced standing is awarded to students entering the Ph.D. or D.E.S. program only. Students may choose from either academic credit or Residence Units. Graduate students must consult with their academic department and the Office of Graduate Student Services.

### 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 on line 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. 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 amended Family Educational Rights and Privacy Act (FERPA) of 1974 prohibits release of educational records without the written consent of the student (for certain exceptions and further restrictions, consult *FACETS*, the University student handbook, <http://www.columbia.edu/cu/facets>).

You may obtain an official transcript of your academic record at Columbia University by writing to:

Office of the Registrar  
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; Social Security number; 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 <http://www.columbia.edu/cu/students/>. There is no charge for issuing transcripts; however, all students pay a one-time transcript fee of \$45 upon their first registration at the University. The normal processing time for transcripts is two to three business days. If you mail in your

request for a transcript, you should allow several additional days for delivery to and from the University.

You may order certifications of your enrollment and degrees via mail, in person, or on the Student Services Web page as described above. When requesting a certification by mail, include the notation "Attention: Certifications" on your envelope. Certifications are provided while you wait if you come to Kent Hall to request them. There is no charge for certifications.

## 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 <http://www.columbia.edu/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 MU will not be included in the computation of the grade-point average.

The mark of R (registration credit; no qualitative grade earned): 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 on INC by filling out the Incomplete Request Form with their class 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.

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 who 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 Office of the Registrar. 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 graduate 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 Office of the Registrar, 205 Kent Hall. Candidates for doctoral and master of philosophy degrees should inquire at their departments but must also follow the instruc-

tions 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 Office of the Registrar, Graduation, Degree Audit, and Diploma Division, 212-854-4330.

# 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 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. 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 time frame, they will be permanently withdrawn from the School. During the course of the leave, students are not permitted to take any courses for the purpose of transferring credit and are not permitted to be on the campus.

## 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 appropriate academic advisement center. Graduate students should see the Office of Graduate Student Services.

Students applying for readmission should complete all parts of the appropriate readmission procedures by May 1 for the autumn term or October 1 for the spring term.

# Policy on Conduct and Discipline

## 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 XLI 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 in *FACETS*, the University student handbook (<http://www.columbia.edu/cu/facets>), and 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 a dean in their academic advisement center; 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;
- Actions that cause or might cause injury to persons or damage to property;
- Harassment of others in the University community or of anyone visiting Columbia;
- Theft of property;
- Possession or distribution 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 bodily harm;
- 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 (see the University Residence Halls publication Services, Policies, and Procedures); this also applies to all fraternity and sorority housing;
- Violating the University’s Alcohol Policy (see *FACETS*);
- Violating the University’s Sexual Misconduct Policy (see page 226);
- Violating the rules governing Administration Information Systems (AIS) 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.

## Procedures

1. Many violations of Residence Halls rules are handled by the resident advisers and assistant directors of residential programs. Some serious offenses are referred directly to the Assistant Dean of Advising and Residential Programs. Violations in University Apartment Housing are handled 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.
2. Most violations of rules concerning fraternities or sororities as organizations are handled by the Office of Fraternity and Sorority Affairs. Some serious offenses are referred directly to the Office of the Dean of Student Affairs.
3. In matters involving rallies, picketing, and other mass demonstrations, the Rules of University Conduct outlines procedures.
4. The Office of the Dean 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.

When sufficient evidence exists, a student is charged with a particular offense and a hearing is scheduled. Present at a hearing for undergraduate students are the charged student and at least two members of the Student Affairs staff. 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 probation to suspension or dismissal. The student may also be barred from certain University facilities or activities. An accused student has the right to appeal a decision that results from a disciplinary hearing. The appeal must be made in writing within the time period specified in the letter regarding the decision, and to the person specified in the letter.

In general, under University policy and federal law, information about Dean's Disciplinary proceedings against a student is confidential and may not be disclosed to others. A limited exception to this principle is that the outcome of Dean's Disciplinary proceedings alleging a "sexual assault" must be disclosed both to the accuser and the accused.

The following statement on plagiarism is in the Guide for New Students and is included here for the convenience of students in the School.

### 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.

Every year there are instances in which students attempt to submit the work of other people as their own. Because intellectual integrity is the hallmark of educational institutions, academic dishonesty is one of the most serious offenses that a student can commit at Columbia. It is punishable by suspension or dismissal from the School.

In making clear Columbia's policy on plagiarism, it is not feasible to include here all the various forms—they are innumerable—that plagiarism might take. It is useful, however, to list several obvious varieties in order to dispel confusion about actions that the School will not tolerate:

1. Submitting essays, or portions of essays, written by other people as one's own;
2. Failing to acknowledge, through proper footnotes and bibliographic entries, the source of ideas essentially not one's own, including resources from the Internet;
3. Failing to indicate paraphrases or ideas or verbatim expressions not one's own through proper use of quotations and footnotes;
4. Submitting written work for one course to a second course without having received prior permission from both instructors;
5. Collaborating on an assignment or examination without specific permission from the faculty member to do so;
6. Selling of notes, syllabi, or papers.

This list, of course, does not pretend to be definitive. If questions arise concerning proper use of quotations, footnotes, or bibliographies, the student should contact the instructor. Seeking informed advice from a faculty member is the best way to avoid confusion about matters that can be complicated.

In the past, plagiarism very rarely has been the result of confusion or misunderstanding. It is safe to say that students who do not want to plagiarize will not be guilty of doing it. Students who willfully attempt it are cheating themselves as well as others. The School will not permit such counterproductive activity.

Undergraduate students should direct questions about rules or procedures to their adviser; graduate students, to the Office of Graduate Student Services.

## Columbia University Equal Opportunity, Nondiscrimination, and Affirmative Action Statements

### **COLUMBIA UNIVERSITY EQUAL EDUCATIONAL OPPORTUNITY STATEMENT**

Columbia University admits students to all the rights, privileges, programs, and activities. It does not discriminate against any person on the basis of race, color, sex, national and ethnic origin, age, religion, or other legally protected status in the administration of its educational policies, admissions policies, scholarship and loan programs, and athletic and other University-administered programs.

### **COLUMBIA UNIVERSITY EQUAL EMPLOYMENT OPPORTUNITY, NONDISCRIMINATION, AND AFFIRMATIVE ACTION STATEMENT**

Columbia University is an equal opportunity and affirmative action employer. It provides equal employment opportunity to all employees and applicants for employment without regard to race, color, sex, national and ethnic origin, age, religion, or any other legally protected status and takes affirmative action to recruit, employ, train, and promote qualified minorities, women, covered Veterans and individuals with disabilities. It prohibits discrimination against employees or applicants for employment on the basis of race, color, sex, gender, religion, creed, national and ethnic origin, age, alienage and citizenship, status as a perceived or actual victim of domestic violence, disability, marital status, sexual orientation, status as a Vietnam era or disabled Veteran, or any other legally protected status.

### **COLUMBIA UNIVERSITY POLICY OF COMPLIANCE WITH FEDERAL, STATE, AND LOCAL LAWS PROMOTING EQUAL OPPORTUNITY, PROHIBITING DISCRIMINATION, AND AUTHORIZING AFFIRMATIVE ACTION**

In accordance with all applicable federal, state, and local laws and pursuant to its own policies and operating procedures, Columbia University provides for equal opportunity, prohibits unlawful discrimination and harassment, and takes affirmative action.

Title VI of the Civil Rights Act of 1964, as amended, prohibits discrimination against any person on the basis of race, color, or national and ethnic origin in programs or activities receiving federal financial assistance.

Title VII of the Civil Rights Act of 1964, as amended, prohibits employment discrimination against any person because of race, color, religion, sex, or national origin.

Executive Order 11246, as amended, prohibits discrimination in employment because of race, color, religion, sex, or national and ethnic origin and requires affirmative action to ensure equality of opportunity in all aspects of employment.

Title IX of the Education Amendments of 1972, as amended, prohibits discrimination on the basis of sex in the conduct or operation of a school's educational programs or activities, including employment in and admission to these programs and activities.

Section 503 of the Rehabilitation Act of 1973 requires a federal contractor to take affirmative action to employ and advance in employment qualified workers with disabilities. Section 504 prohibits discrimination by a federal contractor against any person on the basis of disability in admission to, access to, or employment in its programs and activities.

The Equal Pay Act of 1963 prohibits discrimination on the basis of sex in rates of pay.

The Age Discrimination in Employment Act of 1967, as amended, prohibits discrimination in employ-

ment on the basis of age. The Age Discrimination Act of 1975 prohibits discrimination on the basis of age in programs and activities receiving federal financial assistance.

The Americans with Disabilities Act of 1990 prohibits discrimination in public accommodation and in employment against a qualified person with a disability and requires the University to provide qualified applicants and employees with reasonable accommodation.

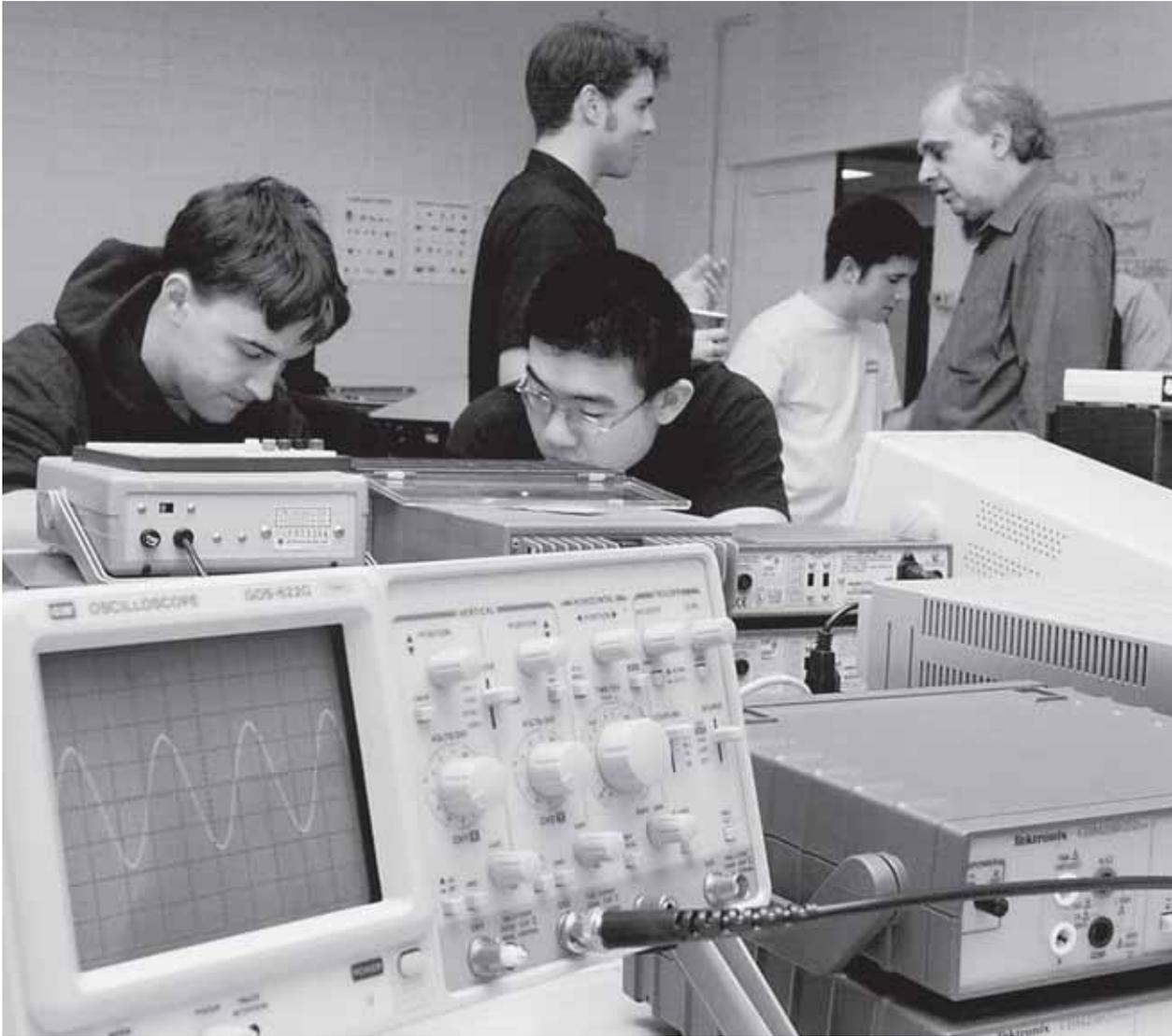
The Vietnam Era Veterans' Readjustment Assistance Act of 1974 and the Veterans Employment Opportunity Act of 1998, as amended, prohibit job discrimination and require affirmative action to employ and advance in employment qualified special disabled Veterans, Veterans of the Vietnam era, recently separated Veterans, and any other Veterans who served on active duty during a war or in a campaign or expedition for which a campaign badge has been authorized.

The Immigration Reform and Control Act of 1986 prohibits employers from discriminating on the basis of citizenship status or perceived citizenship or immigration status. The prohibition extends to employers who hire only U.S. citizens or U.S. citizens and green card holders as well as to employers who prefer to employ unauthorized workers or temporary visa holders rather than U.S. citizens and other workers with employment authorization.

The Small Business Act of 1958, as amended, requires federal contractors to afford maximum practicable business opportunities to Small Business Concerns, including minority and women-owned businesses.

The New York Executive Law, Article 15, Section 296 prohibits discrimination against any person in employment because of age, race, creed, color, national origin, disability, sex, marital status, and genetic predisposition or carrier status.

New York Education Law, Section 313, as amended, prohibits educational institutions from discriminating against persons seeking admission as students to any institution, program,



or course because of race, religion, creed, sex, color, marital status, age, or national origin.

The New York City Human Rights Law, Title 8, Section 8-107, makes it an unlawful discriminatory practice for an employer to discriminate against any person because of their age, race, creed, color, national origin, gender, disability, marital status, sexual orientation, or alienage or citizenship status. It also prohibits educational institutions from discriminating against persons in any of the above categories in the provision of certain accommoda-

tions, advantages, facilities, or privileges.

The University's Office of Equal Opportunity and Affirmative Action has been designated to coordinate compliance activities under each of the programs referred to above. Anyone who believes that he or she has been denied equal opportunity should contact this Office, which may investigate complaints and offer advice and counsel on questions relating to equal opportunity and affirmative action, including information about applicable formal grievance procedures and agen-

cies where complaints may be filed. All employees, students, and applicants for employment and admissions 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. Office of Equal Opportunity and Affirmative Action, Columbia University, 103 Low Library, MC 4333, 535 West 116th Street, New York, NY 10027; 212-854-5511.

# Official University Regulations\*

## Discrimination and Sexual Harassment Policy and Procedure

The University's Discrimination Grievance Procedure is available to enrolled students who feel that they have been the victims of sexual harassment or discrimination on the basis of race, color, religion, national or ethnic origin, sex, sexual orientation, marital status, age, disability, citizenship, the actual or perceived status of an individual as a victim of domestic violence, or Vietnam era or qualified special disabled Veteran status. A copy of the Policy and Procedure is available in *FACETS* (<http://www.columbia.edu/cu/facets>), the University student handbook, and in the Office of Equal Opportunity and Affirmative Action, 103 Low Memorial Library; telephone 212-854-5511.

A complaint may be brought by filing a written complaint with Susan Rieger, the Associate Provost in charge of the University's Office of Equal Opportunity and Affirmative Action (the "Equal Opportunity Officer"), 103 Low Memorial Library, 212-854-5511. A complaint shall be brought within 180 working days after the occurrence of the alleged unlawful discrimination. Where a complaint is not timely filed, however, the Equal Opportunity Officer may determine that special circumstances exist that excuse the delay and consider the complaint as timely filed.

## GENERAL GRIEVANCE PROCEDURE

Students with grievances not related specifically to discrimination or harassment have two options. A student with an academic grievance should first seek to resolve the matter with the instructor or adviser, as appropriate. If the matter cannot be resolved, then the department chair should be contacted. If no satisfactory resolution of the grievance can be reached at the department level, then the student should send his or her grievance in writing to the Vice Dean, who will address the student's concerns and take appropriate action if necessary. For more information, contact the Office of the Vice Dean at 212-854-2993.

Grievances of a nonacademic nature for undergraduate students are handled by the Office of the Dean of Student Affairs or its designee. The Dean of Student Affairs will review and attempt to resolve all grievances submitted in writing. If other students are involved, the Dean of Student Affairs may take appropriate action through the mechanism of Dean's Discipline. Grievances of a nonacademic nature for graduate students are handled by the Office of Graduate Student Services or its designee. The Assistant Dean will attempt to resolve all grievances submitted in writing. If other students are involved, the Assistant Dean may take appropriate action through the mechanism of Dean's Discipline.

Students may also seek resolution of grievances through the University's Ombuds Officer (see the section Columbia University Ombuds Office under "Official University Regulations").

## CHARGE OF THE UNIVERSITY PANEL ON DISCRIMINATION AND SEXUAL HARASSMENT

The Columbia Panel on Discrimination and Sexual Harassment is composed of trusted, accessible, and sympathetic members of the University community who act as informal mediators. Their goal is the protection and counseling of any member of the University who is made to feel personally pressured or uncomfortable because of the behavior of another University member. Members of the Panel provide a safe, impartial, nonadversarial setting in which the problem can be considered or solved through confidential counseling and, when requested, mediation between the complainant and the alleged harasser. The Panel thus provides guidance and protection for the accused as well as identifying false or mistaken accusations, misunderstandings, or unconscious behavior. Panel members are also a link through which the University can take account of, and take appropriate action against, those on campus who are behaving illegally. Names and contact information for members of the Columbia Panel on Discrimination and Sexual Harassment can be found in Appendix F of

\*Since policies and procedures are subject to change, please check the Web site for *FACETS*, the University student handbook (<http://www.columbia.edu/cu/facets>), for the most current information.

*FACETS* (<http://www.columbia.edu/cu/facets>), the University student handbook, or by contacting the Office of Equal Opportunity and Affirmative Action.

### ROMANTIC RELATIONSHIP ADVISORY STATEMENT

Columbia University's educational mission is promoted by the professionalism of its faculty-student and staff-student relationships. Faculty and staff are cautioned that consensual romantic relationships with student members of the University community, while not expressly prohibited, can prove problematic. While some relationships may begin and remain harmonious, they are susceptible to being characterized as nonconsensual and even coercive. This sometimes occurs when such a relationship ends and is exacerbated by the inherent power differential between the parties.

A faculty or staff member involved in a consensual relationship with a student is expected to remove him/herself from academic or professional decisions concerning the student. This expectation arises because the relationship may impair, or may be perceived as impairing, a faculty or staff member's ability to make objective judgments about that student.

The Provost has authorized some departments to adopt more restrictive policies, given the special nature of the relationship between their students and faculty or staff. Individuals are, therefore, encouraged to contact their department head if they have any questions about whether a more restrictive policy applies to them. Departments that wish to establish more restrictive policies should contact Susan Rieger before implementation.

Should a romantic relationship with a student lead to a charge of sexual harassment against a faculty or staff member, the University is obligated to investigate and resolve the charge in accordance with its Sexual Harassment Policy and Procedure.

Questions regarding this Advisory Statement may be directed to Susan

Rieger, Office of Equal Opportunity and Affirmative Action, 103 Low Memorial Library, Mail Code 4333, 535 West 116th Street, New York, NY 10027; 212-854-5511.

## Sexual Misconduct 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 Sexual Misconduct Policy applies to all students in all schools of the University. The Disciplinary Procedure for Sexual Misconduct applies to these same students, with the exception of the Law School, but including the students of Teachers College and Barnard College. The policy prohibits sexual misconduct by any student and provides for comprehensive education of students, faculty, and administrators about the issue of sexual misconduct.

Copies of the policy and procedure are available from the Administrative Coordinator of the Disciplinary Procedure for Sexual Misconduct, 703 Lerner, Mail Code 2617, 2920 Broadway, New York, NY 10027; telephone: 212-854-1717; fax: 212-854-2728; <http://www.columbia.edu/cu/sexualmisconduct/>. The policy and procedure can also be found in the Office of the Dean of Students of every school and in *FACETS*, the University student handbook (<http://www.columbia.edu/cu/facets>).

### POLICY

The University's Policy on Sexual Misconduct 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 misconduct. Columbia University's policy defines sexual misconduct as nonconsensual, intentional physical conduct of a sexual nature,

such as unwelcome physical contact with a person's genitals, buttocks, or breasts. Lack of consent may be inferred from the use of force, threat, physical intimidation, or advantage gained by the victim's mental or physical incapacity or impairment of which the perpetrator was aware or should have been aware.

### COMPLAINT RESOLUTION OPTIONS

Three University-based options are available for resolution of complaints of sexual misconduct against a student:

1. Dean's Discipline within the school of the charged student;
2. mediation through an accredited mediator affiliated with the University, such as the Ombuds Officer; or
3. the University's Disciplinary Procedure for Sexual Misconduct.

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 Administrative Coordinator of the Disciplinary Procedure for Sexual Misconduct (703 Lerner, Mail Code 2617, 2920 Broadway, New York, NY 10027; telephone: 212-854-1717; fax: 212-854-2728; <http://www.columbia.edu/cu/sexualmisconduct>) 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.

Complaints about non-student 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.

## 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.

## University Regulations

According to University regulations, each person whose registration has been completed will be considered a student of the University during the term for which he or she is registered unless the student's connection with the University is officially severed by withdrawal or otherwise. No student registered in any school or college of the University shall at the same time be registered 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 registered.

The privileges of the University are not available to any student until he or she has completed registration. A student who is not officially registered for a University course may not attend the course unless granted auditing privileges. No student may register after the stated period unless he or she obtains the written consent of the appropriate dean or director.

The University reserves the right to withhold the privilege of registration or any other University privilege from any person with an unpaid debt to the University.

## 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 on any particular day or days. No student will be penalized for 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 221.

## The Federal Family Educational Rights and Privacy Act (FERPA)

The University abides by the provisions of the Federal Family Educational Rights and Privacy Act (FERPA) of 1974. This act insures 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 at the Registrar's Office, 205 Kent. This same office can provide a set of guidelines and a policy statement. The guidelines are also available on Columbia's Web site and in the current edition of *FACETS*. Questions about the interpretation of the guidelines should be referred to the University's General Counsel, 412 Low Library.

You may order certifications of your enrollment and degrees via mail or in person, as described above. When requesting a certification by mail, include the notation "Attention: Certifications" on your envelope. Certifications are provided while you wait if you come to Kent Hall to request them. There is no charge for certifications.

## 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 at 660 Schermerhorn Extension; telephone: 212-854-1234; fax: 212-854-6046; e-mail: [ombuds@columbia.edu](mailto:ombuds@columbia.edu). On Wednesdays the Ombuds Officer is at the Health Sciences campus office, 101 Bard Hall, 50 Haven Avenue; telephone: 212-304-7026.

# Student Grievances, Academic Concerns, and Complaints

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](mailto: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 <http://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 <http://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.

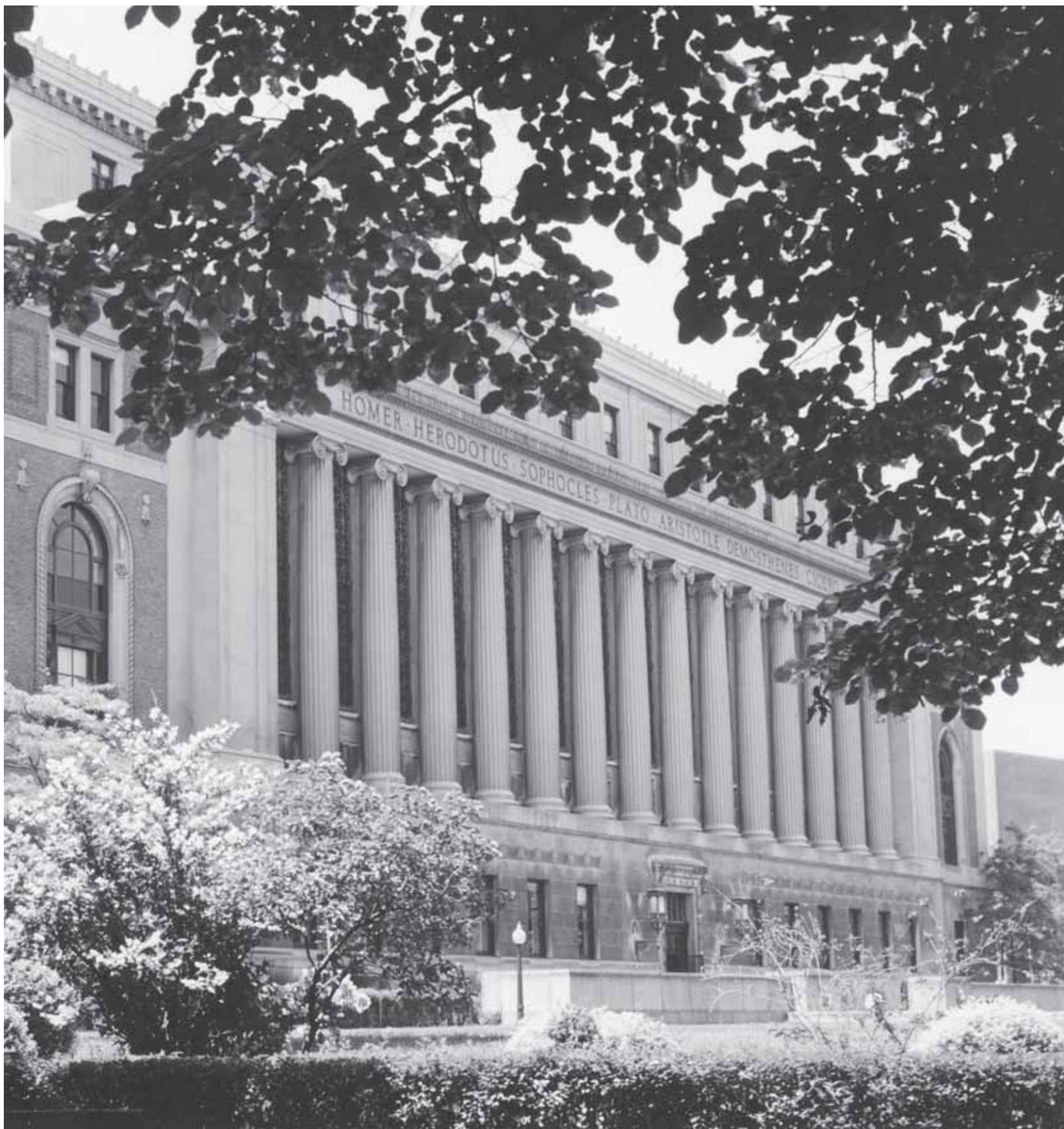
## **C. Discrimination and sexual harassment**

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](http://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 Statement on Professional Ethics and Faculty Obligations and Guidelines for Review of Professional Misconduct, available at [www.columbia.edu/cu/vpaa/fhb/app/app\\_e.html](http://www.columbia.edu/cu/vpaa/fhb/app/app_e.html).

# Directory of University Resources



# Columbia University

## Resource List

### Academic Information Systems (AcIS)

Computing Support Center:  
Walk-in Support Center  
102 Philosophy, Mail Code 4926  
212-854-1919  
consultant@columbia.edu

Mailing Address:  
401 Watson, Mail Code 6001  
212-854-1919

### Academic Success Programs

103 Furnald Hall, 212-854-3514  
Mail Code 4747

- OPUS (HEOP and NOP)
- CC/SEAS Tutoring Service
- McNair Fellows Program

Sunday Coward, *Assistant Dean, Academic Success Programs*  
sfc15@columbia.edu

Limary Carrasquillo-Montalvo,  
*Program Coordinator*  
lc2009@columbia.edu

Jorge Sandoval, *Associate Director, OPUS*  
js2125@columbia.edu

Dahlia Adu-Peasah, *Assistant Director, OPUS*  
da333@columbia.edu

Manoushka Constant, *Program Counselor, OPUS*  
mlc2122@columbia.edu

Sachiel Mondesir, *Tutor Coordinator*  
sm238@columbia.edu

Tamara White, *Administrative Assistant*  
tw2128@columbia.edu

### Admissions (Graduate)

See Graduate Student Services

### Admissions (Undergraduate)

212 Hamilton, 212-854-2522  
Mail Code 2807

Jessica Marinaccio, *Director*  
jm996@columbia.edu

Alice Huang, *Assistant Director*  
ah704@columbia.edu  
combinedplan@columbia.edu

### 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  
<http://www.cce.columbia.edu>  
cce@columbia.edu

Christopher Pratt, *Dean of Career Education*

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**Health Services at Columbia****Primary Care Medical Services**

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212-854-2284  
Mail Code 3601  
<http://www.health.columbia.edu>

Appointments: 212-854-2284

Clinician on Call (for after-hours medical and psychological consultation (Sept. 1–May 31): 212-415-0120

Eating Disorders Team (confidential voice-mail line): 212-854-1177

Enrollment/Immunization Office  
212-854-7210

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  
<http://www.chickering.com/columbiadirect.html>

Travel Medicine Clinic (CU on the Road): 212-854-2284

**Alice!, Columbia University's Health Education Program**

Lerner, 7th floor, 212-854-5453  
Mail Code 2608  
<http://www.alice.columbia.edu>

Presents a wide range of health education and skill-building programs, including Go Ask Alice!, 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. Walk-in sessions Monday–Friday 1:00–2:00 p.m. during the academic year.

**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)**

100 Brooks Hall (Barnard Quad)  
Business Line: 212-854-4366  
24-hour Peer Advocates: 212-854-WALK (9255)  
Peer Counselors (Tuesday–Sunday, 7:00–11:00 p.m.): 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**

Assistant Vice President's Office  
102 Wallach, 212-854-2782  
Mail Code 3001

Customer Service Center  
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mp20@columbia.edu  
Work orders, keys, dining inquiries, miscellaneous student services.

**Office of Housing Services**

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Immigration and Documentation Services  
International Student Orientation  
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**Libraries****Butler Library Information**

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Mail Code 1121

**Engineering Library (Monell)**

422 S. W. Mudd, Mail Code 4707  
Circulation: 212-854-2976  
Reference: 212-854-3206  
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CAMPUS EMERGENCIES: From on-campus 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\

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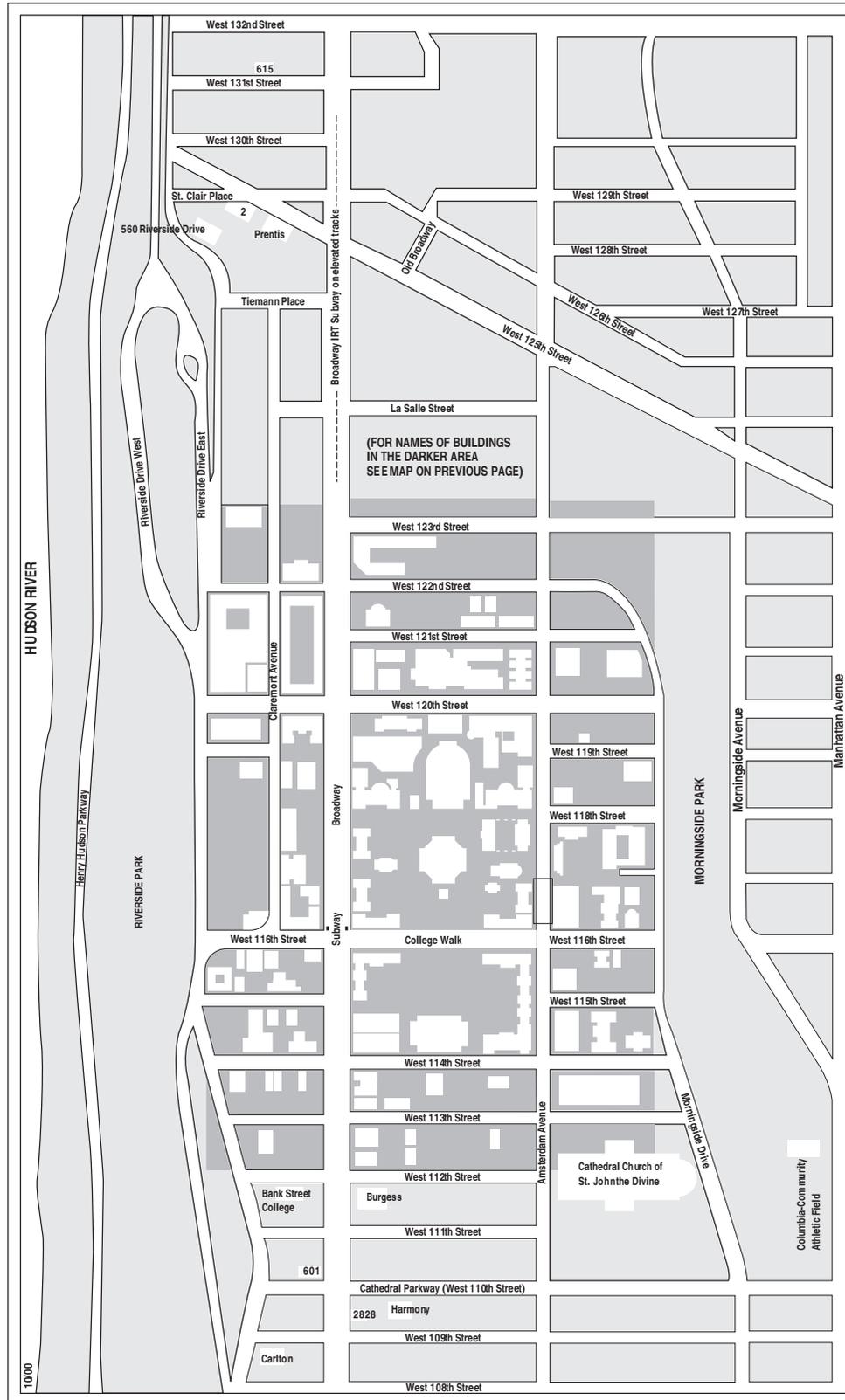
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Student Financial Planning:  
212-854-7082

For quick answers to your questions, visit: <http://askus.columbia.edu/>.



# The Morningside Heights Area of New York City



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# Academic Calendar 2005–2006

The following Academic Calendar was correct and complete when compiled; however, the University reserves the right to revise or amend it, in whole or in part, at any time. Information on the current Academic Calendar may be obtained in the Office of the Registrar, 205 Kent, 212-854-4330. It is also available on the Registrar's Web site: <http://www.columbia.edu/cu/registrar>.

## AUTUMN TERM 2005

### AUGUST

- Aug. 29– Orientation for new students.  
Sept. 5

### SEPTEMBER

- 2 Registration by appointment for first-year students and transfers.  
5 Labor Day. University holiday.  
6 Classes begin. Late registration and change of program begins. First day to change programs.  
6–9, 12–16 Late telephone registration by appointment.  
16 Late registration ends. Last day to (1) register for academic credit, (2) change course programs, (3) submit written notice of withdrawal from the autumn term to the Dean of Student Affairs for full refund of tuition and special fees. No adjustment of fees for individual courses dropped after this date.  
19 Last day to waive or enroll in Student Medical Insurance for fall 2005.

### OCTOBER

- 19 Conferring of October degrees and certificates. Last day for Ph.D. candidates who are to stand for the final examination (defense) in the autumn term to submit applications to the Dean's office.  
20 Midterm date.

### NOVEMBER

- 7–8 Academic holidays.  
17 Last day to drop individual courses without academic penalty. Last day to change a grading option.  
14–18 Telephone registration by appointment for spring 2006.  
24–27 Thanksgiving holidays.

### DECEMBER

- 1 Last day to apply for February and May degrees.  
12 Classes end.  
13–14 Study days.  
15–22 Final examinations.  
Dec. 23– Winter holidays.  
Jan. 16

## SPRING TERM 2006

### JANUARY

- 10–13 Registration by appointment for all classes.  
16 Martin Luther King Jr. Day observed (holiday).  
17 Classes begin; late registration and change of program begins.  
27 Late registration ends. Last day to (1) register for academic credit, (2) change course programs, (3) submit written notice of withdrawal from the spring term to the Dean of Students for full refund of tuition and special fees. No adjustment of fees for individual courses dropped after this date.

### FEBRUARY

- 1 Last day to waive or enroll in Student Medical Insurance for spring 2006.  
8 Award of February degrees. Last day to apply for spring term Ph.D. defense.

### MARCH

- 6 Midterm date. Last day to apply for spring term. Eng.Sc.D. final examinations.  
13–17 Spring holidays.  
23 Last day to drop individual courses without academic penalty and to change grading options.

### MAY

- 1 Last day of classes.  
2–4 Study days.  
5 Last day for continuing students to apply for financial aid for the 2006–2007 academic year.  
5–12 Final examinations.  
14 Baccalaureate Service.  
16 Engineering Class Day.  
17 University Commencement.

