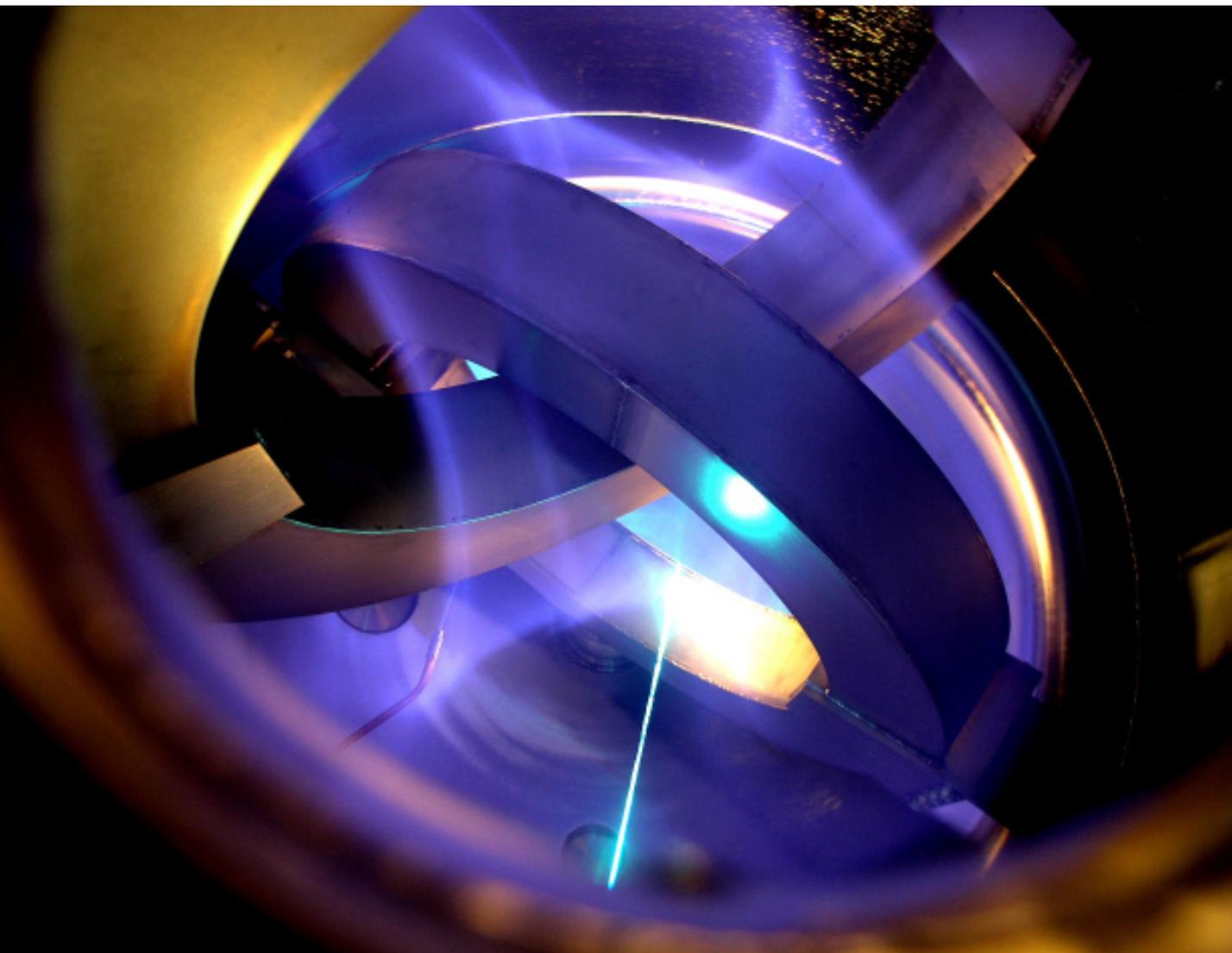


The Fu Foundation School of Engineering and Applied Science

BULLETIN 2009–2010





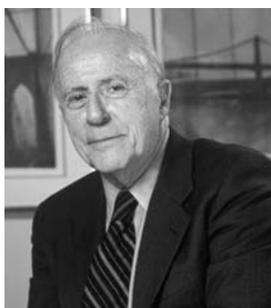
Mission of the Engineering School

The Fu Foundation School of Engineering and Applied Science, as part of a world-class teaching and research university, strives to provide the best in both undergraduate and graduate education. We are preparing engineering leaders who will solve the problems of the new century, fostering scientific inquiry but never losing sight of its human implications.

The School's programs are designed to produce well-educated engineers who can put their knowledge to work for society. This broad educational thrust takes advantage of the School's links to a great liberal arts college and to distinguished graduate programs in law, business, and medicine. Recognizing that engineers are problem solvers and inventors, students are encouraged to pursue entrepreneurship, a blending of business and new technology.

Through a synergy of teaching and research, we seek to educate a distinguished cadre of leaders in engineering and applied science who will thrive in an atmosphere of recently emerging technologies.

A MESSAGE FROM THE DEANS



As students of the Columbia Foundation School of Engineering and Applied Science, you are among the select few who have joined our community for an education that will enable you to become the next leaders in the fields of engineering and applied science. You, too, will become part of the history of this School, which is inextricably entwined with Columbia University's and with that of the City of New York.

Sir Isaac Newton said: "If I have seen farther, it is by standing on the shoulders of giants." Some of Columbia's early giants include John Stevens, Class of 1768, whose technology made early steamboats and locomotives possible. His work provided inspiration for William Barclay Parsons, Class of 1882, the chief engineer of New York City's first subway system and the first Columbia engineer to have a global presence, going to Shanghai in 1898 to become a primary surveyor for China's 1,000-mile-long railway route. Later Columbia inventors who fostered a shrinking globe were Michael Pupin, the developer of the transatlantic undersea telegraph cable, and Edwin Armstrong, who revolutionized modern radio communications. Just this May, our alumnus-astronaut Michael Massimino '84, on an eleven-day mission to service Hubble Space Telescope, became the first person in space to use Twitter. We are excited that you have seized the opportunity to join this list of very notable engineers and applied scientists.

Now, our School is meeting the challenge of educating you as a leader of the next wave of engineers and applied scientists by fostering an engineering education paradigm that is symbolized by the Greek letter π . The first foundation, or support column, of the π is the depth of knowledge you gain in your engineering or applied science major. The second foundation is the knowledge you acquire

through a minor, or your involvement in entrepreneurship initiatives, research opportunities, and community-based service learning. The overarching connector of these two foundations, the crossbeam of the π , is Columbia's famed liberal arts Core Curriculum, the umbrella that positions engineering and applied science within the context of the larger society, for the betterment of the human condition and the sustainability of our planet.

Some of the most exciting work in engineering and applied science today takes place at the intersection of disciplines. Research in materials science, bioengineering, and nanotechnology are but a few examples of where the biological, physical, and digital worlds intersect and where you have the opportunity to have a profound impact on society.

Engineering is not just crunching numbers or solving problems; it is seeing how problems affect society and how society actually changes because of the solutions you provide. You have an opportunity here as students to become involved in the community, so that, as you move into your professional life, you will become a leader who has an impact on the human condition and the sustainability of our planet, whether it is locally, nationally, or globally.

You are part of a school that offers great opportunities for learning and advancement within a premier research university that is situated in the laboratory of the City of New York. We look forward to your becoming part of the Columbia SEAS family as you embark on making your mark on society at large.

Feniosky Peña-Mora
Dean

Morton B. Friedman
Vice Dean

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About the School and University



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 Engineering and Applied Science—included Michael Idvorsky Pupin, a graduate of the Class of 1883. As a professor at Columbia, Pupin did pioneering work in carrier-wave detection and current analysis, with important applications in radio broadcasting; invented the "Pupin coil," which extended the range of long-distance telephones; and taught classes in electromechanics.

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 historic significance of Armstrong's contributions was recognized by the U.S. government when the Philosophy Hall laboratory was designated a National Historic Landmark in 2003.

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 engi-

neers 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 and Applied Science 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 School's newest department, Biomedical Engineering, with close ties to the Medical School, is but one example. Interdisciplinary centers are the norm, with cross-disciplinary research going on in biomedical imaging, environmental chemistry, materials science, medical digital libraries, nanotechnology, 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, Teachers College, and the Graduate School of Architecture, Planning and Preservation. 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 that makes possible, among other things, the sharper display screens found in high-end smart phones. Sequential lateral solidification (SLS) is based on breakthrough research in understanding how a substance is rapidly melted and solidified. The result is an optimal crystalline material that enables a new generation of smart phones. Within a short time, thanks to the innovations taking place in SEAS labs, it may be possible to put an entire computer on a sheet of glass or plastic.

ENGAGED ENTREPRENEURSHIP

Entrepreneurship has emerged as an important central educational theme within The Fu Foundation School of Engineering and Applied Science. SEAS promotes engineering innovation and engaged entrepreneurship through the Center for Technology, Innovation, and Community Engagement (CTICE). The School offers a 15-credit, interdisciplinary minor in entrepreneurship made up of both SEAS and Columbia Business School courses, and now provides a four-year entrepreneurship experience for all interested SEAS students, regardless of major.



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 contemporary civilization in the West and other global 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.

A COLLEGE WITHIN THE UNIVERSITY

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

THE NEW YORK ADVANTAGE

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

Asian in Chinatown; and sports teams from the Jets to the Yankees, New York is the crossroads of the world.

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

In addition to its ties to private industry, Columbia also has a historically close relationship with the public sector of New York, stretching back to the eighteenth century. No other city in the world offers as many impressive examples of the built environment—the world's most famous collection of skyscrapers, long-span bridges, road and railroad tunnels, one of the world's largest subway and water supply systems. Involved in all aspects of the city's growth and capital improve-

ments 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 NewYork-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 NewYork-Presbyterian Hospital) moved to the Washington Heights location. The Engineering School's new Biomedical Engineering Department has offices on both the Morningside and Health Sciences campuses.

Beyond its schools and programs, the measure of Columbia's true breadth and depth must take into account its seventy-odd internationally recognized

centers and institutions for specialized research, which study everything from human rights to molecular recognition, as well as the close affiliations it holds with Teachers and Barnard Colleges, the Juilliard School, the American Museum of Natural History, and both the Jewish and Union Theological Seminaries. Columbia also maintains major off-campus facilities such as the Lamont-Doherty Earth Observatory in Palisades, N.Y., and the Nevis Laboratories in Irvington, N.Y. Involved in many cooperative ventures, Columbia also conducts ongoing research at such facilities as Brookhaven National Laboratory in Upton, N.Y., and the NASA Goddard Institute for Space Studies located just off the Morningside campus.

THE 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 Schapiro Center for Engineering and Physical Science Research. In September 2010 the Interdisciplinary Science and Engineering Building currently under construction is scheduled to open and will house SEAS laboratories in nanotechnology and biomedical imaging. Because of the School's close proximity to the other Morningside facilities and programs, Columbia engineering students have ready access to the whole of the University's resources.

Comprising multiple programs of study, with facilities specifically designed

and equipped to meet the laboratory and research needs of both undergraduate and graduate students, the School is the site of an almost overwhelming array of basic and advanced research installations, from the Columbia Genome Center and Nanoscale Science and Engineering Center to the School's newest major center, the Energy Frontier Research Center, which will examine new and more efficient ways to extract solar energy. Details about specific programs' laboratories and equipment can be found in the sections describing those programs.

SEAS COMPUTING FACILITIES

The Botwinick Multimedia Learning Laboratory at Columbia University has changed the way engineers are educated here.

Created with both education and interaction in mind, the lab provides students and instructors with fifty state-of-the-art Apple MacPro workstations, a full set of professional-grade engineering software tools, and a collaborative classroom learning environment to help them engage in real-world interactions with community clients, SEAS faculty, and professional practitioners. It is home to the School's introductory first-year engineering course, as well as advanced classes in 3-D modeling and animation, technology and society, and entrepreneurship.

The classroom features a wide-screen SMART Board, two high-definition LCD projectors, and a Sony EVI-HD1 PTZ camera with direct-to-disk recording via HD-SDI using a Kona3 video capture card.

CENTRAL COMPUTING RESOURCES

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

Contact the CUIT Helpdesk for Technical Support

E-mail: askCUIT@columbia.edu

By phone: 212-854-1919
 Monday–Thursday: 8:00 a.m.–11:00 p.m.
 Friday: 8:00 a.m.–7:00 p.m.
 Saturday: 10:00 a.m.–6:00 p.m.
 Sunday: 3:00 p.m.–11:00 p.m.

In person (some consultations may require an appointment):

CUIT Client Service Center
 102 Philosophy Hall
 Monday–Friday: 10:00 a.m.–6:00 p.m.

Columbia University Information Technology (CUIT) provides Columbia University students, faculty, and staff with central computing and communications services, including computer accounts, e-mail, telephone and cable TV service, and course management and student information applications. CUIT manages the Columbia wireless network and the high-speed campus Ethernet network, which is available to all students in residence hall rooms. CUIT also manages an array of computer labs, terminal clusters, ColumbiaNet kiosk stations, and electronic classrooms, and provides a variety of technical support services via the CUIT Helpdesk. CUIT services include the following:

- *Computer account IDs* provide access to Columbia's secure online information resources, campus computer labs, and printing on CUIT printers. All Columbia students, faculty, and staff are assigned an ID account (called University Network ID or UNI). uni.columbia.edu.
- *Columbia's Web site* provides access to hundreds of online services and resources, including extensive academic, scholarly, and administrative resources, a myriad of library catalogs and references, the Directory of Classes, registration information, campus publications, and events listings. www.columbia.edu
- *Technical support* is available through the CUIT Helpdesk, which provides assistance to the Morningside campus online, by phone, or in person. (See beginning of this section for hours and contact information.)
- *Courseworks@Columbia* is the University course management system. It allows instructors to develop and maintain course Web sites easily, distribute class materials, link to online reserves, administer quizzes and tests, communicate with students, and promote online discussions. courseworks.columbia.edu
- *Electronic classrooms* provide multimedia capabilities such as computer and projection systems, DVD and CD-ROM players, VCRs, and audio

systems. [www.columbia.edu/ cuit/classrooms](http://www.columbia.edu/cuit/classrooms)

- *Public computer kiosks* are available in various locations around the Morningside campus for accessing Columbia's Web site resources and e-mail. www.columbia.edu/ cuit/facilities/cnet
- *Computer labs and clusters* provide students, faculty, and researchers with access to a range of software. Some locations have part-time consultants to provide lab help. [www.columbia.edu/ cuit/facilities/labs](http://www.columbia.edu/cuit/facilities/labs)
- *Printing facilities* are available throughout the Morningside campus and Barnard College, including CUIT computer labs, libraries, residence halls, and other computer clusters and electronic classrooms. Printing is provided by the NiNJa printing system on high-speed, high-volume printers. [www.columbia.edu/ cuit/facilities/ printers](http://www.columbia.edu/cuit/facilities/ printers)
- *Computer security resources* are available online, including links to download antivirus and anti-spyware software. The site also provides information on how to protect your system when working online. www.columbia.edu/ cuit/security
- *Electronic Data Service (EDS)*, run jointly by CUIT and the Libraries, provides computing support for researchers with data-intensive applications, including special accounts, statistical software, and finding and selecting appropriate data. www.columbia.edu/ cuit/eds
- *Telephone and cable TV service* is available to students living in University residence halls. www.columbia.edu/ acis/telecom/students

THE COLUMBIA UNIVERSITY LIBRARIES

The Columbia University Libraries system is the nation's sixth largest academic library system, with 9.7 million volumes, 117,264 serials, as well as extensive collections of electronic resources, manuscripts, rare books, and microforms and other nonprint formats. The collections and services are organized into 25 libraries, supporting specific academic or professional disciplines. The Library's Web site at www.columbia.edu/ cu/lweb

is a gateway to the print and electronic collections and services.

The Ambrose Monell Engineering Library has a collection of more than 216,000 volumes and receives about 900 serials. The collection includes civil, mechanical, electrical, and chemical engineering; computer science; metallurgy; mining (a good retrospective collection); operations research; applied physics; applied mathematics; and nuclear engineering. Via LibraryWeb, the Engineering Library provides access to full-text electronic journals and 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.

CENTER FOR CAREER EDUCATION

Center for Career Education
Columbia University
East Campus, Lower Level
Mail Code 5727
2960 Broadway
New York, NY 10027
Delivery: 70–74 Morningside Drive
Phone: 212-854-5609
Fax: 212-854-5640
E-mail: cce@columbia.edu
www.careereducation.columbia.edu

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

The Center for Career Education provides career development opportunities for students beginning with their first year at Columbia and offering a series of coordinated programs, workshops, seminars, and individual one-on-one counseling. Career development is a lifelong process that may include self-assessment, competency development, networking, informational interviewing, internships, summer work experience,

study abroad, preparation for the job search or for the graduate/professional school application process, and planning for productive careers. Above all else, it is a process of discovery and learning, which provides a foundation for achieving goals throughout life. The Center can work with students on all these aspects of their career search.

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

Individual career counseling is also available to assist all students and alumni served by the Center. Topics addressed in counseling may include self-assessment, career exploration, and career search tools and strategies.

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

The Center manages full-time and internship opportunities for students throughout the year in two capacities.

On-campus recruiting is conducted throughout the academic year and allows students to submit their resumes and cover letters online to any of the opportunities from employers who have chosen to recruit on campus. These opportunities are listed in LionSHARE. LionSHARE also hosts full-time, part-time, and temporary on- and off-campus employment opportunities advertised year round. While at Columbia, students are encouraged to take advantage of internships that offer opportunities to gain first-hand knowledge of a career field.

The Center offers international internship opportunities through two programs, Columbia Experience Overseas (CEO) and Encouraging Dynamic Global Entrepreneurs (EDGE). The CEO program offers Columbia students high-quality internship experiences in a diverse array of industries in London and Hong Kong through alumni and employer partnerships. EDGE Scotland is a summer program in entrepreneurship and enterprise leadership offered in collaboration with Scottish Enterprise Dunbartonshire and the University of Glasgow, with support from the European Union, the Scottish Executive, and others. It takes place in Dunbartonshire, an economically underdeveloped area of Scotland. Student consulting teams are challenged to solve real-world business problems by analyzing business climate, identifying opportunities for innovation, and proposing solutions and initiatives to create a more entrepreneurial and economically vibrant culture. The Center also offers an internship program in California with many engineering and technology internships and two New York-based internship programs, the Columbia Arts Experience and a civic engagement program called Columbia Communities in Action.

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

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

THE INTERNATIONAL STUDENTS AND SCHOLARS OFFICE (ISSO)

International Students and Scholars Office
Columbia University
Mail Code 5724
2960 Broadway
New York, NY 10027
Phone: 212-854-3587
e-mail isso@columbia.edu

The International Students and Scholars Office (ISSO) offers many services for international students as well as American citizens and permanent residents who have received their education in another

country. Services for international students include preadmission counseling, document and other immigration-related services, the International Orientation program, social and cultural activities, and a program for the spouses of students. The ISSO also provides credential analysis services to the admissions offices of the University. The ISSO is open year-round, and international students are urged to make use of its services during their stay at the University and are also invited to visit the ISSO Web site at www.columbia.edu/cu/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 cultural activities in the New York area and has reduced-rate tickets for plays, concerts, and other events.

Students are required to check in with the ISSO within a week of their arrival at Columbia. The office's street address is 524 Riverside Drive in International House North, just north of 122nd Street. The orientation program for new international students arriving for the September term takes place during orientation week, usually the last week in August or the first week in September. For further information, consult the International Students and Scholars Office using the contact information above.

Undergraduate Studies



The undergraduate programs at The Fu Foundation School of Engineering and Applied Science (SEAS) not only are academically exciting and technically innovative but also lead into a wide range of career paths for the educated citizen of the twenty-first century. Whether you want to become a professional engineer, work in industry or government, or plan to pursue a career in the physical and social sciences, medicine, law, business, or education, SEAS will provide you with an unparalleled education.

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

While pursuing their own interests, undergraduate students are encouraged to participate in a broad range of ongoing faculty research projects encompassed by the Undergraduate Research Involvement Program (URIP). An annual URIP publication sent to students describes

faculty projects in which students may participate, lists necessary qualifications, and details whether the student's participation will be voluntary, for academic credit, or for monetary compensation.

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

POLICY ON DEGREE REQUIREMENTS

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

THE FIRST YEAR— SOPHOMORE PROGRAM

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

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

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

to engage in ethical, analytic, discursive, and imaginative thinking that will prove indispensable later in life.

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

If electing Global Core, students must take two courses from the List of Approved Courses (www.college.columbia.edu/bulletin/core/mc.php) for a letter grade.

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 Iliad on the first day of class.) or COCI C1101-C1102 Introduction to contemporary civilization in the West or	

Global Core
(any 2 courses from approved list) 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 14.) <i>Note:</i> SEAS students may not take BC1003 Introduction to economic reasoning as a substitute for ECON W1105. | 4 |

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

The following course listing by department specifies the Columbia College, Barnard, or SEAS courses that either fulfill or do not fulfill the nontechnical requirement.

(Professional, workshop, lab, project, scientific, studio, music instruction, and master's-level professional courses do not satisfy the 27-point nontechnical requirement.)

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 AMERICAN STUDIES: All courses

ASTRONOMY: No courses

BIOLOGICAL SCIENCES: No courses

BUSINESS: No courses

CHEMISTRY: No courses

CLASSICS: All courses

COLLOQUIA: All courses

COMPARATIVE ETHNIC STUDIES: All courses

COMPARATIVE LITERATURE AND SOCIETY
All courses

COMPUTER SCIENCE: No courses

CREATIVE WRITING: All courses

DANCE

All courses except performance classes

DRAMA AND THEATRE ARTS

All courses except workshops, rehearsal, or performance classes, THTR BC2120 Technical production, THTR BC3135 Set design, and THTR BC3134 Lighting design

EARTH AND ENVIRONMENTAL SCIENCES

No courses

EAST ASIAN LANGUAGES AND CULTURE

All courses

ECOLOGY, EVOLUTION AND ENVIRONMENTAL BIOLOGY: No courses except EEEB W4700

ECONOMICS

All courses except:
W3211 Intermediate microeconomics
W3213 Intermediate macroeconomics
W3412 Introduction to econometrics
W3025 Financial economics
W4020 Economics of uncertainty and information
W4211 Advanced microeconomics
W4213 Advanced macroeconomics
W4280 Corporate finance
W4412 Advanced econometrics
W4415 Game theory
W4911 Seminar in microeconomics

W4913 Seminar in macroeconomics
 W4918 Seminar in applied econometrics
 BC1003 Introduction to economic reasoning
 (equivalent to ECON W1105)
 BC1007 Mathematical methods for economics
 BC2411 Statistics for economics
 BC3014 Entrepreneurship
 BC3018 Econometrics
 BC3033 Intermediate macroeconomic theory
 BC3035 Intermediate microeconomic theory
 BC3038 International money and finance
 BC2411 Statistics for economics

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

HUMAN RIGHTS: All courses

ITALIAN: All courses

JAZZ STUDIES: All courses

LATIN: All courses

LATINO STUDIES: All courses

LINGUISTICS: All courses except CLLN W4202

MATHEMATICS: No courses

MEDIEVAL AND RENAISSANCE STUDIES
 All courses

**MIDDLE EASTERN AND ASIAN LANGUAGE
 AND CULTURES:** All courses

MUSIC

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

PHILOSOPHY

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

PHYSICAL EDUCATION: No courses

PHYSICS: No courses

POLITICAL SCIENCE: All courses except:

W4209 Game theory
 W4291 Advanced topics in quantitative research
 W4292 Advanced topics in quantitative research
 W4360 Math methods for political science
 W4910 Principles of quantitative political
 research
 W4911 Analysis of political data
 W4912 Multivariate political analysis

PSYCHOLOGY

Only:
 W1001 The science of psychology
 W2235 Thinking and decision making
 W2240 Human communication
 W2280 Introduction to developmental
 psychology
 W2610 Introduction to personality
 W2620 Abnormal behavior
 W2630 Social psychology
 W2640 Introduction to social cognition
 V2680 Social and personality development
 W3615 Children at risk
 W3630 Seminar in social cognition

RELIGION: All courses

SEAS:

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

SLAVIC LANGUAGES: All courses

SOCIOLOGY:

All courses except:
 SOCI V3212 Statistics and methods

SPANISH AND PORTUGUESE: All courses

SPEECH: No courses

STATISTICS: No courses

SUSTAINABLE DEVELOPMENT: No courses

URBAN STUDIES: All courses

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

WOMEN AND GENDER STUDIES: All courses

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 com-*

puter technologies (4 points), in the
 Botwinick Multimedia Learning
 Laboratory. In this course, students
 learn the basics of engineering design
 along with professional and teamwork
 skills through participation
 in community service projects for real
 clients in local communities.

While students need not officially
 commit to a particular branch of engi-
 neering 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, stu-
 dents should turn to the individual pro-
 gram sections in this bulletin.

Professional-Level Courses for First- and Second-Year Students

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

Each course is designed to acquaint
 SEAS students with rigorous intellectual
 effort in engineering and applied science
 early in their academic careers. If a stu-
 dent chooses to take the second pro-
 fessional-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 addi-
 tion to teaching the subject matter. Each
 course is taught by regular department
 faculty and thus provides a double intro-
 duction to both subject area and faculty.

The courses are:

APPH E1300y Physics of the human body

The human body analyzed from the basic princi-
 ples of physics: energy balance in the body,
 mechanics of motion, fluid dynamics of the heart
 and circulation, vibrations in speaking and hear-
 ing, 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.

EAEE E1100y A better planet by design

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

ELEN E1201x and y Introduction to electrical engineering, with laboratory in circuit design

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

GRAP E1115x and y Engineering graphics

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

MECE E1001x Mechanical engineering: micro-machines to jumbo jets

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

MSAE E1001y Atomic-scale engineering of new materials

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

Physical Education

Two terms of physical education (*C1001-C1002*) are a degree requirement for students in The Fu Foundation School of Engineering and Applied Science. No more than 4 points of physical education courses may be counted toward the degree. A student who intends to participate in an intercollegiate sport should register for the appropriate section of *C1005: Intercollegiate athletics*. Intercollegiate athletes who attend regularly receive 1 point of credit up to the maximum of 4. Those who are advised to follow a restricted or adapted activity program should contact Professor Torrey in the Department of Physical Education and Intercollegiate Athletics. The physical education program offers a variety of activities in the areas of aquatics, dance, fitness, martial arts, individual and dual lifetime sports, team sports, and outdoor education. Most activities are designed for the beginner/intermediate levels. Advanced courses are indicated on the schedule. The majority of the activities are offered in ten time preferences. However, there are early-morning condi-

tioning activities, Friday-only classes at Baker Field, and special courses that utilize off-campus facilities during weekends and vacation periods. The courses offered by the department for each term are included in the online Directory of Classes, and a description of the scheduled activities for each time preference is posted in the Physical Education Office, 336 Dodge Physical Fitness Center, and is included on the Department of Physical Education and Intercollegiate Athletics Web site (www.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, Columbia College, and the School of the Arts.

Visual Arts Courses

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

Advanced Placement

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

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

Each year the school reviews the CEEB advanced placement curriculum

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	3	Requires completion of CHEM C2407 with grade of C or better.	
	4 or 5	6	Requires completion of CHEM C3045-C3046 with grade of C or better.	
Computer science A or AB	4 or 5	3*	Exemption from COMS W1004	
English Language and composition	5	3*	No exemption	
	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*		
	Literature	4 or 5	3*	
German language	4 or 5	3*		
Government and politics United States	5	3*		
	Comparative	5	3*	
History European	5	3*		
	United States	5	3*	
Italian language	4 or 5	3*		
Latin literature	4 or 5	3*		
Mathematics Calculus AB	4 or 5	3**	Requires completion of MATH V1102 with a grade of C or better.	
	Calculus BC	4	3**	Requires completion of MATH V1102 with a grade of C or better.
	Calculus BC	5	6	Requires completion of MATH V1201 (or V1207) with a grade of C or better.
Music theory	5	3*	Exemption from MUSI V1002. MUSI V2318-V2319 determined by department.	
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*	No exemption
Spanish Language	4 or 5	3*		
	Literature	4 or 5	3*	

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

**SEAS students with a 4 or 5 on Calculus AB or a 4 on Calculus BC must begin with Calculus II. If a SEAS student with these scores goes directly into Calculus III, he or she will not be awarded credit and may have to go back and complete Calculus II. Students with A-level or IB calculus credit must start with Calculus II.

and makes determinations as to appropriate placements, credit, and/or exemption. Please see the Advanced Placement Credit Chart at left.

International Baccalaureate (IB)

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

British Advanced Level Examinations

Pending review by the appropriate department at Columbia, students with grades of A or B on British Advanced Level examinations are granted 6 points of credit if the examinations were taken in disciplines offered as undergraduate programs at Columbia College. The appropriate transcript should be submitted to the Center for Student Advising, 403 Lerner.

Other National Systems

Pending review by the appropriate department at Columbia, students whose secondary school work was in other national systems (such as the French Baccalauréat or the German Abitur) may be granted credit in certain disciplines for sufficiently high scores. The appropriate transcript should be submitted to the Center for Student Advising, 403 Lerner.

STUDY ABROAD

Engineering today is a global profession. Engineers are increasingly being called upon to work with other engineers from across the world or they may even find themselves living abroad on an overseas assignment. Learning problem-solving skills in a foreign context will help engineering students to expand their horizons, and their adaptability to cross-cultural communication will make them a valuable addition to a team of engineers.

Study abroad allows engineering students to discover the field through the perspective of engineers working in a different language and culture, enabling them to learn the relationship of culture

to science and develop the range of transferable skills that employers are seeking today. Study abroad will help students develop intellectually, emotionally, culturally, and socially.

SEAS undergraduate students can study abroad for either a semester or a full academic year. Students from every engineering major have studied abroad without adding any time to their course of study at Columbia. Most do so in the spring semester of their sophomore year or in their junior year. SEAS students have the option of studying engineering at one of SEAS's partner universities where course equivalencies have been worked out: University College London (UK); the Ecole Polytechnique (FR)* or the Ecole Centrale de Paris (FR).^{*} Other partnerships are currently being negotiated—check the Office of Global Initiatives' Web site for the latest updates: www.engineering.columbia.edu/global_initiatives.

Students who would like further options can choose a peer university. The Office of Global Initiatives (510 Mudd) and departmental advisers will review requests, and if approved, will help students work out their course equivalencies so they can graduate on time.

It is essential that students begin planning as early as possible—ideally this would be during their first year—by meeting with Dr. Régine Lambrech, director of the Office of Global Initiatives and Education in 510 Mudd (r12488@columbia.edu). She will help students choose their overseas university destination and will explain all SEAS study abroad formalities. Students then also gain approval from their departmental advisers to ensure that their work abroad meets the requirements of their majors. Students must also register with the Office of Global Programs (204 Lewisohn) for study abroad by November 15 for spring programs and April 15 for fall and academic-year programs.

Eligibility Requirements

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

- have at least a 3.0 GPA
- be making good progress toward finishing the Core Curriculum
- have at least intermediate proficiency in the local language, if it is not English (Please note: For programs in countries where the language of instruction is not English, students must take all course work in the local language.)

Students' study-abroad plans must be approved by the Office of Global Initiatives by October 15 for spring programs and March 15 for fall and academic-year programs. A review of each student's academic and disciplinary records is conducted as part of this process. Students on academic or disciplinary probation are not permitted to study abroad during the term of their probation.

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

Study-Abroad Program Information

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

Students should visit the Office of Global Initiatives' Web site to review the various lists of program options and consult with OGI staff for specific information or help in choosing an institution that offers the best courses in their engineering major.

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

Noncredited internships abroad—the EDGE and CEO programs—are coordinated by the Center for Career Education. Please visit the Center's Web site for more information. Other internship options are listed on the Web site of the Office of Global Initiatives.

Academic Credit

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

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

Faculty from the SEAS academic departments have the responsibility to assess all work completed abroad and make decisions about how these courses fit into major requirements. It is imperative that students gain course-by-course approval from their department prior to departure on a study-abroad program. The Office of Global Initiatives will provide students with the forms necessary to obtain this approval.

*Fluent French and excellent mathematical skills are mandatory for study here.

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 is on page 17.

The Combined Plan (3-2) Program within Columbia University

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

The Combined Plan with Other Affiliated Colleges

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

The 3-2 Combined Plan Program B.A./B.S. at The Fu Foundation School of Engineering and Applied Science is designed to provide students with the opportunity to receive both a B.A. degree from an affiliated liberal arts college and

a B.S. degree from SEAS within five years. Students complete the requirements for the liberal arts degree along with a pre-engineering course of study in three years at their college and then complete at Columbia. Combined Plan students, who are guaranteed housing, are required to complete all SEAS requirements within four consecutive semesters. Please note that no change of major is allowed after matriculation.

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

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

Admission to SEAS at the end of the junior year is guaranteed for those students who have a grade-point average of 3.0 or better; are recommended by the liaison officer; and have completed the appropriate steps outlined in 1–4 above.

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

same as above, with the additional requirement that if the applicant has already graduated from the affiliated school, he or she must apply to the Combined Plan Program within one year of graduating.

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

The 4-2 M.S. program is designed to allow students to complete an M.S. degree at SEAS in two years after completion of a B.A. degree at one of the affiliated schools. This program will allow students the opportunity to take 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.

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

The Combined Plan—Affiliated Colleges and Universities

Adelphi University, Garden City, NY
 Albertson College, Caldwell, ID
 Albion College, Albion, MI
 Alfred University, Alfred, NY
 Allegheny College, Meadville, PA
 Arcadia University, Glenside, PA
 Augustana College, Sioux Falls, SD
 Austin College, Sherman, TX
 Baldwin-Wallace College, Berea, OH
 Bard College, Annandale-on-Hudson, NY
 Barnard College, New York, NY
 Bates College, Lewiston, ME
 Beloit College, Beloit, WI
 Bethany College, Bethany, WV
 Birmingham-Southern College, Birmingham, AL
 Bowdoin College, Brunswick, ME
 Brandeis University, Waltham, MA

Carleton College, Northfield, MN
 Carroll College, Helena, MT
 Centenary College of Louisiana, Shreveport, LA
 Centre College, Danville, KY
 Claremont McKenna College, Claremont, CA
 Clark University, Worcester, MA
 Colgate University, Hamilton, NY
 College of Notre Dame, Baltimore, MD
 College of the Holy Cross, Worcester, MA
 College of William and Mary, Williamsburg, VA
 Colorado College, Colorado Springs, CO
 Columbia College, New York, NY
 Davidson College, Davidson, NC
 Denison University, Granville, OH
 DePauw University, Greencastle, IN
 Dillard University, New Orleans, LO
 Doane College, Crete, NE
 Drew University, Madison, NJ
 Earlham College, Richmond, IN
 Eckerd College, St. Petersburg, FL
 Elon College, NC
 Fairfield University, Fairfield, CT
 Fordham University, Bronx, NY
 Franklin and Marshall College, Lancaster, PA
 Georgetown University, Washington, DC
 Gettysburg College, Gettysburg, PA
 Grinnell College, Grinnell, IA
 Hamilton College, Clinton, NY
 Hartwick College, Oneonta, NY
 Hastings College, Hastings, NE
 Hendrix College, Conway, AR
 Hobart and William Smith Colleges, Geneva, NY
 Hofstra University, Hempstead, NY
 Jacksonville University, Jacksonville, FL
 Juniata College, Huntingdon, PA
 Knox College, Galeburg, IL
 Lawrence University, Appleton, WI
 Lewis and Clark College, Portland, OR
 Loyola University Chicago, Chicago, IL
 MacMurray College, Jacksonville, IL
 Marietta College, Marietta, OH
 Miami University, Oxford, OH
 Middlebury College, Middlebury, VT
 Millsaps College, Jackson, MI
 Morehouse College, Atlanta, GA
 Muhlenberg College, Allentown, PA
 Nebraska Wesleyan University, Lincoln, NE
 Oberlin College, Oberlin, OH
 Occidental College, Los Angeles, CA
 Pacific Lutheran University, Tacoma, WA
 Pitzer College, Claremont, CA
 Providence College, Providence, RI
 Queens College, Flushing, NY
 Randolph-Macon College, Ashland, VA
 Reed College, Portland, OR
 Rollins College, Winter Park, FL
 St. John Fisher College, Rochester, NY
 St. Lawrence University, Canton, NY
 Sarah Lawrence College, Bronxville, NY
 School of General Studies, Columbia University, New York, NY
 Scripps College, Claremont, CA
 Seattle Pacific University, Seattle, WA
 Simon's Rock College of Bard, Great Barrington, MA
 Spelman College, Atlanta, GA

State University of New York, Fredonia, NY
 State University of New York, Geneseo, NY
 State University of New York, Binghamton, NY
 Sweet Briar College, Sweet Briar, VA
 University of Puget Sound, Tacoma, WA
 University of Richmond, Richmond, VA
 University of the South, Seawee, TN
 University of the Virgin Islands, St. Thomas, VI
 Ursinus College, Collegeville, PA
 Wabash College, Crawfordsville, IN
 Washington and Jefferson College, Washington, PA
 Washington and Lee University, Lexington, VA
 Wells College, Aurora, NY
 Wesleyan University, Middletown, CT
 Whitman College, Walla Walla, WA
 Whitworth College, Spokane, WA
 Willamette University, Salem, OR
 William Jewell College, Liberty, MO
 Williams College, Williamstown, MA
 Wittenberg University, Springfield, OH
 Wofford College, Spartanburg, SC
 Yeshiva University, New York, NY

THE JUNIOR-SENIOR PROGRAMS

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

Having chosen their program major, students 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, Augustus Schermerhorn, and, of course, Harvey Seeley Mudd.

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

Taking Graduate Courses as an Undergraduate

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

The Bachelor of Science Degree

Students who complete a four-year sequence of prescribed study are awarded the Bachelor of Science degree. The general requirement for the Bachelor of Science degree is the completion of a minimum of 128 academic credits with a minimum cumulative grade-point average (GPA) of 2.0 (C) at the time of graduation. The program requirements, specified elsewhere in this bulletin, include the First Year–Sophomore course requirements, the Junior-Senior

major departmental requirements, and technical and nontechnical elective requirements. Students who wish to transfer points of credit may count no more than 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, and mechanical engineering. For a complete listing of all programs registered with the State of New York, including ABET programs, see page 20.

The 4-1 Program at Columbia College

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

The program will be selective, and admission will be based on the following factors: granting of the B.S. at SEAS at the end of the fourth year; fulfillment of the College Core requirements by the end

of the fourth year at SEAS; a minimum GPA of 3.0 in the College Core and other courses; and the successful completion of any prerequisites for the College major or concentration. To be admitted to the program, a plan needs to be in place for the student to complete the major or concentration in the fifth year.

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 in the fall of their sophomore year, when they also decide on a major.

In considering a minor, students must understand that all minors are not, and cannot, be available to all students. In 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," beginning on page 188.

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 flexi-

ble admissions requirements of most professional schools. Undergraduate students should, however, make careful inquiry into the kinds of specific preparatory work that may be required for admission into highly specialized programs such as medicine.

Pre-Med

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

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

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

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

The following courses are required by medical schools:

One year of calculus for some schools
One year of physics, with lab

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

For further information, please consult the Office of Preprofessional Advising at 212-854-8722 or preprofessional@columbia.edu.

Pre-Law

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

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

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

New York State Initial Certification in Adolescence Education Grades 7–12 for Teachers of Mathematics and the Sciences or in Childhood Education Grades 1–6

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

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

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

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

JOINT PROGRAMS

School of Law

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

School of International and Public Affairs

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

REGISTERED PROGRAMS

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

The letter "X" or the name of a degree on the chart indicates that a program is registered with the New York State Department of Education.

Programs Registered with the New York State Department of Education

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 Engineering 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
Electrical Engineering: Dual B.S./M.S.	909	X	X				
Engineering Mechanics	921	X		Mechanics Engineer			
Financial Engineering	913		X	Financial Engineer*			
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*				
Operations Research: Financial Engineering	913	X					
Solid State Science and Engineering	919		X		X	X	X

*State approval pending.

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

Fax: 212-854-3393
Phone: 212-854-2522
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:
- 3 years or more of a foreign language
 - 3 or 4 years of history and social studies

The Application Process

Students are strongly encouraged to apply online. You may also download a paper copy of the application. Information about both the online application and the downloadable application will be available by September 1, 2009, at www.studentaffairs.columbia.edu/admissions/applications. If you do not have access to the Internet, please call the Office of Undergraduate Admissions at 212-854-2522 to request an application.

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

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

Decision letters are mailed out in early April.

The Early Decision Program

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

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

Required Standardized Testing

Please go to www.studentaffairs.columbia.edu/admissions for our standardized testing requirements. You must register with the appropriate testing agency well in advance of the date on which you wish to be tested. Please note that scores reported to Columbia's School of General Studies (2095) will not reach our office and will not be considered for evaluation. Columbia reserves the right not to evaluate a candidate whose scores are not reported directly by the testing agency. Please do not utilize the "rush" service in sending your test scores to Columbia. Doing so does not speed up the processing of your test scores. We obtain all testing via a secure Web site to which we are provided access by the appropriate testing

agency. Scores that are sent via the “rush” service are sent to us in paper form, which we are no longer able to process.

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

The Test of English as a Foreign Language (TOEFL) or International English Language Testing System (IELTS) 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. Students are required to report all standardized testing. The following codes should be used when completing test registration forms:

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

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

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

Test of English as a Foreign Language
Box 899
Princeton, NJ 08541
609-771-7100
www.toefl.org

International English Language Testing System
www.ielts.org

Advanced Placement

The School gives recognition to the Advanced Placement program. Appropriate placement and credit will be given to students who score according to the School’s criteria (see page 14) in the Advanced Placement examinations

given in May by the College Entrance Examination Board. In addition, required courses may be waived on the basis of faculty placement conferences, permitting students with special preparation to advance in prescribed sequences. No credit is given for college courses taken prior to high school graduation, but appropriate placements may be made.

C. Prescott Davis Scholars Program

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

Higher Education Opportunity Program (HEOP) and National Opportunity Program (NOP)

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

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

Because of the different pace of this program, students are considered to be making minimum satisfactory progress when they complete 24 points of credit in one academic year. HEOP students’ academic performance is otherwise evaluated by the same standards

applied to all undergraduates. HEOP support is available to students wishing to pursue only the Bachelor of Science degree or Columbia’s Combined Plan Program for both the Bachelor of Arts and Bachelor of Science in five years.

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

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

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

APPLICANTS WITH ADVANCED STANDING (TRANSFER APPLICANTS)

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

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

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

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

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

The Combined Plan Programs

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

Secondary school students who wish to follow one of the Combined Plan pro-

grams 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:

- February 15 preferred deadline for the 3-2 Combined Plan Program
- March 14 final deadline for the 3-2 Combined Plan Program
- March 15 for the 4-2 Combined Plan B.S. Program
- February 15 for the 4-2 Combined Plan M.S. Program

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

CAMPUS VISITS AND INTERVIEWS

Prospective students are encouraged to visit the Columbia campus throughout the year. The Office of Undergraduate Admissions hosts information sessions

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

Columbia does not conduct interviews on campus. Interviews are instead conducted around the country and the world by the members of the Alumni Representative Committee. The University provides the names of candidates to the Committee, which conducts interviews from October through February. Candidates will be contacted by a Committee member during this time if interviews are available. Candidates should not call or write the Admissions Office to arrange alumni interviews.

The 2009–2010 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 \$19,648 per term, regardless of the number of course credits taken.

MANDATORY FEES

Orientation fee: \$400 (one-time charge in the first term of registration)
 Student Life fee: \$541 per term
 Health Service fee: \$387 per term
 International Services charge: \$50 per term (international students only)
 Transcript fee: \$95 (one-time charge)

OTHER FEES

Application and late fees

- Application for undergraduate admission: \$70
- Application for undergraduate transfer admission: \$70
- Late registration fee
 - during late registration: \$50
 - after late registration: \$100

Books and course materials:
 Depends upon course

Laboratory fees: See course listings

Room and board (estimated): \$10,200

HEALTH INSURANCE

Columbia University offers the Student Medical Insurance Plan, which provides both Basic and Comprehensive levels of coverage. Full-time students are automatically enrolled in the Basic level of the Plan and billed for the insurance pre-

mium in addition to the Health Service fee. Visit www.health.columbia.edu for detailed information about medical insurance coverage options and directions for making confirmation, enrollment, or waiver requests.

PERSONAL EXPENSES

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

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

LABORATORY CHARGES

Students may need to add another \$100 to \$300 for drafting materials or laboratory fees in certain courses. Each student taking laboratory courses must furnish, at his or her own expense, the necessary notebooks, blank forms, and similar supplies. In some laboratory courses, a fee is charged to cover expendable materials and equipment maintenance. Students engaged in special tests, investigations, theses, or

research work are required to meet the costs of expendable materials as may be necessary for this work and in accordance with such arrangements as may be made between the student and the department immediately concerned.

DAMAGES

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

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

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

TUITION AND FEE REFUNDS

Students who make a complete withdrawal from a term are assessed a withdrawal fee of \$75. Late fees, application fees, withdrawal fees, tuition deposits,

special fees, computer fees, special examination fees, and transcript fees are not refundable.

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

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

Percentage Refund for Withdrawal during First Nine Weeks of Term

(prorated for calendars of a different duration)

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%
10th week and after	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.

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
www.studentaffairs.columbia.edu/finaid

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

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

DETERMINING ELIGIBILITY

Columbia determines the amount each family can contribute to educational costs through an evaluation of the family's financial information as reported on the

application forms described in the section "How to Apply for Financial Aid." The difference between the family contribution and the total cost of attendance at Columbia (including tuition, room, board, fees, books, travel, and personal expenses) represents the student's demonstrated need.

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

The minimum contribution from earnings is currently:

First year	\$2,400
Sophomore	\$2,700
Junior	\$2,900
Senior	\$3,000

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 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 finan-

cial aid packages include a combination of grant and "self-help." The self-help portion of a financial aid package consists of a part-time job during the academic year. Grants from government sources or directly from Columbia cover any remaining need beyond that covered by the self-help award.

Columbia determines the institutional, federal, and New York State financial aid programs for which each student is eligible and awards funds appropriately. In addition to applying to Columbia for assistance, all financial aid applicants are expected to apply for any other grant/scholarship aid for which they may be eligible. Students must notify the Office

of Financial Aid and Educational Financing if any outside awards are received.

Students who receive financial aid from Columbia grant permission to the Office of Financial Aid and Educational Financing to release relevant personal, academic, and financial information to persons or organizations outside Columbia in order to institute or to continue financial assistance that they might be eligible to receive from such sources. Students can expect that Columbia will respect their right to privacy and release information only as necessary.

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

A. Grants and Scholarships

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

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

The *Federal Pell Grant* program is authorized by the Education Amendments of 1972. Under this program the federal government provides grants to students who qualify on the basis of financial need. Pell grants range from \$976 to \$5,350.

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.

Columbia 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 via www.studentaffairs.columbia.edu/finaid/forms/workstudy.php.

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

C. Financing Options

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

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

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

deducted from the loan at the time that it is disbursed. Repayment begins sixty days after the second disbursement of the loan.

HOW TO APPLY FOR FINANCIAL AID

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

All Columbia application materials can be accessed through www.studentaffairs.columbia.edu/finaid.

1. College Scholarship Service (CSS) PROFILE Form

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

CSS code for SEAS: 2111

The deadlines to submit online are:

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



2. Free Application for Federal Student Aid (FAFSA)

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

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

Continuing students should apply online each year.

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

FAFSA code for SEAS: E00486

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

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

March 1:	First-year candidates, both early and regular decision
April 20:	Transfer applicants
May 5:	Continuing students

3. Noncustodial Profile

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 CSS Noncustodial Profile (online form provided as a link once the CSS PROFILE is submitted).

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

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

4. Business/Farm Information

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

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

5. Federal income tax returns

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

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

TAX WITHHOLDING FOR NONRESIDENT ALIEN SCHOLARSHIP AND FELLOWSHIP RECIPIENTS

United States tax law requires the University to withhold tax at the rate of 14 percent on scholarship and fellowship grants paid to nonresident aliens which exceed the cost of tuition, books, fees, and related classroom expenses.

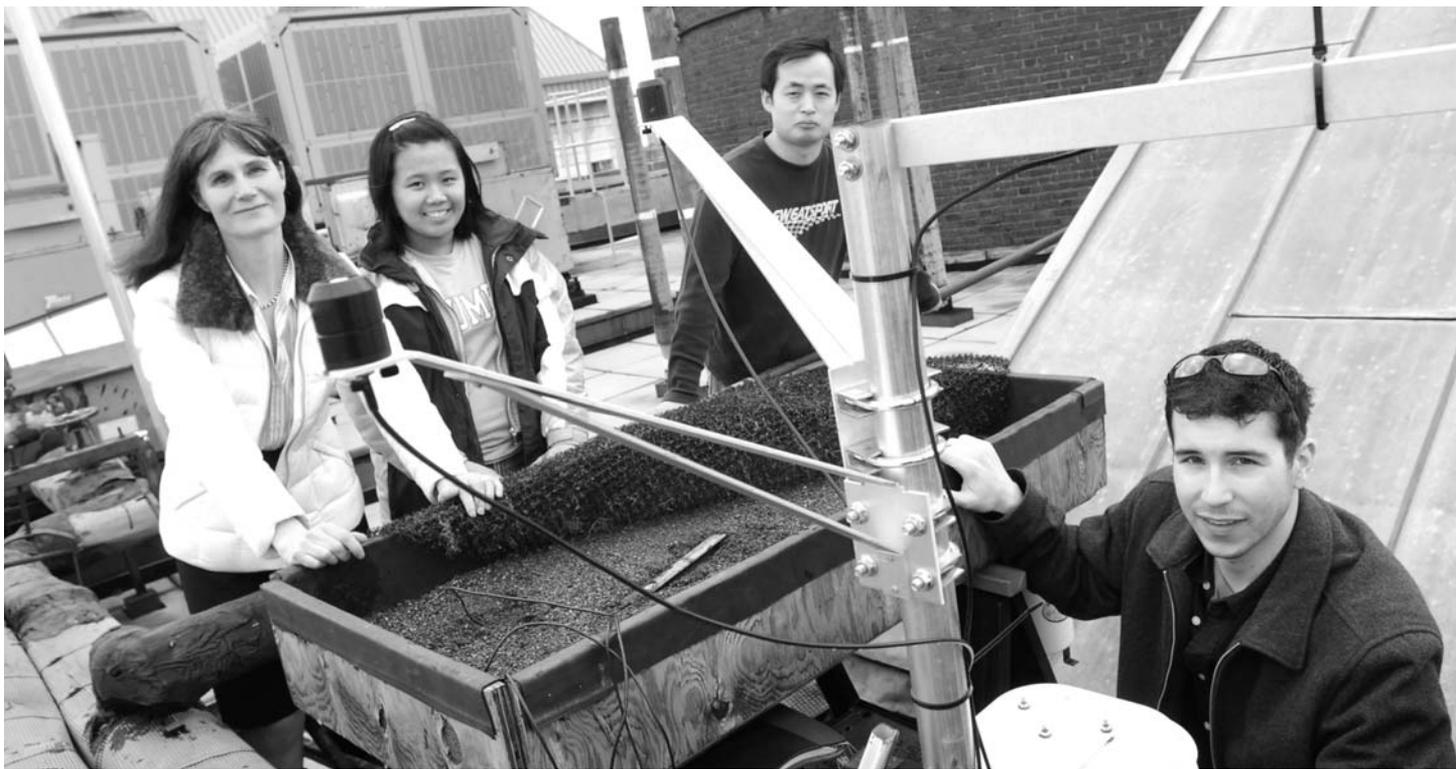
Certain countries have entered into tax treaties with the United States, which may serve to reduce this rate of withholding. However, even when such a treaty applies, the student and the University must report the full amount of such excess to the Internal Revenue Service. If a student claims tax treaty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

The International Students and Scholars Office has prepared a packet of tax information, which is revised annually and is available to students.

International Students and Scholars
Office
Columbia University
524 Riverside Drive, Mail Code 5724
New York, NY 10027
Phone: 212-854-3587
Fax: 212-854-8579

The tax law is complex and may vary with regard to individual circumstances. Therefore, as the University is not in a position to offer individual tax advice, students are advised to consult with a qualified tax professional and/or the consulate of their country of residence.

Graduate Studies



Graduate programs of study in The Fu Foundation School of Engineering and Applied Science are not formally prescribed, but are planned to meet the particular needs and interests of each individual student. Departmental requirements for each degree, which supplement the general requirements given below, appear in the sections on individual graduate programs.

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

In order to complete the requirements for any graduate degree, the student must plan a program with the department of major interest and then have it approved by the Office of Graduate Student Services; the program may be modified later with the permission of the department and the Assistant Dean. No more than one term of course work or, in the case of part-time students, no more than 15 points of credit of course work, completed before the program is approved, may be counted toward the degree. Students registered in the School have a minimum requirement for each Columbia degree of 30 points of

credit of course work completed at Columbia University. The student must enroll for at least 15 of these points while registered as a matriculating student in a degree program in the Engineering School. (See also the section "Special Nondegree Students" on page 35 and the chapter "Columbia Video Network.") Students wishing to change from the Ph.D. degree to the Eng.Sc.D. degree must therefore enroll for at least 15 points while registered in the School. For residence requirements for students registered in the Graduate School of Arts and Sciences or those wishing to change from the Eng.Sc.D. degree to the Ph.D. degree, see the bulletin of the Graduate School of Arts and Sciences.

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

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

Under special conditions, and with the prior approval of the department of his or her major interest and of the Assistant Dean, a student may be permitted to take a required subject at another school. However, credit for such courses will not reduce the

30-point minimum that must be taken at Columbia for each degree.

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

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

THE MASTER OF SCIENCE DEGREE

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

While a suitable Master of Science program will necessarily emphasize some specialization, the program should be well balanced, including basic subjects of broad importance as well as theory and applications. The history of modern economic, social, and political institutions is important in engineering, and this is recognized in the prescribed undergraduate program of the School. If the candidate's undergraduate education has been largely confined to pure science and technology, a program of

general studies, totaling from 6 to 8 points, may be required. Supplementary statements covering these special requirements are issued by the School's separate departments. An applicant who lacks essential training will be required to strengthen or supplement the undergraduate work by taking or repeating certain undergraduate courses before proceeding to graduate study. No graduate credit (that is, credit toward the minimum 30-point requirement for the Master of Science degree) will be allowed for such subjects. Accordingly, Master of Science programs may include from 35 to 45 points and may require three terms for completion. Doctoral research credits cannot be used toward M.S. degree requirements.

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

The 4-2 Master of Science Program

The 4-2 Master of Science Program provides the opportunity for students holding bachelor's degrees from affiliated liberal arts colleges (see the listing under the heading "The Combined Plan—Affiliated Colleges and Universities," on

page 17 of this bulletin) with majors in mathematics, physics, chemistry, or certain other physical sciences to receive the M.S. degree after two years of study at Columbia in the following fields of engineering and applied science: biomedical, chemical, civil, computer, Earth and environmental, electrical, industrial, and mechanical engineering; applied physics; applied mathematics; engineering mechanics; operations research; materials science; and computer science.

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

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

Please contact the Office of Graduate Student Services, The Fu Foundation School of Engineering and Applied Science, 524 S. W. Mudd, Mail Code 4708, 500 West 120th Street, New

York, NY 10027; you should also contact the Combined Plan liaison at your school for program information. You may, in addition, e-mail questions to seasgradmit@columbia.edu.

Joint Program with the School of Business in Industrial Engineering

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

Joint Program with the School of Business in Operations Research

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

Joint Program with the School of Business in Earth Resources Engineering

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

Special Studies with the Harriman Institute

A candidate for an advanced degree in

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

THE PROFESSIONAL DEGREE

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

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

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

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

Two doctoral degrees in engineering are offered by the University: the Doctor of Engineering Science, administered by

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

Doctoral students may submit a petition to the Office of Graduate Student Services to change from the Eng.Sc.D. degree to the Ph.D. degree or from the Ph.D. degree to the Eng.Sc.D. degree. The petition must be submitted within the first year of enrollment or by the completion of 30 points. Any petitions submitted after this period will not be considered. Doctoral degree status can be changed only once; students, therefore, must determine which doctoral degree program is most appropriate for their academic and professional endeavors.

Requirements for the Degrees

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

Candidates for the Ph.D. degree must register full time and complete six Residence Units. A master's degree from an accredited institution may be accepted in the form of advanced standing as the equivalent of one year of residence (30 points of credit or two Residence Units) for either doctoral degree. An application for advanced standing must be completed during the first semester of study. Candidates for the Eng.Sc.D. degree must (in addition to the 60-point requirement) accumulate 12 points of credit in the departmental course E9800: Doctoral research instruction. A holder of the professional degree who wishes to continue work toward the Eng.Sc.D. degree will be required to complete not less than 30 additional points of credit in residence. All doctoral

programs are subject to review by the Committee on Instruction of the School. In no case will more than 15 points of credit be approved for the dissertation and research and studies directly connected therewith without special approval by this Committee. Normally, a doctoral candidate specializes in a field of interest acceptable to a department of the School.

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

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

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

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

Doctoral Research Instruction

In order that the University may recover the costs that are not defrayed by the

University's income from tuition, charges for research required for the Eng.Sc.D. are assessed as given below.

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

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

1. At the time the student begins doctoral research, the student is eligible to register for E9800 (3, 6, 9, or 12 points of credit). Twelve points must have been accumulated by the time the student is to receive the degree.
2. Registration for E9800 at a time other than that prescribed above is not 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 standing, 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 University
540 S. W. Mudd, Mail Code 4719
500 West 120th Street
New York, NY 10027

www.cvn.columbia.edu
E-mail: 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 faculty in multimedia classrooms. Faculty and students meet in classrooms equipped with cameras, electronic writing tablets, and SMART™ boards. The recorded lectures are fully downloadable for study at home, office, or on the road.

CVN students take the same classes, have the same homework assignments, take the same exams, and earn the same degrees as on-campus students in Master of Science (M.S.) or Professional Degree (P.D.) programs.

COURSE OFFERINGS AND DEGREE PROGRAMS

CVN makes select SEAS graduate courses available to off-campus students in autumn (September–December) and spring (January–May) terms. CVN administrators work closely with faculty representatives from each department to select

the classes that best fit the needs of new and continuing students around the world. During the summer semester (and occasionally the autumn and spring terms), CVN makes prerecorded courses available.

SEAS currently offers M.S. degrees in the following disciplines through CVN:

- Applied mathematics
- Biomedical engineering
- Chemical engineering
- Civil engineering
- Computer science
- Earth and environmental engineering
- Electrical engineering
- Operations research
- Methods in finance
- Engineering and management systems
- Materials science and engineering
- Mechanical engineering

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

STUDENT REGISTRATION

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

Although you need not be admitted to a degree 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;

up to 15 credits taken as a CVN nondegree student may be counted toward a degree when applying through CVN, subject to the approval of the student's departmental adviser. Earning credit as a nondegree student does not guarantee acceptance into a degree program.

Only CVN students may transfer up to 6 credits from another university toward an M.S. or P.D. degree, subject to the approval of the student's adviser and the department.

Columbia undergraduates and Ph.D. students are prohibited from taking CVN courses.

PROGRAM BENEFITS

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

Professors and teaching assistants are available via e-mail or phone to address academic questions. CVN's administrative staff is available to assist with registration procedures, technical queries, and academic advising so working professionals can devote their energies to their studies, their families, and their careers.

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
Apply online at: 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 nondegree student may be counted toward a degree.

APPLICATION REQUIREMENTS

Applicants must submit an online application and required supplemental materials, as described below. When filing the online application, the candidate should obtain one official transcript from each postsecondary institution attended and submit them in the original sealed envelope. Consideration for admission will be based not only on the completion of an earlier course of study, but also upon the quality of the record presented and upon such evidence as can be obtained concerning the candidate's personal fitness to pursue professional work.

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

ENGLISH PROFICIENCY REQUIREMENT

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

- M.S. and Professional Degree candidates must reach level 8 on the English Certification Test (ECT) offered

by Columbia's American Language Program (ALP).

- Ph.D. and Eng.Sc.D. candidates must attain level 10 on the English Certification Test (ECT) offered by Columbia's American Language Program (ALP).

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

The ECT 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 ECT 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 ECT.)

A student who does not pass the ECT 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 ECT, please contact the Graduate Student Services Office.

APPLICATION FEES

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



GRADUATE ADMISSION CALENDAR

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

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

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

ONE-TERM SPECIAL STUDENT STATUS

Individuals who meet the eligibility requirements, who are U.S. citizens or U.S. permanent residents, and who wish to take courses for enrichment, may secure faculty approval to take up to two graduate-level courses for one term only as a one-term special student. This

option is also appropriate for individuals who missed applications deadlines. Applications for special student status are available at the Office of Graduate Student Services and must be submitted during the first week of the fall or spring semester.

If a one-term special student subsequently wishes either to continue taking classes the following term or to become a degree candidate, a formal application must be made through the Office of Graduate Student Services.

The 2009–2010 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 \$1,310 per credit, except when a special fee is fixed. Graduate tuition for Ph.D. students is \$17,698 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 \$1,538 per term by The Fu Foundation School of Engineering and Applied Science.

Ph.D. candidates engaged only in research are assessed \$1,538 per term for Matriculation and Facilities by the Graduate School of Arts and Sciences.

MANDATORY FEES

University facilities fee

- Full-time master's programs: \$303 per term
- All other full-time programs: \$288 per term

Health Service fee: \$387 per term

International Services charge: \$50 per term (international students only)

Transcript fee: \$95 (one-time charge)

OTHER FEES

Application and late fees

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

HEALTH INSURANCE

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

PERSONAL EXPENSES

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

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

LABORATORY CHARGES

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

DAMAGES

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

When the laboratory work is done by a group, charges for breakage will be divided among the members of the group. The students responsible for any

damage will be notified that a charge is being made against them. The amount of the charge will be stated at that time or as soon as it can be determined.

TUITION AND FEE REFUNDS

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

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

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

Percentage Refund for Withdrawal during First Nine Weeks of Term

Prorated for calendars of a different duration, if the entire program is dropped:

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%
10th week and after	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.

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, 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, and New York State TAP grants are administered by the Office of Financial Aid and Educational Financing. Questions and problems with regard to awards should be directed to your financial aid adviser.

INSTRUCTIONS FOR FINANCIAL AID APPLICANTS

Forms

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

- 1a. *Prospective Students*—complete an application for admission and submit it to The Fu Foundation School of Engineering and Applied Science's Office of Graduate Student Services;
- 1b. *Continuing Students*—preregister for classes during the preregistration period;
2. complete a Free Application for Federal Student Aid (FAFSA) form and submit it to the U.S. Department of Education (*only U.S. citizens or permanent residents must complete the FAFSA; if you are a noncitizen, you do not need to submit this form*);
3. complete an Express TAP application and submit it to the New York State Higher Education Services Corporation (*only U.S. citizens or permanent residents who reside in New York State must complete the Express TAP application; if you are not a New York State resident, you do not need to submit this form*);
4. file a Columbia University Enrollment Status Sheet. Complete the form and submit it to the Office of Financial Aid and Educational Financing.

Application Process

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

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

Once your FAFSA-on-the-Web application is complete, your online confirmation page will give you a link to the TAP-on-the-Web application. New York State uses the information provided on your TAP application to determine your eligibility for a Tuition Assistance Program (TAP) grant. The TAP-on-the-Web online

form will be partially completed with some information from your FAFSA. Review this data, supply any missing information, and submit the completed form. If you do not finish the online TAP-on-the-Web application, you will be mailed a paper Express TAP Application. As with the TAP-on-the-Web application, your Express TAP Application will also be partially completed with some of your FAFSA data. Verify that the partially completed data is correct, complete the remainder of the form, and return it to HESC in the envelope provided.

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

Deadlines

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

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

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

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

GRADUATE SCHOOL DEPARTMENTAL FUNDING

The graduate departments of The Fu Foundation School of Engineering and

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

Institutional Grants

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

Fellowships

Fellowships are financial and intellectual awards for academic merit that provide stipends to be used by fellows to further their research. If you are awarded a fellowship, you are expected to devote time to your own work, and you are not required to render any service to the University or donor. You may publish research produced by your fellowship work. As a fellow, you may not engage in remunerative employment without consent of the Dean. All applicants for admission and continuing students maintaining satisfactory academic standing will be considered for these funds. Applicants should contact the department directly for information. See pages 216–218 for a complete listing of fellowships.

Assistantships

Teaching and research assistantships, available in many departments, provide tuition exemption and a living stipend. Duties may include teaching, laboratory supervision, participation in faculty

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

ALTERNATIVE FUNDING SOURCES

External Awards

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

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

Funding for International Students

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

International students who apply by the December 15 deadline and are admitted to a graduate program in The Fu Foundation School of Engineering

and Applied Science are automatically considered for departmental funding (institutional grants, fellowships, teaching and research assistantships, readerships, and preceptorships) upon completion of the required financial aid forms referred to above. Spring admissions applicants will not be considered for departmental funding. Continuing international students must preregister for classes during the preregistration period and complete an enrollment status form to be considered for departmental funding.

Most loan programs are restricted to U.S. citizens and permanent residents. However, international students may apply for these domestic loan programs with a cosigner who is a citizen or permanent resident in the United States. Depending on the loan program, you may need a valid U.S. Social Security number.

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.

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

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

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

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

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

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

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

New York State Tuition Assistance Program (TAP)

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

Veterans' Benefits

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

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

Federal Family Education Loans

Federal Subsidized Stafford Student Loan Program

Federal Unsubsidized Stafford Loan Program

Federal Perkins Loan

Federal Graduate PLUS Loan

Detailed information regarding the above loan programs may be found on the Student Financial Services Web site: www.columbia.edu/cu/sfs/docs/Grad_Fin_Aid.

Columbia Comprehensive Educational Financing Plan

Columbia University has developed the

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

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

Private Loans

Several private loan programs are available to both U.S. citizens and international students attending Columbia University. These loans were created to supplement federal and institutional aid. These loan programs require that you (the applicant) have a good credit standing and not be in default on any outstanding loans. International students may be eligible for

a private loan with the assistance of a creditworthy U.S. citizen or permanent resident. In some cases, as an international student, you must have a valid U.S. Social Security number. Contact the financial aid office for more details on this loan program.

EMPLOYMENT

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

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

On-Campus Employment

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

Off-Campus Employment in New York City

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

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.careereducation.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

Phone: 212-854-3711
Fax: 212-854-8223
E-mail: engradfinaid@columbia.edu
www.engineering.columbia.edu/graduate/financing

Faculty and Administration



OFFICERS

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B.A., J.D.

*President of Columbia University***Claude M. Steele**

B.A., M.A., Ph.D.

*Provost***Feniosky Peña-Mora**

B.S., M.S., Sc.D.

*Dean***Morton B. Friedman**

B.S., M.S., D.Sc.

*Vice Dean***Anna Marie O'Neill**

B.B.A.

*Associate Dean***Jack McGourty**

B.A., M.S., Ph.D.

*Associate Dean for Undergraduate Studies***Andrew Laine**

B.S., M.S., D.Sc.

Secretary

FACULTY

Alfred V. Aho*Lawrence Gussman Professor of**Computer Science*

B.A.Sc., Toronto, 1963; M.A., Princeton, 1965; Ph.D., 1967

Peter K. Allen*Professor of Computer Science*

B.A., Brown, 1971; M.S., Oregon, 1976; Ph.D., Pennsylvania, 1985

Dimitris Anastassiou*Professor of Electrical Engineering*

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

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B.S., Columbia, 1986; M.S., 1987; M.Phil., 1990; Ph.D., 1991

Daniel Attinger*Assistant Professor of Mechanical Engineering*

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B.S. and B.A., Brown, 1993; M.S., Stanford, 1995; Ph.D., 1999

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Howard W. Vreeland

Professor Emeritus of Graphics

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Departments and Academic Programs



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
AMCS	Applied Mathematics/ Computer Science
AMST	American Studies
APAM	Applied Physics/Applied Mathematics
APBM	Applied Physics/Biomedical Engineering
APMA	Applied Mathematics
APPH	Applied Physics
ARCH	Architecture
ASCE	Asian Civilizations—East Asian
ASCM	Asian Civilizations—Middle East
BIOC	Biology and Chemistry
BIOL	Biology
BIST	Biostatistics

BMCH	Biomedical Engineering/ Chemical Engineering
BMEB	Biomedical Engineering/Electrical Engineering/Biology
BMEE	Biomedical Engineering/ Electrical Engineering
BMEN	Biomedical Engineering
BMME	Biomedical Engineering/ Mechanical Engineering
BUSI	Business
CBMF	Computer Science/Biomedical Engineering/Medical Informatics
CHAP	Chemical Engineering/ Applied Physics and Applied Math
CHCB	Chemistry/Biology/Computer Science
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
CSEE	Computer Science/Electrical Engineering
CSOR	Computer Science/Operations Research
DNCE	Dance
DRAN	Decision, Risk and Operations (Business School)
EACE	Earth and Environmental Engineering/ Civil Engineering

EAEI	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
ECIE	Economics/Industrial Engineering
ECON	Economics
EDUC	Education
EEBM	Electrical Engineering/ Biomedical Engineering
EECS	Electrical Engineering/ Computer Science
EEHS	Electrical Engineering/History
EEME	Electrical Engineering/ Mechanical Engineering
EESC	Earth and Environmental Sciences
ELEN	Electrical Engineering
ENGI	Engineering
ENGL	English
ENME	Engineering Mechanics
FINC	Finance/Economics
FREN	French
GERM	German
GRAP	Graphics
HIST	History
HUMA	Humanities
IEME	Industrial Engineering/ Mechanical Engineering

IEOR	Industrial Engineering and Operations Research
INAF	International Affairs
INTA	Earth and Environmental Engineering/ Civil Engineering/ International and Public 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
RELI	Religion
SCNC	Science
SIEO	Statistics/Industrial Engineering and Operations Research
SOCI	Sociology
SPAN	Spanish
STAT	Statistics
VIAR	Visual Arts

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

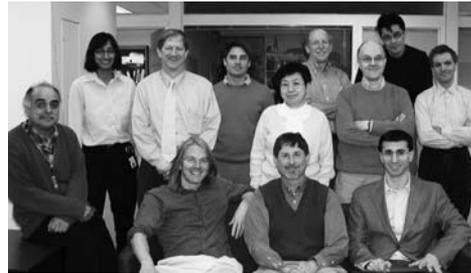
Room assignments and course changes for all courses are available online at www.columbia.edu/cu/bulletin/uwb.

The School reserves the right to withdraw or modify the courses of instruction or to change the instructors at any time.

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

Applied Physics and Applied Mathematics: www.apam.columbia.edu

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



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Thomas C. Marshall

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 169.

Current Research Activities in Applied Physics and Applied Mathematics

Plasma physics and fusion energy.

In experimental plasma physics, research is being conducted on (1) equilibrium, stability, and transport in fusion plasmas: high-beta tokamaks, spherical tokamaks, and levitated dipoles; (2) magnetospheric

physics: trapped particle instabilities and stochastic particle motion; (3) confinement of toroidal nonneutral plasmas; (4) plasma source operation and heating techniques; and (5) the development of new plasma measurement techniques. The results from our fusion science experiments are used as a basis for collaboration with large national and international experiments. For example, our recent demonstration of active feedback control of high temperature plasma

instability is guiding research on NSTX at the Princeton Plasma Physics Laboratory, on the DIII-D tokamak at General 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, optical diagnostics of film processing, new laser systems, nonlinear optics, ultrafast optoelectronics, photonic switching, optical physics of surfaces, laser-induced crystallization, and photon integrated circuits.

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

port in molecular nanostructures; and the DOE Energy Frontier Research Center, which focuses on conversion of sunlight into electricity in nanometer-sized thin films.

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

Atmospheric, oceanic, and earth physics. Current research focuses on the dynamics of the atmosphere and the

ocean, climate modeling, cloud physics, radiation transfer, remote sensing, 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 department faculty and graduate students, many others participate in these projects, including full-time research faculty, faculty and students from other departments, and visiting scientists.

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 jointly constructed the Levitated

Dipole Experiment (LDX), a large plasma confinement experiment incorporating a levitated superconducting ring. The Columbia Non-neutral Torus (CNT) 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 investigates plasma transport in magneto-spheric geometry and the generation of strong plasma flow from 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 a clean room that includes 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 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 department has recently acquired a SiCortex supercomputer with 1,458 cores, which is used for a wide range of departmental computational activities. 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 Beowulf 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; the IBM SUR cluster at Brookhaven National Laboratory in Upton, New York; and others.

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

Current Research Activities and Laboratory Facilities in Materials Science and Engineering

See page 168.

UNDERGRADUATE PROGRAMS

The Department of Applied Physics and Applied Mathematics offers three undergraduate programs: applied physics, applied mathematics, and materials science and engineering. The materials science and engineering program is described on pages 168–169.

The applied physics and applied mathematics programs provide an excellent preparation for graduate study or for careers in which mathematical and technical sophistication are important. Using the large number of electives in these programs, students can tailor their programs to fit their personal and career interests. By focusing their technical electives, students can obtain a strong base of knowledge in a specialized area. In addition to formal minors, some areas of specialization that are available are described on pages 59–60. All technical electives are normally at the 3000 level or above.

UNDERGRADUATE PROGRAM IN APPLIED PHYSICS

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

cialization 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.

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

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

DYNAMICAL SYSTEMS

APMA E4101 or PHYS G4003

OPTICAL OR LASER PHYSICS:

APPH E4110 or E4112

NUCLEAR SCIENCE: APPH E4010

PLASMA PHYSICS: APPH E4301

PHYSICS OF FLUIDS: APPH E4200

CONDENSED MATTER PHYSICS: PHYS G4018

BIOPHYSICAL MODELING: APMA E4400

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

All students must take 30 points of electives in the third and fourth years,

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

UNDERGRADUATE PROGRAM IN APPLIED MATHEMATICS

The applied mathematics program is flexible and intensive. A student must take the required courses listed below, or prove equivalent standing, and then may elect the other courses from mathematics, computer science, physics, Earth and environmental sciences, biophysics, economics, business and finance, or other application fields. Each student tailors his or her own program in close collaboration with an adviser. He or she must also register for the applied mathematics seminar during both the junior and senior years. During the junior year, the student attends the seminar lectures for 0 points; during the senior year, he or she attends the seminar lectures as well as tutorial problem sessions for 3 or 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 27 points of elective content in the third and fourth years, at least 15 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.

Transfers into the applied mathematics program from other majors require a GPA of 3.0 or above, and the approval of the applied mathematics program chair.

UNDERGRADUATE DOUBLE MAJOR IN APPLIED PHYSICS AND APPLIED MATHEMATICS

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

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

SPECIALTY AREAS IN APPLIED PHYSICS AND APPLIED MATHEMATICS

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

Technical Electives

• Applications of Physics

Courses that will give a student a broad background in applications of physics are:

MSAE E3103x: Elements of materials science (J)
ELEN E3000x: Introduction to circuits, systems, and electronics (J)

APPH E4010x: Introduction to nuclear science
APPH E4110x: Modern optics
APPH E4112y: Laser physics
APPH E4200x: Physics of fluids
APPH E4301y: Introduction to plasma physics

PHYS G4018y: Solid-state physics

APMA E4101y: Introduction to dynamical systems

• Earth and Atmospheric Sciences

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

A. ATMOSPHERE, OCEANS AND CLIMATE

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

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

• Basic Physics and Astrophysics

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

PHYS W3002y: From quarks to the cosmos: applications of modern physics

ASTR C3601x: General relativity, black holes, and cosmology (J)

ASTR C3602y: Physical cosmology and extragalactic astronomy (J)

APMA E4101x: Introduction to dynamical systems

ASTR G4001y: Astrophysics, I

• Business and Finance

The knowledge of physics and mathematics that is gained in the applied physics and applied mathematics

programs is a strong base for a career in business or finance.

A. ECONOMICS

- ECON W3211x,y:** Intermediate microeconomics (J)
ECON W3213x,y: Intermediate macroeconomics (J)

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
ECIE W4280: Corporate 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 E4101x:** Introduction to dynamical systems
APMA E4001y: Principles of applied mathematics
APMA E4301x: Numerical methods for partial differential equations
APMA E4302x: Parallel scientific computing
MATH V3386x: Differential geometry
MATH W4386x-W4387y: Geometrical concepts in physics

• 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 E4101x:** Introduction to dynamical systems
APMA E4150x: Applied functional analysis
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:** Physics of the human body

RECOMMENDED:

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

OTHER TECHNICAL ELECTIVES (A COURSE IN 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:** Introduction to numerical methods
APMA E4301x: Numerical methods for partial differential equations
AMCS E4302: Parallel scientific computing
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

• 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 168.

GRADUATE PROGRAMS

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

M.S. Program in Applied Physics

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

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

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

APMA E4001: Principles of applied mathematics

APMA E4101: Introduction to dynamical systems

APMA E4150: Applied functional analysis

APMA E4200: Partial differential equations

APMA E4204: Functions of a complex variable

APMA E4300: Introduction to numerical methods

APMA E4301: Numerical methods for partial differential equations

APMA E6301: Analytic methods for partial differential equations

APMA E6302: Numerical analysis for partial differential equations

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

CSOR W4231: Analysis of algorithms

COMS W4236: Introduction to computational complexity

COMS W4241: Numerical algorithms and complexity

COMS W4252: Computational learning theory

Industrial engineering/operations research elective courses include:

IEOR E4003: Industrial economics

IEOR E4004: Introduction to operations research: deterministic models

IEOR E4007: Optimization: models and methods

IEOR E4106: Introduction to operations research: stochastic models

SIEO W4150: Introduction to probability and statistics

IEOR E4403: Advanced engineering and corporate economics

IEOR E4407: Game theoretic models of operations

SIEO W4606: Elementary stochastic processes,

IEOR E4700: Introduction to financial engineering

Other elective courses include:

MECE E4100: Mechanics of fluids

MSAE E4215: Mechanical behavior of structural materials

EEME E6601: Introduction to control theory

M.S. Program in Medical Physics

This CAMPEP-approved 36-point program in medical physics leads to the M.S. degree. It is administered by faculty from the School of Engineering and Applied Science in collaboration with faculty from the College of Physicians and Surgeons and the Mailman School of Public Health. It provides preparation toward certification by the American Board of Radiology. The program consists of a core curriculum of medical physics courses, anatomy, lab, seminar, and two practicums. Specific course requirements are *APPH E4010*, *E4710/11*, *E4500*, *E4550*, *E4600*, and *APBM E4650*, and, in the Mailman School of Public Health, *EHSC P6330*, *P9319*, *P9330*, and *P9335*. Some opportunities for specialization exist. 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.

Certificate of Professional Achievement in Medical Physics

This graduate program of instruction leads to the Certificate of Professional Achievement and requires satisfactory completion of at least four of the following courses:

APPH E4500: Health physics

APPH E4600: Dosimetry

EHSC P6330: Radiation science

EHSC P9319: Clinical nuclear medicine physics

EHSC P9330: Diagnostic radiological physics

EHSC P9335: Radiation therapy physics

APBM E4650: Anatomy for physicists and engineers

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

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

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

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

See page 169.

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

APPLIED PHYSICS PROGRAM: FIRST AND SECOND YEARS

APPLIED PHYSICS PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS¹	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and ODE (3) ²
PHYSICS (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)
CHEMISTRY/ BIOLOGY (choose one course)	CHEM C1403 (3), or higher or BIOL W2001 (4) or BIOL C2005 (4), or higher			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) ————— Z0006 (0) —————	C1010 (3) Z1003 (0) —————	C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES			HUMA C1001, COCI C1101, or Global Core (3–4) HUMA W1121 or W1123 (3)	HUMA C1002, COCI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
REQUIRED TECH ELECTIVES	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see pages 12–13)			
COMPUTER SCIENCE	A computer language of the student's choice at the 1000 level or higher			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹With the permission of the faculty adviser, students with advanced standing may start the calculus sequence at a higher level.

²Applied physics majors should satisfy their ODE requirement with the Mathematics Department (ordinarily MATH E1210).

Students who take APMA E2101 prior to declaring their major in applied physics may use this course to satisfy their ODE requirement.

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 169.

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 con-

centrate are laser modification of surfaces, the free-electron laser, optical diagnostics of film processing, inelastic light scattering in nano-materials, nonlinear optics, ultrafast optoelectronics photonic switching, optical physics of surfaces, and photon integrated circuits. Specific course requirements for the optical and laser physics doctoral program are set with the academic adviser.

Solid-State Physics

This academic program encompasses the study of the electrical, optical, magnetic, thermal, high-pressure, and ultrafast dynamical properties of solids, with an aim to understanding them in terms of the atomic and electronic structure. The program emphasizes the formation, processing, and properties of thin films, low-dimensional structures—such as

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) Linear algebra	APMA E3102 (3) Partial differential equations	Course in first AP area (3)	
		APPH E4901 (1) Seminar		APPH E4903 (2) Seminar	
ELECTIVES	TECH ¹	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

¹They must include at least 2 points of laboratory courses. If PHYS W3081 is taken as part of the first two years of the program, these technical electives need not include laboratory courses. Technical electives must be at the 3000 level or above unless prior approval is obtained.

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 Nano-scale 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. Instructor to be announced.

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, introduction 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 pts. Not given in 2009–2010.

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

APPH E3300y Applied electromagnetism

Lect. 3. 3 pts. Professor Venkataraman.

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

APPLIED MATHEMATICS PROGRAM: FIRST AND SECOND YEARS

APPLIED MATHEMATICS PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS¹	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202(3) and ODE (3) ²
PHYSICS (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)
CHEMISTRY/BIOLOGY (choose one course)	CHEM C1403 (3), or higher or BIOL W2001 (4) or BIOL C2005 (4), or higher			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	C1010 (3) Z1003 (0)	C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES			HUMA C1001, COCI C1101, or Global Core (3–4) HUMA W1121 or W1123 (3)	HUMA C1002, COCI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
REQUIRED TECH ELECTIVES	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see pages 12–13)			
COMPUTER SCIENCE	A computer language of the student's choice at the 1000 level or higher			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹With the permission of the faculty adviser, students with advanced standing may start the calculus sequence at a higher level.

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

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. Professor Ostrow.

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

APPH E4018y Applied physics laboratory

Lab: 4. 2 pts. Professor Mauel.

Prerequisite: ELEN E3401 or the equivalent. Typical experiments are in the areas of plasma physics, microwaves, laser applications, optical

spectroscopy physics, and superconductivity.

APPH E4090x Nanotechnology

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

Professor Herman.

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

APPH E4100x Quantum physics of matter

Lect: 3. 3 pts. Professor Venkataraman.

Prerequisite: APPH E3100. Corequisite: APMA E3102 or the equivalent. Basic theory of quantum mechanics, well and barrier problems, the har-

monic 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 2009–2010.

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 2009–2010.

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

APPLIED MATHEMATICS: THIRD AND FOURTH YEARS

APPLIED MATHEMATICS: THIRD AND FOURTH YEARS					
		SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES		APMA E3101 (3) ¹ Linear algebra (Applied math, I)	APMA E3102 (3) ¹ Partial differential equations (Applied math, II)	MATH W4061 (3) Modern analysis	APMA E3900 (3) ³ Research
		APMA E4901 (0) Seminar	Course from Group A or Group B ²	APMA E4101 (3) Introduction to dynamical systems (Applied math, III)	Courses designated MATH, APMA, or STAT (3)
		Course from Group A or Group B ²	APMA E4300 (3) Introduction to numerical methods (Computational math, I)	APMA E4903 (4) Seminar	
		APMA E4204 (3) ¹ Complex variables			
ELECTIVES	TECH ⁴	3 points	3 points	3 points	6 points
	NONTECH	3 points	3 points	3 points	3 points
TOTAL POINTS		15	15	16	15

¹MATH V2010 may be substituted for APMA E3101; APMA E4200 or MATH V3028 may be substituted for APMA E3102; MATH V3007 may be substituted for APMA E4204.

²One course from Group A and one course from Group B required for graduation. Group A: SIEO W3658: Probability; SIEO W4105: Probability; SIEO W3600: Introduction to probability and statistics; SIEO W4150: Introduction to probability and statistics; MATH W4155: Probability theory. Group B: STAT W3105: Introduction to statistics; STAT W3107: Statistical inference; STAT W4107: Statistical inference; STAT W4109: Probability and statistical inference; SIEO W 4606: Elementary stochastic processes; IEOR E3106: Introduction to stochastic models; IEOR E4106: Introduction to operations research: stochastic models; IEOR E4703: Monte Carlo simulation; COMS W4771: Machine learning.

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

⁴Any course in science or engineering at the 3000 level or above qualifies as a technical elective.

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 E4130y Physics of solar energy

Lect: 3. 3 pts. Professor Chen.

Prerequisites: General physics (PHYS C1403 or C1602), general chemistry (one term, such as CHEM C1403), and mathematics, including ordinary differential equations and complex numbers (such as MATH V1202 or E1210), or the instruc-

tor's permission. The physics of solar energy, including solar radiation, the analemma, atmospheric effects, thermodynamics of solar energy, physics of solar cells, energy storage and transmission, and physics and economics in the solar era.

APPH E4200x Physics of fluids

Lect: 3. 3 pts. Professor Mauel.

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

APPH E4210y Geophysical fluid dynamics

Lect: 3. 3 pts. Professor Polvani.

Prerequisites: APMA E3101 and E3102 or the equivalents and APPH E4200 or the equivalent, or permission of the instructor. Fundamental concepts in the dynamics of rotating, stratified flows. Geostrophic and hydrostatic balances, potential vorticity, f and beta plane approximations, gravity

and Rossby waves, geostrophic adjustment and quasigeostrophy, baroclinic and barotropic instabilities, Sverdrup balance, boundary currents, Ekman layers.

APPH E4300x Applied electrodynamics

Lect: 3. 3 pts. Professor Boozer.

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

APPH E4301y Introduction to plasma physics

Lect: 3. 3 pts. Professor Maurer.

Prerequisite: APPH E4300. Definition of a plasma. Plasmas in laboratories and nature, plasma production. Motion of charged particles in electric and magnetic fields, adiabatic invariants. Heuristic treatment of collisions, diffusion, 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: 3. 3 pts. J. A. Meli.

Co- or prerequisite: APPH E4010. Basic radiation physics: radioactive decay, radiation producing devices, characteristics of the different types of radiation (photons, charged and uncharged particles) and mechanisms of their interactions with materials. Essentials of the determination, by measurement and calculation, of absorbed doses from ionizing radiation sources used in medical physics (clinical) situations and for health physics purposes.

APBM E4650y Anatomy for physicists and engineers

Lect: 3. 3 pts. Members of the faculty.

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

APPH E4710x-E4711y Radiation instrumentation and measurement laboratory, I and II

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

Co- or prerequisite: APPH E4010. Lab fee: \$50 each term. E4710: theory and use of α , β , γ , and X ray 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; diagnostic x-ray and fluoro Q/C; planar gamma camera imaging; image analysis.

APPH E4901x Seminar: problems in applied physics

Lect: 1. 1 pt. Professors Herman and Venkataraman. Required for, and can be taken only by, all applied

physics majors and minors in the junior year. Discussion of specific and self-contained problems in areas such as applied electrodynamics, physics of solids, and plasma physics. Topics change yearly.

APPH E4903x Seminar: problems in applied physics

Lect: 1. Tutorial: 1. 2 pts. Professors Herman and Venkataraman.

Required for, and can be taken only by, all applied physics majors in the senior year. Discussion of specific and self-contained problems in areas such as applied electrodynamics, physics of solids, and plasma physics. Formal presentation of a term paper required. Topics change yearly.

APPH E4990x and y Special topics in applied physics

Lect: 3. 1–3 pts. Instructors to be announced.

Prerequisite: Permission of the instructor. Topics and instructors change from year to year. For advanced undergraduate students and graduate students in engineering, physical sciences, and other fields.

APAM E4999x and y and S4999 Curricular practical training

1 pt. Members of the faculty.

Prerequisites: Internship and adviser's approval (must be obtained in advance). Only for master's students in the Department of Applied Physics and Applied Mathematics who may need relevant work experience as part of their program of study. Final report required. This course may not be taken for pass/fail or audited.

APPH E6081x Solid state physics, I

Lect: 3. 3 pts. Professor Pinczuk.

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

APPH E6082y Solid state physics, II

Lect: 3. 3 pts. Professor Kim.

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 E6091y Magnetism and magnetic materials

Lect: 3. 3 points. Offered in alternate years.

Not given in 2009–2010.

Prerequisite: MSAE E4206, APPH E6081, or the equivalent. Types of magnetism. Band theory of ferromagnetism. Magnetic metals, insulators, and semiconductors. Magnetic nanostructures: ultra-

thin films, superlattices, and particles. Surface magnetism and spectroscopies. High-speed magnetization dynamics. Spin electronics.

APPH E6101x Plasma physics, I

Lect: 3. 3 points. Professor Katsuro-Hopkins.

Prerequisite: APPH E4300. Debye screening. Motion of charged particles in space- and time-varying electromagnetic fields. Two-fluid description of plasmas. Linear electrostatic and electromagnetic waves in unmagnetized and magnetized plasmas. The magnetohydrodynamic (MHD) model, including MHD equilibrium, stability, and MHD waves in simple geometries. Fluid theory of transport.

APPH E6102y Plasma physics, II

Lect: 3. 3 pts. Professor Boozer.

Prerequisite: APPH E6101x. Magnetic coordinates. Equilibrium, stability, and transport of toroidal plasmas. Ballooning and tearing instabilities. Kinetic theory, including Vlasov equation, Fokker-Planck equation, Landau damping, kinetic transport theory. Drift instabilities.

APPH E6110x Laser interactions with matter

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

Not given in 2009–2010.

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 Spiegelman.

Prerequisite: Calculus III. A unified, single-semester introduction to differential equations and linear algebra with emphases on (1) elementary analytical and numerical technique and (2) discovering the analogs on the continuous and discrete sides of the mathematics of linear operators: superposition, diagonalization, fundamental solutions.

Concepts are illustrated with applications using the language of engineering, the natural sciences, and the social sciences. Students execute scripts in Mathematica and MATLAB (or the like) to illustrate and visualize course concepts (programming not required).

APMA E3101x Linear algebra

Lect: 3. 3 pts. Professor Gentine.

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 Partial differential equations

Lect: 3. 3 pts. Professor Langmore.

Prerequisite: MATH E1210 or the equivalent.

Introduction to partial differential equations; integral theorems of vector calculus. Partial differential equations of engineering in rectangular, cylindrical, and spherical coordinates. Separation of the variables. Characteristic-value problems. Bessel functions, Legendre polynomials, other orthogonal functions; their use in boundary value problems. Illustrative examples from the fields of electromagnetic theory, vibrations, heat flow, and fluid mechanics.

APMA E3900x and y Undergraduate research in applied mathematics

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

This course may be repeated for credit, but no more than 6 points may be counted toward the satisfaction of the B.S. degree requirements. Candidates for the B.S. degree may conduct an investigation in applied mathematics or carry out

a special project under the supervision of the staff. Credit for the course is contingent upon the submission of an acceptable thesis or final report.

APMA E4001y Principles of applied mathematics

Lect: 3. 3 pts. Professor Schmitt.

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 Introduction to dynamical systems

Lect: 3. 3 pts. Professor Weinstein.

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

APMA E4150x Applied functional analysis

Lect: 3. 3 pts. Professor Bal.

Prerequisites: Advanced calculus and a course in basic analysis, or the instructor's permission.

Introduction to modern tools in functional analysis that are used in the analysis of deterministic and stochastic partial differential equations and in the analysis of numerical methods: metric and normed spaces, Banach space of continuous functions, measurable spaces, the contraction mapping theorem, Banach and Hilbert spaces, bounded linear operators on Hilbert spaces and their spectral decomposition, and (time permitting) distributions and Fourier transforms.

APMA E4200x Partial differential equations

Lect: 3. 3 pts. Professor Sobel.

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 Introduction to numerical methods

Lect: 3. 3 pts. Professor Chow.

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

APMA E4301x Numerical methods for partial differential equations

Lect: 3. 3 pts. Professor Spiegelman.

Prerequisites: APMA E4300 and E3102 or E4200,

or their equivalents. Numerical solution of partial differential equations (PDE) arising in various physical fields of application. Finite difference, finite element, and spectral methods. Elementary finite volume methods for conservation laws. Time stepping, method of lines, and simultaneous space-time discretization. Direct and iterative methods for boundary-value problems. Applied numerical analysis of PDE, including sources of numerical error and notions of convergence and stability, to an extent necessary for successful numerical modeling of physical phenomena.

Applications will include the Poisson equation, heat equation, wave equation, and nonlinear equations of fluid, solid, and gas dynamics. Homework assignments will involve substantial programming.

AMCS E4302x Parallel scientific computing

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

Professor Chow.

Prerequisites: APMA E3101, E3102, and E4300, or their equivalents. Corequisites: APMA E4301

and programming ability in C/C++ or FORTRAN/F90. An introduction to the concepts, the hardware and software environments, and selected algorithms and applications of parallel scientific computing, with an emphasis on tightly coupled computations that are capable of scaling to thousands of processors. Includes high-level descriptions of motivating applications and low-level details of implementation, in order to expose the algorithmic kernels and the shifting balances of computation and communication between them. Students run demonstration codes provided on a Linux cluster. Modest programming assignments using MPI and PETSc culminate in an independent project leading to an in-class report.

APMA E4400y Introduction to biophysical modeling

Lect: 3. 3 pts. Professor Wiggins.

Prerequisites: PHYS W1401 or the equivalent and APMA E2101 or MATH E1210 or the equivalent. Introduction to physical and mathematical models of cellular and molecular biology. Physics at the cellular scale (viscosity, heat, diffusion, statistical mechanics). RNA transcription and regulation of genetic expression. Genetic and biochemical networks. 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 pt. Professor Wiggins.

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

APMA E4903x Seminar: problems in applied mathematics

Lect: 1. Tutorial: 2. 3 or 4 pts. Professor Wiggins.

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

APMA E4990x and y Special topics in applied mathematics

Lect: 3. 1–3 pts. Instructors to be announced.

Prerequisites: Advanced calculus and junior year applied mathematics, or their equivalents. This course may be repeated for credit. Topics and instructors from the Applied Mathematics Committee and the staff change from year to

year. For advanced undergraduate students and graduate students in engineering, physical sciences, biological sciences, and other fields.

APMA E6209x Approximation theory

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

Not given in 2009–2010.

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: 3. 3 pts. Professor Bal.

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

APMA E6302x Numerical analysis of partial differential equations

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

Not given in 2009–2010.

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: 3. 3 pts. Not given in 2009–2010.

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 Langmore;

y: Not given in 2009–2010.

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: 3. 3 pts. Offered in alternate years.

Professor Marzuola.

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.

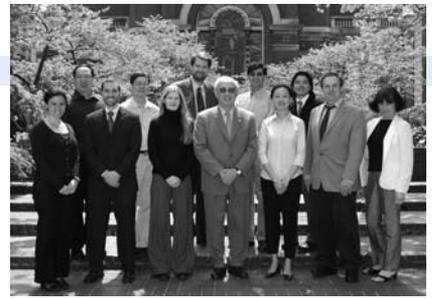
Problems in the dynamics of geophysical fluid flows. May be repeated for up to 10 points of credit.

COURSES IN MATERIALS SCIENCE AND ENGINEERING

See page 171.

BIOMEDICAL ENGINEERING

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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., and M.D./Ph.D.) prepare students to apply engineering and applied science to problems in biology, medicine, and the understanding of living systems and their behavior, and to develop

biomedical systems and devices. Modern engineering encompasses sophisticated approaches to measurement, data acquisition and analysis, simulation, and systems identification. These approaches are useful in the study of individual cells, organs, entire organisms, and populations of organisms. The increasing value of mathematical models in the analysis of living systems is an important sign of the success of contemporary activity. The programs offered in the Department of Biomedical Engineering seek to emphasize the confluence of basic engineering science and applied engineering with the physical and biological sciences, particularly in the areas of biomechanics, cell and tissue

engineering, and biomedical imaging. Programs in biomedical engineering are taught by its own faculty, members of other SEAS departments, and faculty from other University divisions who have strong interests and involvement in biomedical engineering. Several of the faculty hold joint appointments in Biomedical Engineering and other University departments. Courses offered by the Department of Biomedical Engineering are complemented by courses offered by other departments in The Fu Foundation School of Engineering and Applied Science, and by many departments in the Faculty of Medicine, the School of Dentistry and Oral Surgery, and the Mailman School of Public Health, as well

as the science departments within the Graduate School of Arts and Sciences. The availability of these courses in a university that contains a large medical center and enjoys a basic commitment to interdisciplinary research is important to the quality and strength of the program.

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

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

Facilities

The Department of Biomedical Engineering has been supported by University funding, awards from the Whitaker Foundation, and research funding from the NIH, NSF, and numerous research foundations. The extensive new facilities that have recently been added both at the Medical Center and Morningside campus include 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 incor-

porates equipment normally reserved for advanced research and provides exceptional access to current practices in biomedical engineering and related sciences. Adjacent to the new laboratories is a lounge that serves as a meeting point for biomedical engineering undergraduate and graduate students.

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

UNDERGRADUATE PROGRAM

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

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

The undergraduate curriculum is designed to provide broad knowledge of the physical and engineering sciences and their application to the solution of biological and medical problems. Students are strongly encouraged to take courses in the order specified in the course tables on pages 74–77; implications of deviations should be discussed with a departmental adviser before registration. The first two years provide a strong grounding in the physical and chemical sciences, engineering fundamentals, and mathematics. This background is used to provide a unique physical approach to the study of biological systems. The last two years of the undergraduate program provide substantial exposure to modern biology and include courses in engineering and 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 most U.S. medical schools.

All biomedical engineering students are expected to register for nontechnical electives, both those specifically required by the School of Engineering and Applied Science and those needed to meet the 27-point total of nontechnical electives required for graduation.

First and Second Years

As outlined in this bulletin, in the first two years all engineering students are expected to complete a sequence of courses in mathematics, physics, chemistry, computer science, engineering, English composition, and physical education, as well as nontechnical electives including the humanities. For most of these sequences, the students may choose from two or more tracks. If there is a question regarding the acceptability of a course as a nontechnical elective, please consult the approved listing of courses beginning on page 11 or contact your advising dean for clarification.

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

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

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

Third and Fourth Years

The biomedical engineering programs at Columbia at all levels are based on engineering and biological fundamentals. This is emphasized in our core requirements across all tracks. In the junior year, all students begin their biomedical engineering study with the two-semester *Introduction to molecular and cellular biology, I and II (BIOL C2005-C2006)*, which gives students a comprehensive overview of modern biology from molecular to organ system levels. Parallel to these biology studies, all students take the two-semester *Quantitative physiology,*

I and II sequence (*BMEN E4001-E4002*) which is taught by biomedical engineering faculty and emphasizes quantitative applications of engineering principles in understanding biological systems and phenomena from molecular to organ system levels. In the fields of biomedical engineering, experimental techniques and principles are fundamental skills that good biomedical engineers must master. Beginning in junior year, all students take the three-semester sequence *Biomedical engineering laboratory, I-III (BMEN E3810, BMEN E3820, BMEN E3830)*. In this three-semester series, students learn through hands-on experience the principles and methods of biomedical engineering experimentation, measurement techniques, quantitative theories of biomedical engineering, data analysis, and independent design of biomedical engineering experiments, the scope of which cover a broad range of topics from all three tracks—biomechanics, cell and tissue engineering, and biomedical imaging. In the senior year, students take the required course *Ethics for biomedical engineers (BMEN E4010)*, a SEAS 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 design course, *Biomedical engineering design (BMEN E3910 and BMEN E3920)*, in which students work within a team to tackle an open-ended design project in biomedical engineering. The underlying philosophy of these core requirements is to provide our biomedical engineering students with a broad knowledge and understanding of topics in the field of biomedical engineering. Parallel to these studies in core courses, students take track-specific required courses to obtain an in-depth understanding of their chosen concentration. The curriculum of all three academic tracks—biomechanics, cell and tissue engineering, and biomedical imaging—prepares students who wish to pursue careers in medicine by satisfying most requirements in the pre-medical programs 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 sched-

ules leading to a bachelor's degree in biomedical engineering.

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

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

Technical Elective Requirements

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

1. Technical elective courses with sufficient engineering content that can count toward the 48 units of engineering courses required for ABET accreditation:
 - a. all 3000-level or higher courses in the Department of Biomedical Engineering, except: *BMEN E4010, E4103, E4104, E4105, E4106, E4107 and E4108* (Note that only 3 points of *BMEN E3998* may be counted toward technical elective degree requirements.)
 - b. all 3000-level or higher courses in the Department of Mechanical Engineering, except: *MECE E4007: Creative engineering and entrepreneurship*
 - c. all 3000-level or higher courses in the Department of Chemical Engineering, except: *CHEN E4020: Safeguarding intellectual and business property*
 - d. all 3000-level or higher courses in the Department of Electrical Engineering, except: *EEHS E3900: History of telecommunications: from the telegraph to the Internet*

- e. all 3000-level or higher courses in the Civil Engineering and Engineering Mechanics program, except: *CIEN E4128, E4129, E4130, E4131, E4132, E4133, E4134, E4135, and E4136*
- f. all 3000-level or higher courses in the Earth and Environmental Engineering program
2. Courses from the following departments are not allowed to count toward the required 48 units of engineering courses:
- Department of Applied Physics and Applied Mathematics
 - Department of Computer Science
 - Department of Industrial Engineering and Operations Research
 - Program of Materials Science and Engineering

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

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

GRADUATE PROGRAM

The graduate curriculum in biomedical engineering employs the same three tracks that compose the undergraduate curriculum: biomechanics, cell and tissue engineering, and biomedical imaging. Initial graduate study in biomedical engineering is designed to expand the student's undergraduate preparation in the direction of the track chosen. In addition, sufficient knowledge is acquired in other areas to facilitate broad appreciation of problems and effective collaboration with specialists from other scientific, medical, and engineering disciplines. The Department of Biomedical Engineering offers a gradu-

ate program leading to the Master of Science degree (M.S.), the Doctor of Philosophy degree (Ph.D.), the Doctor of Engineering Science degree (Eng.Sc.D.), and the M.D./Ph.D. degree program. Applicants who have a Master of Science degree or equivalent may apply directly to the doctoral degree program. All applicants are expected to have earned the bachelor's degree in engineering or in a cognate scientific program. The Graduate Record Examination (General Test only) is required of all applicants. Students whose bachelor's degree was not earned in a country where English is the dominant spoken language are required to take the TOEFL test. M.S. degree candidates must reach level 8 on the English Placement Test (EPT) offered by Columbia's American Language Program (ALP). Doctoral degree candidates must attain level 10 on the English Placement Test (EPT). The ALP examination must be taken at orientation upon arrival. It is strongly recommended the students enroll in an appropriate ALP course if they have not achieved the required proficiency after the first examination. In addition, the individual tracks require applicants to have taken the following foundation courses:

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

Applicants lacking some of these courses may be considered for admission with stipulated deficiencies that must be satisfied in addition to the requirements of the degree program. The Fu Foundation School of Engineering and Applied Science does not admit students holding the bachelor's degree directly to doctoral studies; admission is offered either to the M.S. program or to the M.S. program/doctoral track. The Department

of Biomedical Engineering also admits students into the 4-2 program, which provides the opportunity for students holding a bachelor's degree from certain physical sciences to receive the M.S. degree after two years of study at Columbia.

CURRICULUM AND EXAM REQUIREMENTS

Master's Degree

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

Doctoral Degree

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

Doctoral students must complete a program of 30 points of credits beyond the M.S. degree. The course in computational modeling of physiological systems (*BMEN E6003*) is required for the doctoral program. At least two graduate mathematics courses must be taken, which may include the mathematics course required for the M.S. degree. Students must register for *BMEN E9700: Biomedical engineering seminar* and for research rotations during the first two semesters of graduate study. Remaining courses should be selected

in consultation with the student's faculty adviser to prepare for the doctoral qualifying examination and to develop expertise in a clearly identified area of biomedical engineering. Up to 12 credits of research (*BMEN E9500*) may be applied toward doctoral degree course requirements.

All graduate students admitted to the doctoral degree program must satisfy the equivalent of three semesters' experience in teaching (one semester for M.D./Ph.D. students). This may include supervising and assisting undergraduate students in laboratory experiments, grading, and preparing lecture materials to support the teaching mission of the department. The Department of Biomedical Engineering is the only engineering department that offers Ph.D. training to M.D./Ph.D. students. These candidates are expected to complete their Ph.D. program within 3.5 years, with otherwise the same 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.

Doctoral Committee and Thesis

Students who pass the qualifying examination choose a faculty member to serve as their research adviser. Each student is expected to submit a research proposal and present it to a thesis committee that consists of three to five faculty members. The committee considers the scope of the proposed research, its suitability for doctoral research and the appropriateness of the research plan. The committee may approve the proposal without reservation or may recommend modifications. In general, the student is expected to submit his/her research proposal after five semesters of doctoral studies. In accord with

regulations of The Fu Foundation School of Engineering and Applied Science, each student is expected to submit a thesis and defend it before a committee of five faculty, two of whom hold primary appointments in another department. Every doctoral candidate is required to have had accepted at least one first-author full-length paper for publication in a peer-reviewed journal prior to recommendation for award of the degree.

COURSES IN BIOMEDICAL ENGINEERING

See also the sections for Applied Physics, Chemical Engineering, Computer Science, and Computer Engineering in this bulletin, and the Columbia College and Graduate School of Arts and Sciences bulletins for courses in the biological sciences: biomedical informatics, cell biology, microbiology, and physiology.

BMEN E1001x Engineering in medicine

Lect: 3. 3 pts. Professor Hung 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 spring of their sophomore year if they choose the biomechanics track.

BMEN E2400x or y Biomedical imaging track

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

BMEN E2500x or y Cell and tissue engineering track

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

ECBM E3060x Introduction to genomic information science and technology

Lect: 3. 3 pts. Professor Anastassiou. Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function, and manipulation of the biomolecular sequences of nucleic acids and pro-

teins. The role of enzymes and gene regulatory elements in natural biological functions as well as in biotechnology and genetic engineering. Recombination and other macromolecular processes viewed as mathematical operations with simulation and visualization using simple computer programming. This course shares lectures with ECBM E4060, but the work requirements differ somewhat.

BMEN E3150y The cell as a machine

Lect: 3. 3 pts. Not given in 2009–2010. Prerequisite: MATH V1101 or V1105. 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 Huang. 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.

BMCH 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. Instructor to be announced. 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. Instructor to be announced. Statistical analysis of experimental measurements: analysis of variance, power analysis. Circuit implementation of nerve conduction, alginate bead forma-

BIOMEDICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS

CLASSES OF 2009–2011

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3)
PHYSICS (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)	
CHEMISTRY (three tracks, choose one)	C1403 (3.5) ————— C1604 (3.5) ————— C3045 (3.5) —————	C1404 (3.5) ————— and Lab C1500 (3) either semester C2507 (3) ————— C3046 (3.5), C2507 (3)	C3443 (3.5) C3443 (3.5)	
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) ————— Z0006 (0) —————	C1010 (3) Z1003 (0) —————	C1010 (3)	
COMPUTER SCIENCE	COMS W1005 (3) Matlab (in semester I or III)			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			
NONTECHNICAL REQUIREMENTS			HUMA C1001, C0CI C1101, or Global Core (3–4) HUMA W1121 (3) or W1123 (3)	HUMA C1002, C0CI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
TECHNICAL REQUIREMENTS	Professional-level course (except ELEN E1201) (either semester)		ELEN E1201 Intro. to EE (3.5)	APMA E2101 Intro. to applied math (3) ENME E3105 Mechanics (4)

tion, 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. Instructor to be announced.

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 Hillman 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, development of design prototype, need, approach, benefits and competition analysis. Semester II: spiral develop process and testing, iteration and refinement of the initial design/prototype and business plan development. A laboratory fee of \$100 is collected each semester.

BMEN E3998x or y, or s Projects in biomedical engineering

Hours to be arranged. 1 to 3 pts. Professors Anastassiou, Ateshian, Brown, Das, Guo, Hess, Hielscher, Hillman, Homma, Huang, Hung, Jacobs, Kam, Konofagou, Laine, Leonard, H. H. Lu, Mao, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic.

Independent projects involving experimental, the-

oretical, computational, or engineering design work. May be repeated, but no more than 3 points may be counted toward degree requirements as engineering technical electives. Requires approval of instructor prior to registration.

BMEN E4000x or y Special topics

Lect: 3. 3 pts. Professor Jacobs.

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 Jacobs.

Prerequisites or corequisites: CHEM C3443 or the equivalent and BIOL C2005. Physiological systems at the cellular and molecular level are examined in a highly quantitative context. Topics include chemical kinetics, molecular binding and enzymatic processes, molecular motors, biological membranes, and muscles.

BIOMEDICAL ENGINEERING: THIRD AND FOURTH YEARS CLASSES OF 2009–2011

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII	
REQUIRED COURSES: ALL TRACKS	BIOL C2005 (4) Introductory biol. I BMEN E4001 (3) Quantitative physiol. I STAT W1211 (3) Intro. to statistics	BIOL C2006 (4) Introductory biol. II 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 3920 (4) BME design II BMEN E3830 (3) BME laboratory III BMEN E4010 (2) ⁴ Ethics for BMEs	
NONTECH ELECTIVES	0–3 points	3 points	0–3 points	3 points	
TRACK-SPECIFIC COURSES	CELL & TISSUE ENG.¹	BMEN E2500 (0) BMEN E4210 (4) Thermo. biolog. sys. MSAE E3103 (3) Elements of mat. sci.	BMCH E3500 (3) Biol. transport. proc. or BMEN E3320 (3) Fluid biomech. Technical elective (3)	BMEN E4501 (3) Tissue eng. I Technical elective (6)	BMEN E4502 (3) Tissue eng. II
	BIOMECH.²	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 (6)	BMEN 4300 (3) Solid biomech.
	BIOMED. IMAGING³	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 Technical elective (3)	BMEN E4410 (3) Ultrasound imaging or BMEN E4898 (3) Biophotonics
TOTAL POINTS	16–17	19	19	15	

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

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

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

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

BMEN E4002y Quantitative physiology, II: organ systems

Lect: 3. 3 pts. Professor Morrison.

Prerequisites or corequisites: CHEM C3443;

BIOL C2005, C2006. Students are introduced to a quantitative, engineering approach to cellular biology and mammalian physiology. Beginning with biological issues related to the cell, the course

progresses to considerations of the major physiological systems of the human body (nervous, circulatory, respiratory, renal).

BMEN E4010y Ethics for biomedical engineers

Lect: 2. 2 pts. Professor Loike.

Prerequisite: Senior status in biomedical engineering or the instructor's permission. Covers a

wide range of ethical issues expected to confront graduates as they enter the biotechnology industry, research, or medical careers. Topics vary and incorporate guest speakers from Physicians and Surgeons, Columbia Law School, Columbia College, and local industry.

BIOMEDICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS CLASS OF 2012 AND LATER

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3)
PHYSICS (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)	
CHEMISTRY (three tracks, choose one)	C1403 (3.5) ————— C1604 (3.5) ————— C3045 (3.5) —————	C1404 (3.5) ————— and Lab C1500 (3) either semester C2507 (3) ————— C3046 (3.5), C2507 (3)	C3443 (3.5) C3443 (3.5)	
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) ————— Z0006 (0) —————	C1010 (3) Z1003 (0) —————	C1010 (3)	
COMPUTER SCIENCE	COMS W1005 (3) Matlab (in semester I or III)			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			
NONTECHNICAL REQUIREMENTS	HUMA W1121 (3) or W1123 (3)		HUMA C1001, C0CI C1101, or Global Core (3–4)	HUMA C1002, C0CI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
TECHNICAL REQUIREMENTS	Professional-level course (except ELEN E1201) (either semester)		ELEN E1201 Intro. to EE (3.5)	APMA E2101 Intro. to applied math (3) ENME E3105 Mechanics (4)
	STAT W1211 (3) Intro to statistics (either semester)			

BMEB W4011x Computational neuroscience: Circuits in the brain

Lect: 3. 3 pts. Professors Lazar and Yuste.

Prerequisite: ELEN E3801 or BIOL W3004.

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

ECBM E4060x Introduction to genomic information science and technology

Lect: 3. 3 pts. Professor Anastassiou.

Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function, and manipulation of the biomolecular 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 bio-

medical engineering graduate student interested in acquiring in-depth knowledge of anatomy relevant to his/her doctoral research. Lectures and tutorial sessions may be taken with or without the associated laboratory (BMEN 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 rele-

**BIOMEDICAL ENGINEERING: THIRD AND FOURTH YEARS
CLASS OF 2012 AND LATER**

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES: ALL TRACKS	BIOL C2005 (4) Introductory biol. I BMEN E3810 (3) BME laboratory I BMEN E4001 (3) Quantitative physiol. I	BIOL C2006 (4) Introductory biol. II BMEN E3820 (3) BME laboratory II BMEN E4002 (3) Quantitative physiol. II	BMEN E3910 (4) BME design I BMEN E3830 (3) BME laboratory III	BMEN 3920 (4) BME design II BMEN E4010 (2) ⁴ Ethics for BMEs
NONTECH ELECTIVES	0–3 points	3 points	0–3 points	3 points
TRACK-SPECIFIC COURSES	CELL & TISSUE ENG. ¹	BMEN E2500 (0) BMEN E4210 (4) Thermo. biolog. sys. MSAE E3103 (3) Elements of mat. sci.	BMCH E3500 (3) Biol. transport. proc. or BMEN E3320 (3) Fluid biomech.	BMEN E4501 (3) Tissue eng. I Technical elective (6) BMEN E4502 (3) Tissue eng. II Technical elective (3)
	BIOMECH. ²	BMEN E2300 (0) MECE E3100 (3) Mech. of fluids	BMEN E3320 (3) Fluid biomech.	ENME E3113 (3) Mech. of solids MECE E3301 (3) Thermodynamics Technical elective (6) BMEN 4300 (3) Solid biomech. Technical elective (3)
	BIOMED. IMAGING ³	BMEN E2400 (0) ELEN E3801 (3.5) Signals & systems	BMEN E4420 (3) Biosig. proc. & modeling	ELEN E4810 (3) Dig. sig. processing BMEN E4894 (3) Biomed. imaging BMEN E4430 (3) Principles of MRI Technical elective (3)
TOTAL POINTS	16–17	16	19	15

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

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

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

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

vant 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 Mow.
Prerequisites: 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. Instructor to be announced.
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. Not given in 2009–2010.
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 Introduction to cell mechanics

Lect: 3. 3 pts. Professor Jacobs.
Prerequisite: BMEN E3320. Introduction to how cells function as mechanical structures and how mechanical factors influence cellular behavior. Topics include basics of cell biology, continuum mechanics, and statistical mechanics. Concepts applied to the mechanical behavior of cells, cytoskeletal polymers, polymer networks, and membranes. Experimental approaches in cell mechanics are surveyed and compared and mechanics of cellular motility and adhesion ana-

lyzed. The mechanobiology of contractile cells including fibroblasts and myocytes; cell and molecular biology of mechanosensing by cells such as stem cells, chondrocytes, osteoblasts, and osteocytes.

BMEN E4400x Wavelet applications in biomedical image and signal processing

Lect: 3. 3 pts. Not given in 2009–2010.
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 E4440y Physiological control systems

Lect: 3. 3 pts. Professor Chbat.
Prerequisites: APMA E2101 and instructor's per-

mission or senior standing. Dynamic system modeling and simulation of cardiovascular, respiratory, and thermoregulatory systems. Open and closed physiological loops. Internal and external controllers: baroreflex, chemoreflex, and ventilator. Fundamentals of time and frequency domain analyses and stability. Emulation of normal and pathophysiological conditions. Clinical relevance and decision support. Matlab and SIMULINK programming environments will be utilized.

BMEN E4450y Dental and craniofacial tissue engineering

Lect: 3. 3 pts. Not given in 2009–2010.
Prerequisites: MSAE E3103, BMEN E4210, and BMEN E4501 or equivalent. Principles of dental and craniofacial bioengineering, periodontal tissue engineering; beyond guided tissue regeneration, craniofacial regeneration by stem cells and engineered scaffolds, biomaterials. Engineering approaches in tissue regeneration, bone biology and development; instructive cues for tissue engineers.

BMEN E4501x Tissue engineering, I: biomaterials and scaffold design

Lect: 3. 3 pts. Professor H. H. Lu.
Prerequisites: BIOL C2005-C2006, BMEN E4001-E4002. An introduction to the strategies and fundamental bioengineering design criteria in the development of biomaterials and tissue engineered grafts. Material structural-functional relationships, biocompatibility in terms of material and host responses. Through discussions, readings, and a group design project, students acquire an understanding of cell-material interactions and identify the parameters critical in the design and selection of biomaterials for biomedical applications.

BMEN E4502y Tissue engineering, II: biological tissue substitutes

Lect: 3. 3 pts. Professor Hung.
Prerequisites: BIOL C2005-C2006 and BMEN E4001-E4002. An introduction to the strategies and fundamental bioengineering design criteria behind the development of cell-based tissue substitutes. Topics include biocompatibility, biological grafts, gene therapy-transfer, and bioreactors.

BMEN E4540y Bioelectrochemistry

Lect: 3. 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 E4550y Micro- and nano-structures in cellular engineering

Lect: 3. 3 pts. Professor Kam.
Prerequisites: BIOL W2005 and BIOL W2006 or

the equivalent. Design, fabrication, and application of micro- and nano-structured systems for cell engineering. Recognition and response of cells to spatial aspects of their extracellular environment. Focus on neural, cardiac, co-culture, and stem cell systems. Molecular complexes at the nanoscale.

BMEN E4560y Dynamics of biological membranes

Lect: 3. 3 pts. Not given in 2009–2010.

Prerequisite: Undergraduate cell biology or BMEN E4001. The structure and dynamics of biological (cellular) membranes are discussed, with an emphasis on biophysical properties. Topics will include membrane composition, fluidity, lipid asymmetry, lipid-protein interactions, membrane turnover, membrane fusion, transport, lipid phase behavior. In the second half of the semester, students will lead discussions of recent journal articles.

BMEN E4570x Science and engineering of body fluids

Lect: 3. 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 E4590x BioMems: cellular and molecular applications

Lect: 3. 3 pts. Not given in 2009–2010.

Prerequisites: CHEM C3443 or CHEN C3545 or the equivalent and MATH V1201. Corequisites: BIOL W2005 or the equivalent. Topics include biomicro-electromechanical, microfluidic, and lab-on-a-chip systems in biomedical engineering, with a focus on cellular and molecular applications. Microfabrication techniques, biocompatibility, miniaturization of analytical and diagnostic devices, high-throughput cellular studies, microfabrication for tissue engineering, and in vivo devices.

BMEN E4601y Cellular electricity

Lect: 2 Lab: 3. 3 pts. Not given in 2009–2010.

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.

APBM E4650x Anatomy for physicists and engineers

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

Prerequisite: Engineering or physics background. A systemic approach to the study of the human body from a medical imaging point of view: skeletal, respiratory, cardiovascular, digestive, and uri-

nary systems; breast and women's issues; head and neck; and central nervous system. Lectures are reinforced by examples from clinical two- and three-dimensional and functional imaging (CT, MRI, PET, SPECT, U/S, etc.).

BIOL G4700y Seminar in stem cell biology

Lect: 3. 3 pts. Professors Bulinsk, Kalderon, Hung, Vunjak-Novakovic.

Alternating weeks of high-level research seminars with guest speakers and class discussions will cover selected topics at the forefront of stem cell biology research in a course designed for Ph.D. and advanced master's students. Grading based on class participation, written assignments every other week, and a term paper with an original synthesis of ideas or a research proposal.

BMME E4702x Advanced musculoskeletal biomechanics

Lect: 2.5 Lab: 0.5. 3 pts. Not given in 2009–2010.

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. Not given in 2009–2010.

Prerequisite: Basic knowledge of the C programming language. Acquisition and presentation of data for medical interpretation. Operating principles of medical devices: technology of medical sensors, algorithms for signal analysis, computer interfacing and programming, interface design. Laboratory assignments cover basic measurement technology, interfacing techniques, use of Labview software instrument interrogation and control, automated ECG analysis, ultrasonic measurements, image processing applied to x-ray images and CAT scans.

BMEN E4738y Transduction and acquisition of biomedical data

Lect: 2 Lab: 1. 3 pts. Not given in 2009–2010.

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. Professor Olson.

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. Professor Leonard.

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 E6003x: Computational modeling of physiological systems

Lect: 3. 3 pts. Professor Morrison.

Prerequisites: BMEN E4001-E4002 and APMA E4200 or the equivalent. Advanced modeling and quantitative analysis of selected molecular, cellular, or organ systems. Four systems are analyzed, with emphasis on biologic systems. Systems may include muscle contraction, respiratory physiology, nerve transmission, pharmacokinetics, circulatory control, auditory signal processing, cell signaling, molecular transport, excitable membranes, and/or statistical data analysis.

EEBM E6020y Methods of computational neuroscience

Lect: 3. 4.5 pts. Instructor to be announced.
 Prerequisite: BMEB W4011 or the instructor's permission. Formal methods in computational neuroscience, including methods of signal processing, communications theory, information theory, systems and control, system identification and machine learning. Molecular models of transduction pathways. Robust adaptation and integral feedback. Stimulus representation and groups. Stochastic and dynamical systems models of spike generation. Neural diversity and ensemble encoding. Time encoding machines and neural codes. Stimulus recovery with time decoding machines. MIMO models of neural computation. Synaptic plasticity and learning algorithms. Major project(s) in Matlab.

BMEE E6030y Neural modeling and neuroengineering

Lect: 3. 3 pts. Professor Sajda.
 Prerequisites: APMA E3101, ELEN 3202, and ELEN-BMEN E4011, or the equivalent, or the instructor's permission. Engineering perspective on the study of multiple levels of brain organization, from single neurons to cortical modules and systems. Mathematical models of spiking 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.

EEBM E6090x or y, E6099x Topics in computational neuroscience and neuroengineering

Lect: 2. 3 pts. Not given in 2009–2010.
 Prerequisite: The instructor's permission. Selected advanced topics in computational neuroscience and neuroengineering. Content varies from year to year, and different topics rotate through the course numbers 6090–6099.

BMEN E6301y Modeling of biological tissues with finite elements

Lect: 3. 3 pts. Not given in 2009–2010.
 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. Professor Arthesian.
 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 E6420y Advanced microscopy: fundamentals and applications

Lect: 3. 3 pts. Professor Hillman.
 Prerequisites: PHYS C1401, C1402, C1403 or C1601, C1602, C2601 or C2801, C2802, or the equivalent (general physics sequence). Fundamentals of techniques including confocal, two photon, atomic force, and electron microscopy. Application of methods to modern biomedical imaging targets. Analysis and interpretation of microscopy data.

BMEN E6500x Tissue and molecular engineering laboratory

Lect: 4. 4 pts. Professor Huang.
 Prerequisites: BIOL C2005 and C2006, or the instructor's permission. Hands-on experiments in molecular and cellular techniques, including fabrication of living engineered tissues. Covers sterile technique, culture of mammalian cells, microscopy, basic subcloning and gel electrophoresis, creation of cell-seeded scaffolds, and the effects of mechanical loading on the metabolism of living cells or tissues. Theory, background, and practical demonstration for each technique will be presented. Lab required.

EEBM E9070x or y Seminar in computational neuroscience and neuroengineering

Lect: 3. 3 pts. Not given in 2009–2010.
 Prerequisite: Open to doctoral candidates and qualified M.S. candidates with the instructor's permission. Study of recent developments in computational neuroscience and neuroengineering.

BMEN E9100x or y, or s Master's research

1 to 6 pts. Professors Anastassiou, Ateshian, Brown, Das, Guo, Hess, Hielscher, Hillman,

Homma, Huang, Hung, Jacobs, Kam, Konofagou, Laine, Leonard, H. H. Lu, Mao, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic. Candidates for the M.S. degree and candidates for the M.S. degree leading to the doctoral degree may conduct an investigation of some problem in biomedical engineering. 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 Anastassiou, Ateshian, Brown, Das, Guo, Hess, Hielscher, Hillman, Homma, Huang, Hung, Jacobs, Kam, Konofagou, Laine, Leonard, H. H. Lu, Mao, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic. All doctoral candidates (Ph.D., Eng.Sc.D., and M.D./Ph.D.) 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. Doctoral candidates admitted as M.S. candidates leading to the doctoral degree should not register for this course.

BMEN E9700x or y Biomedical engineering seminar

Sem: 1. 0 pt. Professor Sia.
 All matriculated graduate students are required to attend the seminar as long as they are in residence. No degree credit is granted. The seminar is a principal medium of communication among those with biomedical engineering interests within the University. Guest speakers from other institutions, Columbia faculty, and students within the Department who are advanced in their studies frequently offer sessions.

BMEN E9800x or y, or s Doctoral research instruction

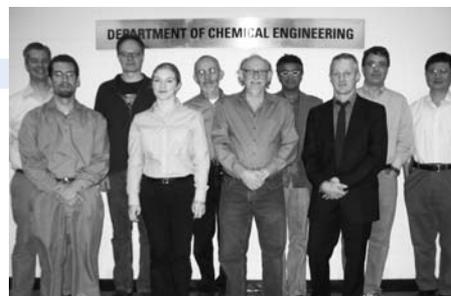
3, 6, 9, or 12 pts. Professors Anastassiou, Ateshian, Brown, Das, Guo, Hess, Hielscher, Hillman, Homma, Huang, Hung, Jacobs, Kam, Konofagou, Laine, Leonard, H. H. Lu, Mao, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic. Only candidates for the Eng.Sc.D. degree in biomedical engineering must register for 12 points of doctoral research instruction. Registration may not be used to satisfy the minimum residence requirement for the degree. Not for Ph.D. candidates.

BMEN E9900x or y, or s Doctoral dissertation

0 pts. Professors Anastassiou, Ateshian, Brown, Das, Guo, Hess, Hielscher, Hillman, Homma, Huang, Hung, Jacobs, Kam, Konofagou, Laine, Leonard, H. H. Lu, Mao, Morrison, Mow, Sajda, Sheetz, Sia, and Vunjak-Novakovic. A candidate for the doctorate in biomedical engineering is required to register for this course in every term after the student's course work has been completed and until the dissertation has been accepted.

CHEMICAL ENGINEERING

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www.cheme.columbia.edu



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Chemical engineering is a highly interdisciplinary field concerned with materials and processes at the heart of a broad range of technologies. Practicing chemical engineers are the experts in charge of the development and production of diverse products in traditional chemical industries as well as many emerging new technologies. The chemical engineer guides the passage of the product from the laboratory to the marketplace, from ideas and prototypes to functioning articles and processes, from theory to reality. This requires a remarkable depth and breadth of understanding of physical and chemical aspects of materials and their production.

The expertise of chemical engineers is essential to production, marketing, and application in such areas as pharmaceuticals, high-performance materials in the aerospace and automotive industries, biotechnologies, semiconductors in the electronics industry, paints and plastics, petroleum refining, synthetic fibers, artificial organs, biocompatible

implants and prosthetics and numerous others. Increasingly, chemical engineers are involved in new technologies employing highly novel materials whose unusual response at the molecular level endows them with unique properties. Examples include environmental technologies, emerging biotechnologies of major medical importance employing DNA- or protein-based chemical sensors, controlled-release drugs, new agricultural products, and many others.

Driven by this diversity of applications, chemical engineering is perhaps the broadest of all engineering disciplines: chemistry, physics, mathematics, biology, and computing are all deeply involved. The research of the faculty of Columbia's Chemical Engineering Department is correspondingly broad. Some of the areas under active investigation are the fundamental physics, chemistry, and engineering of polymers and other soft materials; the electrochemistry of fuel cells and other interfacial engineering phenomena; the bioengineering of artificial organs and immune

cell activation; the engineering and biochemistry of sequencing the human genome; the chemistry and physics of surface-polymer interactions; the biophysics of cellular processes in living organisms; the physics of thin polymer films; the chemistry of smart polymer materials with environment-sensitive surfaces; biosensors with tissue engineering applications; the physics and chemistry of DNA-DNA hybridization and melting; the chemistry and physics of DNA microarrays with applications in gene expression and drug discovery; the physics and chemistry of nanoparticle-polymer composites with novel electronic and photonic properties. Many experimental techniques are employed, from neutron scattering to fluorescence microscopy, and the theoretical work involves both analytical mathematical physics and numerical computational analysis.

Students enrolling in the Ph.D. program will have the opportunity to conduct research in these and other areas. Students with degrees in chemical engi-

neering and other engineering disciplines, in chemistry, in physics, in biochemistry, and in other related disciplines are all natural participants in the Ph.D. program and are encouraged to apply. The Department of Chemical Engineering at Columbia is committed to a leadership role in research and education in frontier areas of research and technology where progress derives from the conjunction of many different traditional research disciplines. Increasingly, new technologies and fundamental research questions demand this type of interdisciplinary approach.

The undergraduate program provides a chemical engineering degree that is a passport to many careers in directly related industries as diverse as biochemical engineering, environmental management, and pharmaceuticals. The degree is also used by many students as a springboard from which to launch careers in medicine, law, management, banking and finance, politics, and so on. For those interested in the fundamentals, a career of research and teaching is a natural continuation of their undergraduate studies. Whichever path the student may choose after graduation, the program offers a deep understanding of the physical and chemical nature of things and provides an insight into an exploding variety of new technologies that are rapidly reshaping the society we live in.

Current Research Activities

Science and Engineering of Polymers and Soft Materials.

Theoretical and experimental studies of novel or important macromolecules and their applications, especially surface-active species: ultrasonic sensor, scanning probe microscopy and reflectivity studies of adsorption and self-assembly of highly branched “dendrimers” at the solid-liquid interface, with the aim of creating novel surface coatings; fluorescence tracer studies of molecular level mobility in ultrathin polymer films with the aim of improving resolution in lithography; reflectivity studies and computer simulation of flexible polymer adsorption and the response of adsorbed polymer layers to imposed flows with the aim of improving polymer processing operations; optical microscopy studies and numerical simulation

of microporous polymer membrane formation with the aim of improving ultrafiltration membrane technology; synthesis and structural characterization of bioactive polymer surfaces in order to realize new in-vivo devices; contact angle, x-ray photoelectron spectroscopy, and reflectivity analysis, and lattice model simulation, of responsive polymer surfaces based on unique polymeric “surfactants” in order to develop “smart” surface-active materials; preparation and IR/fluorescence characterization of DNA-decorated surfaces for “recognition” of DNA in solution in order to further medical diagnostic technologies; preparation and characterization via TEM, AFM, and reflectivity of nano-particle–block copolymer composites 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 research instrumentation and computational facilities for its undergraduate and graduate students, postdoctoral associates, and faculty. Departmental equipment is considered to be in most cases shared, which means that equipment access is usually open to all qualified individuals with a need to use particular instrumentation.

The most extensive collection of instrumentation in the department is associated with the polymer and soft matter research faculty. Faculty banded together to create a unique shared-facilities laboratory, completed at the end of 2001. The shared facilities include a fully equipped polymer synthesis lab with four fumes hoods, a 10'x16' soft wall clean room, metal evaporator system, a Milligen 9050 peptide synthesizer, and polymer thin film preparation and substrate cleaning stations. Also installed are new, computer-controlled thermal analysis, rheometric, and light-scattering setups. Specialized instrumentation for surface analysis includes an optical/laser system dedicated to characterization of polymer surface dynamics by Fluorescence Recovery after Photobleaching and a PHI 5500 X-ray photoelectron spectrophotometer with monochromator that is capable of angle-dependent depth profiling and XPS imaging. The system can also perform SIMS and ion scattering experiments. A digital image analysis system for the characterization of sessile and pendant drop shapes is also available for the purpose of polymer surface and interfacial tension measurements as well as contact angle analysis. An X-ray reflectometer that can perform X-ray standing wave-induced fluorescence measurements is also housed in the new shared equipment laboratory, along with instrumentation for characterizing the friction and wear properties of polymeric surfaces. The laboratory also houses an infrared spectrometer (Nicolet Magna 560, MCT detector) with a variable angle grazing incidence, temperature-controlled attenuated-total-reflectance, transmission, and liquid cell accessories. These facilities are suitable for mid-IR, spectroscopic investigations of bulk materials as well as thin films. The laboratory also has a UV-Vis spectrometer (a Cary 50), an SLM 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 spectrophoto-

meter (Jobin Yvon, Inc. Fluorolog-3), Waters HPLC, and a sequencing gel electrophoresis apparatus (Life Technologies Model S2), as well as the facilities required for state-of-the-art synthetic chemistry. The division of DNA sequencing and chemical biology at the Columbia Genome Center consists of 6,000 sq. ft. of laboratory space and equipment necessary for carrying out the state-of-the-art DNA analysis. The laboratory has one Amersham Pharmacia Biotech MegaBace1000 sequencer, three ABI 377 sequencers with complete 96 land upgrades, a Qiagen 9600 Biorobot, a Hydra 96 microdispenser robot, and standard molecular biology equipment.

NSF-Columbia MRSEC Shared Facilities. Through their participation in an NSF-MRSEC grant, faculty also have access to shared facilities located in the Schapiro Center for Engineering and Physical Science Research at Columbia University. The shared facilities include a Scintag X2 X-ray diffractometer aligned for low-angle reflectivity work, and a Beaglehole Instruments Picometer modulated ellipsometer. As needed, these capabilities are available for characterization of the surface coverage and composition of modified surfaces and thin organic films. Access to atomic force microscopy, scanning and transmission electron microscopy, and scanning tunneling microscopy is possible through collaborations within the NSF-MRSEC program and with colleagues in the Chemistry and Materials Science Departments. The NSF-Columbia MRSEC facility is located within five minutes' walking distance from the Chemical Engineering Department.

UNDERGRADUATE PROGRAM

Chemical Engineering

The undergraduate program in chemical engineering at Columbia, recently revised, has five formal educational objectives:

- A. Prepare students for careers in industries that require technical expertise in chemical engineering.
- B. Prepare students to assume leadership positions in industries that require technical expertise in chemical engineering.

- C. Enable students to pursue graduate-level studies in chemical engineering and related technical or scientific fields (e.g., biomedical or environmental engineering, materials science).
- D. Provide a strong foundation for students to pursue alternative career paths, especially careers in business, management, finance, law, medicine, or education.
- E. Establish in students a commitment to life-long learning and service within their chosen profession and society.

The expertise of chemical engineers is essential to production, marketing, and application in such areas as pharmaceuticals, high performance materials as in the automotive and aerospace industries, semiconductors in the electronics industry, paints and plastics, consumer products such as food and cosmetics, petroleum refining, industrial chemicals, synthetic fibers, and just about every bioengineering and bio-technology area from artificial organs to biosensors. Increasingly, chemical engineers are involved in exciting new technologies employing highly novel materials, whose unusual response at the molecular level endows them with unique properties. Examples include controlled release drugs, materials with designed interaction with *in vivo* environments, “nanomaterials” for electronic and optical applications, agricultural products, and a host of others. This requires a depth and breadth of understanding of physical and chemical aspects of materials and their production that is without parallel.

The chemical engineering degree also serves as a passport to exciting careers in directly related industries as diverse as biochemical engineering, environmental management, and pharmaceuticals. Because the deep and broad-ranging nature of the degree has earned it a high reputation across society, the chemical engineering degree is also a natural platform from which to launch careers in medicine, law, management, banking and finance, politics, and so on. Many students choose it for this purpose, to have a firm and respected basis for a range of possible future careers. For those interested in the fundamentals, a career of research and teaching is a natural continuation of undergraduate studies.

The first and sophomore years of study introduce general principles of science and engineering and include a broad range of subjects in the humanities and social sciences. Although the program for all engineering students in these first two years is to some extent similar, there are important differences. The Professional Engineering Elective, usually taken in Semester II, is designed to provide an overview of an engineering discipline. Those wishing to learn about chemical engineering are encouraged to take *CHEN E1040: Molecular engineering and product design*, taught by the Chemical Engineering Department. Students who major in chemical engineering are not currently required to take computer science or programming, and should in their sophomore year take *CHEN E3100: Material and energy balances* (see table on page 86).

In the junior-senior sequence one specializes in the chemical engineering major. The table on page 87 spells out the core course requirements, which are split between courses emphasizing engineering science and those emphasizing practical and/or professional aspects of the discipline. Throughout, skills required of practicing engineers are developed (e.g. writing and presentation skills, competency with computers).

The table on page 87 shows that a significant fraction of the junior-senior program is reserved for electives, both technical and nontechnical. Nontechnical electives are courses that are not quantitative, such as those taught in the humanities and social sciences. These provide an opportunity to pursue interests in areas other than engineering. A crucial part of the junior-senior program is the 12-point technical elective requirement. Technical electives are science and/or technology based and feature quantitative analysis. Generally, technical electives must be 3000 level or above but there are a few exceptions: *PHYS C1403*, *PHYS C2601*, *BIOL C2005*, *BIOL C2006*, and *BIOL W2501*. The technical electives are subject to the following constraints:

- One technical elective must be within SEAS but taken outside of chemical engineering (that is, a course with a designator other than *BMCH*, *CHEN*, *CHEE*, or *CHAP*).

- One technical elective must be within chemical engineering (i.e. with the designator *BMCH*, *CHEN*, *CHEE*, or *CHAP*).
- The technical electives must include 6 points of “advanced natural science” course work, including chemistry, physics, biology, and certain engineering courses. Qualifying engineering courses are determined by Chemical Engineering Department advisers.

The junior-senior technical electives provide the opportunity to explore new interesting areas beyond the core requirements of the degree. Often, students satisfy the technical electives by taking courses from another SEAS department in order to obtain a minor from that department. Alternately, you may wish to take courses in several new areas, or perhaps to explore familiar subjects in greater depth, or you may wish to gain experience in actual laboratory research. Three points of *CHEN E3900: Undergraduate research project* may be counted toward the technical elective content.

The program details discussed above, and the accompanying tables, apply to undergraduates who are enrolled at Columbia as freshmen and declare the chemical engineering major in the sophomore year. However, the chemical engineering program is designed to be readily accessible to participants in any of Columbia’s Combined Plans and to transfer students. In such cases, the guidance of one of the departmental advisers in planning your program is required (contact information for the departmental UG advisers is listed on the department’s Web site).

Columbia’s program in chemical engineering leading to the B.S. degree is fully accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

Requirements for a Minor in Chemical Engineering

See page 189.

Requirements for a Minor in Biomedical Engineering

Students majoring in chemical engineering who wish to include in their records

a minor in biomedical engineering may do so by taking *BMEN E4001* or *E4002*; *BIOL C2005*; *BMEN E4501* and *E4502*; and any one of several chemical engineering courses approved by the BME Department. See also page 189.

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 matter, with particular emphasis on interfacial properties and materials with important related applications. Synthetic polymers are by far the most important material in this class.

CHEE E4252: Introduction to surface and colloid chemistry

CHEN E4620: Introduction to polymers

CHEN E4640: Polymer surfaces and interfaces

CHEN E6620Y: Physical chemistry of macromolecules

CHEN E6910: Theoretical methods in polymer physics

CHEN E6920: Physics of soft matter

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

CHEMICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS

CHEMICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and one of the following: MATH E1210 (3) Ord. diff. equations or APMA E2101 (3) Intro. to appl. math.
PHYSICS (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)	
CHEMISTRY (three tracks, choose one)	C1403 (3.5) and Lab C1500 (3) C1604 (3.5) C3045 (3.5)	C1404 (3.5) ————— C2507 (3) C3046 (3.5) and Lab C2507 (3)	C3443 (3.5)	
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) ————— Z0006 (0) —————	C1010 (3) Z1003 (0) —————	C1010 (3)	
REQUIRED ELECTIVES	NONTECH		One core humanities elective (3–4 points) ²	Three core humanities electives (11 points) ²
	TECH		Professional engineering elective (3) ¹	
CHEM. ENG. REQUIREMENT			CHEN E3100 (4) ³ Material & energy balances	
COMPUTER SCIENCE				
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			
TOTAL POINTS⁴	16.5	16.5	17.5	17

¹ Students are encouraged to take CHEN 1040: Molecular engineering and product design.

² Four core humanities electives should be taken as follows: In Semester III, HUMA C1001, C1101 (4), or any initial course in one of the Global Core sequences offered by the College (3–4); in Semester IV, HUMA C1002, C1102 (4), or the second course in the Global Core sequence elected in Semester III (3–4); also in Semester IV, ECON W1105 (4) with W1105 recitation (0) and either HUMA C1121 or C1123 (3).

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

⁴ Taking the first track in each row and E1102 in Semester II.

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

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

CHEMICAL ENGINEERING: THIRD AND FOURTH YEARS

		SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES		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
		CHEE E3010 (4) Principles of chem. eng. thermodynamics	CHEN E3210 (4) Chem. eng. thermodynamics	CHEN E4140 (3) Chem. & biochem. separations	CHEN E4320 (4) Molecular phenomenon in chem. eng.
		CHEN E4230 (3) Reaction kinetics & reactor design	CHEN E4300 (2) Chem. eng. control		
REQUIRED LABS		CHEN C3543 (3) ¹ Org. chem. lab			CHEN 3810 (3) Chem. eng. lab
REQUIRED ELECTIVES	NONTECH	3 points	3 points	3 points	
	TECH ²	3 points	3 points	3 points	3 points
TOTAL POINTS (normal track)		17	17	15	14

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

²The 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 a departmental adviser for details).

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).

Interfacial Engineering and Electrochemistry.

Electrochemical processes are key to many alternative energy systems (batteries and fuel cells), to electrical and magnetic-device manufacturing (interconnects and magnetic-storage media), and to advanced materials processing. Electrochemical processes are also involved in corrosion and in some waste-treatment systems. Key employers of engineers and scientists with knowledge of electrochemical/interfacial engineering include companies from the computer, automotive, and chemical industries. Knowledge of basic electrochemical principles, environmental sciences, and/or materials science can be useful to a career in this area.

CHEN E4201: Engineering applications of electrochemistry

CHEN E4252: Introduction to surface and colloid science

CHEN E6050: Advanced electrochemistry

CHEN 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); and *Physical chemistry of macromolecules* (CHEN E6620). Other courses in the "Science and Engineering of Polymers and Soft Materials" concentration are also relevant. When complete, the concentration will include courses directly addressing biomaterials and immunological response.

COURSES IN CHEMICAL ENGINEERING

See also Center for Biomedical Engineering. *Note:* Check the department Web site for the most current course offerings/descriptions.

CHEN E1040y Molecular engineering and product design

Lect: 3. 3 pts. Professor West.

An introductory course intended to expose students to chemical engineering. Examines the ways in which chemical and biological sciences are interpreted through analytical, design, and engineering frameworks to generate products that enhance human endeavor. Students are introduced to the culture of chemical engineering and the wide variety of chemical engineering prac-

tices, through lectures by department faculty and practicing chemical engineers, trips to industrial facilities, reverse engineering of chemical products, and a chemical design competition.

CHEE 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 McNeill.

Prerequisites: First-year chemistry and physics or equivalents. This course serves as an introduction 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. Instructor to be announced.

Prerequisites: Classical mechanics, vector calculus, ordinary differential equations. Focuses on the momentum and energy transport in pure (one-component) Newtonian fluids, i.e. elementary fluid mechanics, elementary conduction-dominated heat transfer, and forced convection heat transfer in fluids. This is an introductory-level course. It includes a review of the mathematical methods needed (vector calculus and ordinary differential equations). Applications to problems important in modern chemical engineering are used to illustrate concepts.

CHEN E3120y Transport phenomena, II

Lect: 4. 4 pts. Professor Durning.

Prerequisite: CHEN E3110, of which this course is a continuation. Focuses on the mass transport in isothermal mixtures of Newtonian fluids, i.e., elementary diffusion-dominated mass transfer, and forced convection mass transfer in fluid mixtures. Includes instruction in new mathematical methods needed (introductory partial differential equations). Applications to problems important in modern chemical engineering are used to illustrate concepts.

CHEN E3210y Chemical engineering thermodynamics

Lect: 3. 4 pts. Professor Koberstein.

Prerequisites: CHEN E3010 and E3100. This course deals with fundamental and applied thermodynamic principles that form the basis of chemical engineering practice. Topics include phase equilibria, methods to treat ideal and non-ideal mixtures, and estimation of properties using computer-based methods.

BMCH E3500y Transport in biological systems

Lect: 3. 3 pts. Professor Leonard.

Prerequisites: CHEM C3443 and 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.

CHEN E3810y Chemical engineering laboratory

Lab: 3. 3 pts. Professors Borden and Spencer.

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, heterogeneous catalysis and mathematical model development. Safety awareness is integrated throughout the course.

CHEN E3900x and y Undergraduate research project

0 to 6 pts. The staff.

Candidates for the B.S. degree may conduct an investigation of some problem in chemical engineering or applied chemistry or carry out a special project under the supervision of the staff. Credit for the course is contingent upon the submission of an acceptable thesis or final report. No more than 6 points in this course may be counted toward the satisfaction of the B.S. degree requirements.

CHEN E4010x Mathematical methods in chemical engineering

Lect: 3. 3 pts. Professor Leonard.

Open to undergraduates only with the instructor's permission. Application of selected mathematical methods to solution of chemical engineering problems.

CHEN E4020x Protection of industrial and intellectual property

Lect: 3. 3 pts. Professor Pearlman.

To expose engineers, scientists, and technology managers to areas of the law they are most likely to be in contact with during their careers. Principles are illustrated with various case studies, together with active student participation.

CHEN E4030y Biocolloid engineering design*Lect: 3. 3 pts. Professor Borden.*

Prerequisite: CHEE E4252 or the instructor's permission. Introduction to biocolloid engineering and design for applications in molecular imaging and targeted drug and gene delivery. Emphasis on self-assembling structures including microbubbles, micelles, vesicles, emulsions, and polymer complexes. Treatment of biocompatibility and interactions with cells, biological fluids, and physiological systems.

CHEE 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 Durning.*

Prerequisite: CHEN E3120. Tensor analysis; kinematics of continua; balance laws for one-component media; constitutive laws for free energy and stress in one-component media; exact and asymptotic solutions to dynamic problems in fluids and solids; balance laws for mixtures; constitutive laws for free energy, stress and diffusion fluxes in mixtures; solutions to dynamic problems in mixtures.

CHAP E4120x Statistical mechanics*Lect: 3. 3 pts. Professor O'Shaughnessy.*

Prerequisite: CHEN 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, and interactions between charged polymers and charged interfaces, ordering transitions.

CHEN E4140x Chemical and biochemical separations*Lect: 3. 3 pts. Professor Banta.*

Prerequisites: CHEN E3100, E3120, and E3210, or the instructor's permission. Design and analysis of unit operations employed in chemical and biochemical separations. Emphasis is placed on learning the fundamental aspects of distillation, gas adsorption, and crystallization through a combination of lectures, open-ended problem solving,

self-learning exercises, and computer process simulation.

CHEN E4201x Engineering applications of electrochemistry*Lect: 3. 3pts. Professor West.*

Prerequisites: Physical chemistry and a course in transport phenomena. Engineering analysis of electrochemical systems, including electrode kinetics, transport phenomena, mathematical modeling, and thermodynamics. Common experimental methods are discussed. Examples from common applications in energy conversion and metallization are presented.

CHEN E4230y Reaction kinetics and reactor design*Lect: 3. 3 pts. Professor Leonard.*

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

CHEE E4252x Introduction to surface and colloid chemistry*Lect: 3. 3 pts. Professor Somasundaran.*

Prerequisite: Elementary physical chemistry. Thermodynamics of surfaces, properties of surfactant solutions and surface films, electrostatic and electrokinetic phenomena at interfaces, adsorption; interfacial mass transfer and modern experimental techniques.

CHEN E4300x Chemical engineering control*Lab: 2. 2 pts. Professor Borden.*

Prerequisites: Ordinary differential equations (including Laplace transforms), CHEN E3100, and CHEN E4230. An introduction to process control applied to chemical engineering through lecture and laboratory. Concepts include the dynamic behavior of chemical engineering systems, feedback control, controller tuning, and process stability.

CHEN E4320x Molecular phenomena in chemical engineering*Lect: 3. 4 pts. Professor O'Shaughnessy.*

This new course located strategically at the end of the curriculum is intended to provide students with a molecular basis for the engineering concepts covered in the curriculum. It is meant to both validate the basic science and math foundations developed earlier and to stimulate the student toward applying modern molecular concepts of chemical engineering that will define their future.

CHEN E4330y Advanced chemical kinetics*Lect: 3. 3 pts. Professor McNeill.*

Prerequisite: CHEN E4230y or the instructor's permission. Complex reactive systems. Catalysis. Heterogeneous systems, with an emphasis on coupled chemical kinetics and transport phenomena. Reactions at interfaces (surfaces, aerosols, bubbles). Reactions in solution.

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 Kumar.*

Prerequisites: CHEN E4140 and E3100. An introduction to the process engineering function. The design of chemical process, process equipment, and plants and the economic and ecological evaluation of the chemical engineering project. Use of statistics to define product quality is illustrated with case studies.

CHEN E4510y Process and product design, II*Lect: 4. 4 pts. Professors Kumar and Hill.*

Prerequisite: CHEN E4500. Students carry out a semester-long process or product design course with significant industrial involvement. The project culminates with a formal written design report and a public presentation.

CHEE E4530y Corrosion of metals*Lect: 3. 3 pts. Professor Duby.*

Prerequisite: CHEN E3010. The theory of electrochemical corrosion, corrosion tendency, rates, and passivity. Application to various environments. Cathodic protection and coatings. Corrosion testing.

CHEN E4600x Atmospheric aerosols*Lect: 3. 3 pts. Professor McNeill.*

Prerequisite: CHEN E3120 or the instructor's permission. Atmospheric aerosols and their effects on atmospheric composition and climate. Major topics are aerosol sources and properties, field and laboratory techniques for characterization, gas-aerosol interactions, secondary organic aerosols, and aerosol direct and indirect effects on climate.

CHEN E4620y Introduction to polymers and soft materials*Lect: 3. 3 pts. Professor Durning.*

Prerequisites: An elementary course in physical chemistry or thermodynamics. Organic chemistry, statistics, calculus and mechanics are helpful, but not essential. An introduction to the chemistry and physics of soft materials systems (polymers, colloids, organized surfactant systems, and others), emphasizing the connection between microscopic structure and macroscopic physical properties. To develop an understanding of each system, illustrative experimental studies are discussed along with basic theoretical treatments. High molecular weight organic polymers are discussed

first (basic notions, synthesis, properties of single polymer molecules, polymer solution and blend thermodynamics, rubber and gels). Colloidal systems are treated next (dominant forces in colloidal systems, flocculation, preparation and manipulation of colloidal systems) followed by a discussion of self-organizing surfactant systems (architecture of surfactants, micelles and surfactant membranes, phase behavior).

CHEN E4640x or y Polymer surfaces and interfaces

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

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 E4645x or y Inorganic polymers, hybrid materials and gels

Lect: 3. 3 pts. Professor Koberstein.

Prerequisite: Organic chemistry. The focus of the first part of the course is on the preparation, characterization, and applications of inorganic polymers, with a heavy emphasis on those based on main-group elements. Main topics are characterization methods, polysiloxanes, polysilanes, polyphosphazenes, ferrocene-based polymers, other phosphorus-containing polymers, boron-containing polymers, preceramic inorganic polymers, and inorganic-organic hybrid composites. The focus of the second part of the course is on gels, both physical and chemical. Topics will include gel chemistry, including epoxies, polyurethanes, polyesters, vinyl esters, and hydrogels, as well as theoretical methods used to characterize the gel point and gel properties.

CHEN E4660y Biochemical engineering

Lect: 3. 3 pts. Not given in 2009–2010.

Prerequisite: BMEN E4001 or the equivalent. Engineering of biochemical and microbiological reaction systems. Kinetics, reactor analysis, and design of batch and continuous fermentation and enzyme processes. Recovery and separations in biochemical engineering systems.

CHEN 4680x Soft materials laboratory

Lect/lab: 3. 3 pts. Professors Durning and Koberstein.

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 E4740x: Biological transport and rate phenomena, II

Lect: 3. 3 pts. Professor Leonard.

Prerequisites: Any two of the following: CHEN E3110; BIOL C2005; CHEN E3210 or BMCH E3500. Analysis of transport and rate phenomena in biological systems and in the design of biomimetic transport-reaction systems for technological and therapeutic applications. Modeling of homogeneous and heterogeneous biochemical reactions. The bases of biological transport: roles of convection, ordinary diffusion, forced diffusion. Systems where reaction and transport interact strongly. Applications to natural and artificial tissue beds, tumor modeling, controlled release, natural and artificial organ function.

CHEN E4750y The genome and the cell

Lect: 3. 3 pts. Not given in 2009–2010.

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

CHEN E4760y Genomics sequencing laboratory

Lect: 1. Lab: 2. 3 pts. Professor Ju.

Prerequisites: Undergraduate-level biology, organic chemistry, and the instructor's permission. The chemical, biological, and engineering principles involved in the genomics sequencing process will be illustrated throughout the course for engineering students to develop the hands-on skills in conducting genomics research.

CHEN E4800x Protein engineering

Lect: 3. 3 pts. Professor Banta.

Prerequisite: CHEN E4230 (may be taken concurrently) or the instructor's permission. Fundamental tools and techniques currently used to engineer protein molecules. Methods used to analyze the impact of these alterations on different protein functions, with specific emphasis on enzymatic catalysis. Case studies reinforce concepts covered and demonstrate the wide impact of protein engineering research. Application of basic concepts in the chemical engineering curriculum (reaction kinetics, mathematical modeling, thermodynamics) to specific approaches utilized in protein engineering.

CHEN E6050y Advanced electrochemistry

Lect: 3. 3 pts. Not given in 2009–2010.

Prerequisite: The instructor's permission. An advanced overview of the fundamentals of electrochemistry, with examples taken from modern applications. An emphasis is placed on mass transfer and scaling phenomena. Principles are reinforced through the development of mathematical models of electrochemical systems. Course projects will require computer simulations. The course is intended for advanced graduate students, conducting research involving electrochemical technologies.

CHEE E6220y Equilibria and kinetics in hydrometallurgical systems

Lect: 3. 3 pts. Professor Duby.

Prerequisite: CHEE E4050 or EAEE E4003. Detailed examination of chemical equilibria in hydrometallurgical systems. Kinetics and mechanisms of homogeneous and heterogeneous reaction in aqueous solutions.

CHEE E6252y Applied surface and colloid chemistry

Lect: 2. Lab: 3. 3 pts. Professor Somasundaran.

Prerequisite: CHEN E4252. Applications of surface chemistry principles to wetting, flocculation, flotation, separation techniques, catalysis, mass transfer, emulsions, foams, aerosols, membranes, biological surfactant systems, microbial surfaces, enhanced oil recovery, and pollution problems. Appropriate individual experiments and projects.

CHEN E6620y Physical chemistry of macromolecules

Lect: 3. 3 pts. Professors Durning and Koberstein. Modern studies of static and dynamic behavior in macromolecular systems. Topics include single-chain behavior adsorption, solution thermodynamics, the glass transition, diffusion, and viscoelastic behavior. The molecular understanding of experimentally observed phenomena is stressed.

CHEN E6920y Physics of soft matter

Lect: 2. 3 pts. Not given in 2008–2009. 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. Professor O'Shaughnessy. This research seminar introduces topics at the forefront of biological research in a format and language accessible to quantitative scientists and engineers lacking biological training. Conceptual and technical frameworks from both biological and physical science disciplines are utilized. The objective is to reveal to graduate students where potential lies to apply techniques from their own disciplines to address pertinent biological questions in their research. Classes entail reading, criticism, and group discussion of research

papers and textbook materials providing overviews to various biological areas including evolution, immune system, development and cell specialization, the cytoskeleton and cell motility, DNA transcription in gene circuits, protein networks, recombinant DNA technology, aging, and gene therapy.

CHEN E9000x and y Chemical engineering colloquium

Col: 1. 0 pts. The staff. All graduate students are required to attend the department colloquium as long as they are in residence. No degree credit is granted.

CHEN E9400x and y Master's research

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 disserta-

tions. 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. Prerequisites: 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.

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The Department of Civil Engineering and Engineering Mechanics focuses on two broad areas of instruction and research. The first, the classical field of civil engineering, deals with the planning, design, construction, and maintenance of the built environment. This includes buildings, foundations, bridges, transportation facilities, nuclear and conventional power plants, hydraulic structures, and other facilities essential to society. The second is the science of mechanics and its applications to various engineering disciplines. Frequently referred to as applied mechanics, it includes the study of the mechanical and other properties of materials, stress analysis of stationary and movable structures, the dynamics and vibrations of complex structures, aerodynamic and hydrodynamics, and the mechanics of biological systems.

MISSION

The Department aims to provide students with a technical foundation anchored in theory together with the breadth needed to follow diverse career paths, whether in the profession via advanced study or apprenticeship, or as a base for other pursuits.

Current Research Activities

Current research activities in the Department of Civil Engineering and Engineering Mechanics are centered in the areas outlined below. A number of these activities impact directly on problems of societal importance, such as rehabilitation of the infrastructure, mitigation of natural or man-made disasters, and environmental concerns.

Solid mechanics: mechanical properties of new and exotic materials, consti-

tutive equations for geologic materials, failure of materials and components, properties of fiber-reinforced cement composites, damage mechanics.

- *Multihazard risk assessment and mitigation:* integrated risk studies of the civil infrastructure from a multihazard perspective including earthquake, wind, flooding, fire, blast, and terrorism. The engineering, social, financial, and decision-making perspectives of the problem are examined in an integrated manner.
- *Probabilistic mechanics:* random processes and fields to model uncertain loads and material/soil properties, nonlinear random vibrations, reliability and safety of structural systems, computational stochastic mechanics, stochastic finite element and boundary element techniques, Monte Carlo simulation techniques, random micromechanics.

- **Structural control and health monitoring:** topics of research in this highly cross-disciplinary field include the development of “smart” systems for the mitigation and reduction of structural vibrations, assessment of the health of structural systems based on their vibration response signatures, and the modeling of nonlinear systems based on measured dynamic behavior.

Fluid mechanics: solid-laden turbulent flows, porous surface turbulence, flow through porous media, numerical simulation of flow and transport processes, flow and transport in fractured rock.

Environmental engineering/water resources: modeling of flow and pollutant transport in surface and subsurface waters, unsaturated zone hydrology, geoenvironmental containment systems, analysis of watershed flows including reservoir simulation.

Structures: dynamics, stability, and design of structures, structural failure and damage detection, fluid and soil structure interaction, ocean structures subjected to wind-induced waves, inelastic dynamic response of reinforced concrete structures, earthquake-resistant design of structures.

Geotechnical engineering: soil behavior, constitutive modeling, reinforced soil structures, geotechnical earthquake engineering, liquefaction and numerical analysis of geotechnical systems.

Structural materials: cement-based materials, micro- and macro-models of

fiber-reinforced cement composites, utilization of industrial by-products and waste materials, beneficiation of dredged material.

Earthquake engineering: response of structures to seismic loading, seismic risk analysis, active and passive control of structures subject to earthquake excitation, seismic analysis of long-span cable-supported bridges.

Flight structures: aeroelasticity, aeroacoustics, active vibration and noise control, smart structures, noise transmission into aircraft, and vibro-acoustics of space structures.

Construction engineering and management: contracting strategies; alternative project delivery systems, such as design-build, design-build-operate, and design-build-finance-operate; minimizing project delays and disputes; advanced technologies to enhance productivity and efficiency; strategic decisions in global engineering and construction markets.

Infrastructure delivery and management: decision support systems for infrastructure asset management; assessing and managing infrastructure assets and systems; capital budgeting processes and decisions; innovative financing methods; procurement strategies and processes; data management practices and systems; indicators of infrastructure performance and service.

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 hardwired to the computing facility, which is also accessible remotely to users. Numerous personal computers and graphics terminals exist throughout the department, and a PC lab is available to students in the department in addition to the larger school-wide facility.

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

CIVIL ENGINEERING PROGRAM: FIRST AND SECOND YEARS

CIVIL ENGINEERING PROGRAM: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	APMA E2101 (3) Intro. to applied math.
PHYSICS (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)	
CHEMISTRY	one-semester lecture (3–4): C1403 or C1404 or C3045 or C1604 Chem lab C1500 (3) either semester or physics lab			
MECHANICS	ENME-MECE E3105 (4) either semester			
CIVIL ENGINEERING	CIEN E1201 (3) or equivalent			CIEN E3004 (3) Urban infra. systems
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	C1010 (3) Z1003 (0)	C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES			HUMA C1001, COCI C1101, or Global Core (3–4) HUMA W1121 or W1123 (3)	HUMA C1002, COCI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
COMPUTER SCIENCE	Computer Language: W1005 (3) (any semester)			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹ EAEE is recommended for students concentrating in environmental engineering and water resources.

equipped to perform a wide spectrum of experimental research in cement-based materials. The Donald M. Burmister Soil Mechanics Laboratory is used in both undergraduate and graduate instruction for static and dynamic testing of soils and foundations. The geotechnical centrifuge located in the Carleton Laboratory is used for geotechnical and geoenvironmental research.

The Institute of Flight Structures

The Institute of Flight Structures was established within the department through a grant by the Daniel and Florence Guggenheim Foundation. It provides a base for graduate training in aerospace and aeronautical related applications of structural analysis and design.

Center for Infrastructure Studies

The Center was established in the department to provide a professional environment for faculty and students from a variety of disciplines to join with industry and government to develop and apply the technological tools and knowledge bases needed to deal with the massive problems of the city, state, and regional infrastructure. The Center is active in major infrastructure projects through a consortium of universities and agencies.

UNDERGRADUATE PROGRAMS

The Department of Civil Engineering and Engineering Mechanics offers undergraduate programs in civil engineering and engineering mechanics. Both are

intended to prepare students with firm technical bases while nurturing decision-making and leadership potential.

The civil engineering program is designed to enable the student, upon completion of the B.S. degree program, to enter the profession—for example, in industry, on a construction project, in a consulting engineering office, through a government agency—or to begin graduate study, or both. The program is fully accredited by the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET) and provides a broad traditional civil engineering background that focuses on basic theory and design. Technical electives can be selected to obtain a strong technical base in a particular field

CIVIL ENGINEERING: THIRD AND FOURTH YEARS				
	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
CORE REQUIRED COURSES	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 (4) Soil mech.	CIEN E4111 (3) Uncertainty & risk in infrastructure systems CIEN E3129 (3) Proj. mgmt. for construction	
CONCENTRATIONS	GEOTECH ENG. (GE) OR STRUCT. ENG. (SE)	ENME E3106 (3) Dynamics & vibrations CIEN E3121 (3) Struct. anal.	ENME E3114 (4) Exper. mech. of materials CIEN E3127 (3) Struct. design projects (SE) or CIEN E4241 (3) Geotech. eng. fund. (GE)	CIEN E4332 (3) Finite element anal. CIEN E3128 (4) Design projects
	TECH ELECTIVES	3 points	3 points	12 points
	CIVIL ENG. & CONSTR. MNGMT.	ENME E3114 (4) Exper. mech. of materials CIEN E3121 (3) Struct. anal. or CIEE E3250 (3) Hydrosystems eng.	CIEN E4133 (3) Capital facility planning & financing CIEN E3127 (3) or CIEN E4241 (3)	CIEN E4131 (3) Princ. of constr. tech. CIEN E3128 (4) Design projects
	TECH ELECTIVES	6 points	3 points	9 points
	WATER RES./ ENVIRON. ENG.	CIEE E3255 (3) Environ. control / pollution CIEE E3250 (3) Hydrosystems eng. CIEN E3303 (1) Independent studies	CIEN E4163 (3) Environ. eng. wastewater CIEE E4260 (4) Urban ecology studio	CIEN E4250 (3) Waste containm. design & practice or CIEN E4257 (3) contam. transport in subsurface sys. EAEE E4006 (3) Field methods for environ. eng.
TECH ELECTIVES	6 points	3 points	9 points	
NONTECH ELECTIVES	3 points	3 points		
TOTAL POINTS	16	17	15 (water res./environ. eng. 16)	16 (water res./environ. eng. 15)

ENGINEERING MECHANICS PROGRAM: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and ODE (3)
PHYSICS (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)	
CHEMISTRY	one-semester lecture (3–4): C1403 or C1404 or C3045 or C1604 Chem lab C1500 (3) either semester or physics lab			
MECHANICS	ENME-MECE E3105 (4) any semester			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	C1010 (3) Z1003 (0)	C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES			HUMA C1001, COCI C1101, or Global Core (3–4) HUMA W1121 or W1123 (3)	HUMA C1002, COCI C1102 or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
REQUIRED TECH ELECTIVES	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see pages 12–13)			
COMPUTER SCIENCE	Computer Language: W1005 (3) (any semester)			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

of civil engineering or other engineering disciplines.

The engineering mechanics program provides a strong analytical background in mechanics for students planning to continue on to graduate school and to pursue research. Admission to the engineering mechanics program requires a grade point average of B or better and maintenance of performance while in the program.

Program Objectives

In developing and continually updating our program to achieve the stated mission of the Department, we seek to achieve the following objectives:

1. To provide a firm foundation in the basic math, science, and engineering

sciences that underlie all technological development so our graduates will be well equipped to adapt to changing technology in the profession.

2. To provide the broad and fundamental technical base needed by graduates who will enter the profession through the increasingly common path of a specialized M.S., but also provide suitable preparation to those who choose to enter the professional workforce with a B.S. to develop specialized expertise by way of apprenticeship.
3. To provide the breadth and choices in our programs that can accommodate and foster not only students with differing technical objectives, but also those who will use their technical background to follow other career paths.

4. To provide a basis for effective writing and communication as well as a background to foster awareness of societal issues.

Engineering Mechanics

The prerequisites for this program are the courses listed in the First Year–Sophomore Program, or their equivalents, with the provision that *ENME E3105: Mechanics* be taken in the sophomore year and that the student have obtained a grade of B or better.

Civil Engineering

The prerequisites for this program are the courses listed in the First Year–Sophomore Program or their equivalents. The civil engineering program

ENGINEERING MECHANICS: THIRD AND FOURTH YEARS					
		SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES		ENME E3113 (3) Mech. of solids	ENME E3114 (4) Experimental mech.	CIEN E4332 (3) Finite element	ENME E4202 (3) Advanced mech.
		ENME E3161 (4) Fluid mechanics	CIEN 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			
ELECTIVES	TECH	3 points	6 points	6 points	9 points
	NONTECH			3 points	3 points
TOTAL POINTS		16	16	18	15

offers three areas of concentration: civil engineering and construction management, geotechnical engineering or 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: The art of structural design*, which all students are required to take in the spring semester of the first year or later. An equivalent course could be substituted for *E1201*.

Minor in Architecture

Civil engineering program students may want to consider a minor in architecture (see page 189).

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, vibrations and dynamics, earthquake engineering, or any combination thereof, such as fluid-structure interaction. The Graduate Record Examination (GRE) is required for admission to the department.

Civil Engineering

By selecting technical electives, students may focus on one of several areas of concentration or prepare for future endeavors such as architecture. Some typical concentrations are:

- **Structural engineering:** applications to steel and concrete buildings, bridges, and other structures
- **Geotechnical engineering:** soil mechanics, engineering geology, and foundation engineering
- **Construction engineering and management:** capital facility planning

and financing, strategic management, managing engineering and construction processes, construction industry law, construction techniques, managing civil infrastructure systems, civil engineering and construction entrepreneurship

- **Environmental engineering and water resources:** transport of waterborne substances, hydrology, sediment transport, hydrogeology, and geoenvironmental design of containment systems

Engineering Mechanics

Programs in engineering mechanics offer comprehensive training in the principles of applied mathematics and continuum mechanics and in the application of these principles to the solution of engineering problems. The emphasis is on basic principles, enabling students to choose from among a wide range of technical areas. Students may work on problems in such disciplines as systems analysis, acoustics, and stress analysis, and in fields as diverse as transportation, environmental, structural, nuclear, and aerospace engineering. Program areas include:

- **Continuum mechanics:** solid and fluid mechanics, theories of elastic and inelastic behavior, and damage mechanics
- **Vibrations:** nonlinear and random vibrations; dynamics of continuous media, of structures and rigid bodies, and of combined systems, such as fluid-structure interaction; active, passive, and hybrid control systems for structures under seismic loading; dynamic soil-structure interaction effects on the seismic response of structures
- **Random processes and reliability:** problems in design against failure under earthquake, wind, and wave loadings; noise, and turbulent flows; analysis of structures with random properties
- **Fluid mechanics:** turbulent flows, two-phase flows, fluid-structure interaction, fluid-soil interaction, flow in porous media, computational methods for flow and transport processes, and flow and transport in fractured rock under mechanical loading
- **Computational mechanics:** finite element and boundary element techniques, symbolic computation, and bioengineering applications

A flight structures program is designed to meet the needs of industry in the fields of high-speed and space flight. The emphasis is on mechanics, mathematics, fluid dynamics, flight structures, 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 (CIEN)

See also Engineering Mechanics (ENME), at the end of this section.

CIEN E1201y The art of structural design

Lect: 3. 3 pts. Professor Deodatis.

Introduction to the basic scientific and engineering principles used for the design of buildings, bridges, and other parts of the built infrastructure. Application of these principles to the analysis and design of a number of actual large-scale structures. Experimental verification of these principles through laboratory experiments. Coverage of the history of major structural design innovations and of the engineers who introduced them. Critical examination of the

unique aesthetic/artistic perspectives inherent in structural design. Consideration of management, socioeconomic, and ethical issues involved in the design and construction of large-scale structures. Introduction to some recent developments in sustainable engineering, including green building design and adaptable structural systems.

CIEN E3004y Urban infrastructure systems

Lect: 3. 3 pts. Professor Chiara.

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 with equal emphasis given to water resources/environmental engineering, geotechnical engineering, and construction engineering and management topics.

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 Betti.

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 Betti.

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 Meyer.

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, 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. Every student in the course will be exposed with equal emphasis to issues related to geotechnical

engineering, water resources/environmental engineering, structural engineering, and construction engineering and management.

CIEN E3129x Project management for construction

Lect: 3. 3 pts. Professor Taylor.

Prerequisite: Senior standing in civil engineering or permission of the instructor. Introduction to project management for design and construction processes. Elements of planning, estimating, scheduling, bidding, and contractual relationships. Computer scheduling and cost control. Critical path method. Design and construction activities. Field supervision.

CIEN E3141y Soil mechanics

Lect: 3. Lab: 3. 4 pts. Professor Ling.

Prerequisite: ENME E3113. Index properties and classification; compaction; permeability and seepage; effective stress and stress distribution; consolidation; shear strength of soil; consolidation; slope stability..

CIEN E3250y Hydrosystems engineering

Lect: 3. 3 pts. Professor Gong.

Prerequisite(s): CHEN E3110 or ENME E3161 or equivalent, SIEO W3600 or equivalent, or the instructor's permission. A quantitative introduction to hydrologic and hydraulic systems, with a focus on integrated modeling and analysis of the water cycle and associated mass transport for water resources and environmental engineering. Coverage of unit hydrologic processes such as precipitation, evaporation, infiltration, runoff generation, open channel and pipe flow, subsurface flow and well hydraulics in the context of example watersheds and specific integrative problems such as risk-based design for flood control, provision of water, and assessment of environmental impact or potential for non-point source pollution. Spatial hydrologic analysis using GIS and watershed models. Note: This course is to be joint listed with CIEN, and replaces the previous CIEN 3250.

CIEN E3255y Environmental control and pollution reduction systems

Lect: 3. 3 pts. Professor Castaldi.

Prerequisite: ENME E3161 or MECE E3100.

Review of engineered systems for prevention and control of pollution. Fundamentals of material and energy balances and reaction kinetics. Analysis of engineered systems to address environmental problems, including solid and hazardous waste, and air, water, soil, and noise pollution. Life cycle assessments and emerging technologies.

CIEN E3260y Engineering for developing communities

Lect: 3. 3 pts. Professor Culligan.

Introduction to engineering problems faced by developing communities and exploration of design solutions in the context of a real project with a community client. Emphasis is on the design of sustainable solutions that take account of social,

economical, and governance issues and that can be implemented now or in the near future. This course is open to all undergraduate engineering students. Multidisciplinary teamwork and approaches are stressed. Outside lecturers address issues specific to developing communities and the particular project under consideration.

CIEN E3303x and y Independent studies in civil engineering for juniors

1–3 pts. *By conference. The faculty.*
A project on civil engineering subjects approved by the chairman of the department. Lab fee: \$200.

CIEN E3304x and y Independent studies in civil engineering for seniors

1–3 pts. *By conference. The faculty.*
A project on civil engineering subjects approved by the chairman of the department. Lab fee: \$200.

CIEN E4010y Transportation engineering

Lect: 3. 3 pts. Professor Peterson.
Comprehensive multidisciplinary course in engineering and planning design principles applied to understanding major transportation systems, from people to planes. Fundamentals of pedestrian, road, rail, aviation and marine planning, designing, financing, legislating, and analyzing. Engineering principles of human control, vehicles, feedback control and signal systems, lane systems, energy, goods movement, networks, and parking. Novel system design presentation.

CIEN E4021x Elastic and plastic analysis of structures

Lect: 3. 3 pts. Professor Meyer.
Prerequisite: CIEN E3121 or the equivalent.
Overview of classical indeterminate structural analysis methods (force and displacement methods), approximate methods of analysis, plastic analysis methods, collapse analysis, shakedown theorem, structural optimization.

CIEN E4022y Bridge design and management

Lect: 3. 3 pts. Professor Yanev.
Prerequisite: CIEN E3125 or the equivalent.
Bridge design history, methods of analysis, loads: static, live, dynamic. Design: allowable stress, ultimate strength, load resistance factor, supply/demand. Steel and concrete superstructures: suspension, cable-stayed, prestressed, arches. Management of the assets, life-cycle cost, expected useful life, inspection, maintenance, repair, reconstruction. Bridge inventories, condition assessments, data acquisition and analysis, forecasts. Selected case histories and field visits.

CIEN E4100y Earthquake and wind engineering

Lect: 3. 3 pts. Professor Smyth.
Prerequisite: ENME E3106 or the equivalent.
Basic concepts of seismology. Earthquake characteristics, magnitude, response spectrum, dynamic response of structures to ground motion. Base isolation and earthquake-resistant design. Wind loads and aeroelastic instabilities. Extreme winds. Wind effects on structures and gust factors.

CIEN E4111x Uncertainty and risk in infrastructure systems

Lect: 3. 3 pts. Professor Smyth.
Prerequisites: Working knowledge of calculus. Introduction to basic probability; hazard function; reliability function; stochastic models of natural and technological hazards; extreme value distributions; Monte Carlo simulation techniques; fundamentals of integrated risk assessment and risk management; topics in risk-based insurance; case studies involving civil infrastructure systems, environmental systems, mechanical and aerospace systems, construction management.

CIEN E4129x and y Managing engineering and construction processes

Lect: 3. 3 pts. Professor Nagaraja.
Prerequisite: Senior standing in civil engineering or the instructor's permission. Introduction to the principles, methods, and tools necessary to manage design and construction processes. Elements of planning, estimating, scheduling, bidding, and contractual relationships. Valuation of project cash flows. Critical path method. Survey of construction procedures. Cost control and effectiveness. Field supervision.

CIEN E4130x Design of construction systems

Lect: 3. 3 pts. Professor Tirolo.
Prerequisite: CIEN 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 E4131x and y Principles of construction techniques

Lect: 3. 3 pts. Professors Hart and Papachristos.
Prerequisite: CIEN E4129 or the equivalent.
Current methods of construction, cost-effective designs, maintenance, safe work environment. Design functions, constructability, site and environmental issues.

CIEN E4132y Prevention and resolution of construction disputes

Lect: 3. 3 pts. Professor Nikain.
Prerequisite: CIEN E4129 or the equivalent.
Contractual relationships in the engineering and construction industry and the actions that result in disputes. Emphasis on procedures required to prevent disputes and resolve them quickly and cost-effectively. Case studies requiring oral and written presentations.

CIEN E4133x Capital facility planning and financing

Lect: 3. 3 pts. Professor Chang.
Prerequisite: CIEN E4129 or the equivalent. Planning and financing of capital facilities with a strong

emphasis upon civil infrastructure systems. Project feasibility and evaluation. Design of project delivery systems to encourage best value, innovation, and private sector participation. Fundamentals of engineering economy and project finance. Elements of life-cycle cost estimation and decision analysis. Environmental, institutional, social, and political factors. Case studies from transportation, water supply, and wastewater treatment.

CIEN E4134y Construction industry law

Lect: 3. 3 pts. Professors Rubin and Quintas.
Prerequisite: Graduate standing or the instructor's permission. Practical focus upon legal concepts applicable to the construction industry. Provides sufficient understanding to manage legal aspects, instead of being managed by them. Topics include contractual relationships, contract performance, contract flexibility and change orders, liability and negligence, dispute avoidance/resolution, surety bonds, insurance, and site safety.

CIEN E4135y Strategic management in global design and construction

Lect: 3. 3 pts. Professor Taylor.
Core concepts of strategic planning, management, and analysis within the global design and construction industry. Global industry analysis, strategic planning models, industry trends, and project network dynamics. Strategies for information technology, emerging markets, and globalization. Case studies to demonstrate key concepts in real-world environments.

CIEN E4136y Global entrepreneurship in civil engineering

Lect: 3. 3 pts. Not given in 2009–2010.
Capstone practicum where teams develop business plans for a new enterprise serving the global architecture, engineering, and construction industry. The innovation process; identification of attractive entrepreneurial opportunities and global market segments; development of an entry strategy; product/service development planning; acquisition of financing; protecting intellectual property; group dynamics and organizational design; plans for recruiting and retaining personnel; personnel compensation/incentives. Invited industry speakers.

CIEN E4163x Environmental engineering: wastewater

Lect: 3. 3 pts. Professor Becker.
Prerequisites: Introductory chemistry (with laboratory) and fluid mechanics. Fundamentals of water pollution and wastewater characteristics. Chemistry, microbiology, and reaction kinetics. Design of primary, secondary, and advanced treatment systems. Small community and residential systems.

CIEN E4210x Forensic structural engineering

Lect: 3. 3 pts. Professor Ratay.
Prerequisite: CIEN E3125 or the equivalent.
Review of significant failures, civil/structural engineering design and construction practices, ethical standards and the legal positions as necessary

background to forensic engineering. Discussion of standard-of-care. Study of the process of engineering evaluation of structural defects and failures in construction and in service. Examination of the roles, activities, conduct, and ethics of the forensic consultant and expert witness. Students are assigned projects of actual cases of nonperformance or failure of steel, concrete, masonry, geotechnical and temporary structures, in order to perform, discuss, and report their own investigations under the guidance of the instructor.

CIEI E4212x Structural assessment and failure

Lect: 3. 3 pts. Not given in 2009–2010.

Prerequisites: ENME E3113 and CIEI 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.

CIEI E4213x Elastic and inelastic buckling of structures

Lect: 3. 3 pts. Professor Laufs.

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.

CIEI E4226y Advanced design of steel structures

Lect: 3. 3 pts. Professor Woelke.

Prerequisite: CIEI 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.

CIEI E4232y Advanced design of concrete structures

Lect: 3. 3 pts. Professor Panayotidi.

Prerequisite: CIEI E3125 or the equivalent. Design of concrete slabs, deep beams, walls, and other plane structures; introduction to design of prestressed concrete structures.

CIEI E4233x Design of large-scale bridges

Lect: 3. 3 pts. Professor Zoll.

Prerequisites: CIEI E3121 or the equivalent and CIEI 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.

CIEI E4234y Design of large-scale building structures

Lect: 3. 3 pts. Professors Tomasetti, Brazil, Panariello, and Gottlieb.

Prerequisites: CIEI E3121 and CIEI 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.

CIEI E4241x Geotechnical engineering fundamentals

Lect: 3. 3 pts. Professor Mohammad.

Prerequisite: CIEI 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.

CIEI E4242x Geotechnical earthquake engineering

Lect: 3. 3 pts. Professor Ling.

Prerequisite: CIEI 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.

CIEI E4243x Foundation engineering

Lect: 3. 3 pts. Professor Brant.

Prerequisite: CIEI 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 CIEI E4246.

CIEI E4244y Geosynthetics and waste containment

Lect: 3. 3 pts. Professor Brant.

Prerequisite: CIEI E4241 or the equivalent. Properties of geosynthetics. Geosynthetic design for soil reinforcement. Geosynthetic applications in solid waste containment system. To alternate with CIEI E4242.

CIEI E4245x Tunnel design and construction

Lect: 3. 3 pts. Professor Munfah.

This course covers the engineering design and construction of different types of tunnel, including cut and cover tunnel, rock tunnel, soft ground tunnel, immersed tube tunnel, and jacked tunnel. The design for the liner, excavation, and instrumentation are also covered. A field trip will be arranged to visit the tunneling site.

CIEI E4246y Earth retaining structures

Lect: 3. 3 pts. Professor Leifer.

Prerequisite: CIEI 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 CIEI E4243.

CIEE E4252x Environmental engineering

Lect: 3. 3 pts. Professor Gong.

Prerequisites: CHEM C1403, or the equivalent; ENME E3161 or the equivalent. Engineering aspects of problems involving human interaction with the natural environment. Review of fundamental principles that underlie the discipline of environmental engineering, i.e., constituent transport and transformation processes in environmental media such as water, air, and ecosystems. Engineering applications for addressing environmental problems such as water quality and treatment, air pollutant emissions, and hazardous waste remediation. Presented in the context of current issues facing practicing engineers and government agencies, including legal and regulatory framework, environmental impact assessments, and natural resource management.

CIEI E4253x Finite elements in geotechnical engineering

Lect: 3. 3 pts. Professor Ling.

Prerequisites: CIEI E3141 and CIEI 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 CIEI E4254.

CIEI 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 Urban ecology studio

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

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 E6131x Quantitative infrastructure risk management

Lect: 3. 3 pts. Professor Chiara.

Prerequisite: IEOR E4003 or CIEN E4133, or the equivalent. Core concepts of risk analysis, risk mitigation, and quantitative risk management applied to civil infrastructure systems. State of art of simulation applied to infrastructure risk management during construction and operation. Public Private Partnership (PPP) risk management: identification, quantification, mitigation of risks in transportation and energy PPP systems. Risk management during construction using the envelop method.

CIEN 6132y Advanced systems and technologies for global project collaboration

Lect: 3. 3 pts. Professor Taylor.

Prerequisite: CIEN E4129 or the equivalent.

Systems and technologies that support collaborative work in global projects. Information technologies for design, visualization, project management, and collaboration in globally distributed networks of design, fabrication, and construction organizations, including Web-based, parametric computer-aided modeling, project organizational simulation, and other emerging applications. Global team project with students at collaborating universities abroad.

CIEN E6133y Advanced construction and infrastructure risk management using real options

Lect: 3. 3 pts. Professor Chiara.

Prerequisite: CIEN E6131. Advanced concepts of risk analysis and management applied to civil engineering systems. Identifying and valuing flexibility in construction and operation. Tools to perform risk analysis in flexible civil infrastructure systems. Valuation methods for real options. Risk flexibility analysis: integrating real options analysis with quantitative risk analysis. Applications to case studies on construction management, life-cycle cost analysis for infrastructure assets, public-private partnerships projects, real estate developments, and renewable energy infrastructure projects.

CIEN E6246y Advanced soil mechanics

Lect: 2.5. 3 pts. Not given in 2009–2010.

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 E6248x Experimental soil mechanics

Lect: 2.5. 3 pts. Not given in 2009–2010.

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 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. Professors Betti and Hone.

Prerequisites: PHYS C1402 and MATH V1101-V1102 and V1201. Elements of statics; dynamics of a particle and systems of particles; dynamics of rigid bodies.

ENME E3106x Dynamics and vibrations

Lect: 2. 3 pts. Professor Smyth.

Prerequisite: MATH E1210. Corequisite: ENME E3105. Kinematics of rigid bodies; momentum and energy methods; vibrations of discrete and continuous systems; eigen-value problems; natural frequencies and modes. Basics of computer simulation of dynamic problems using MATLAB or Mathematica.

ENME E3113x Mechanics of solids

Lect: 3. 3 pts. Professor Yin.

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 Yin.

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 Waisman.

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 Yin.

Stress and deformation formulation in two- and three-dimensional solids; viscoelastic and plastic material in one and two dimensions.

ENME E4114y Mechanics of fracture and fatigue

Lect: 3. 3 pts. Professor Testa.

Prerequisite: Undergraduate mechanics of solids course. Elastic stresses at a crack; energy and stress intensity criteria for crack growth; effect of plastic zone at the crack; fracture testing applications. Fatigue characterization by stress-life and strain-life; damage index; crack propagation; fail safe and safe life analysis.

ENME E4202y Advanced mechanics

Lect: 3. 3 pts. Professor Dasgupta.

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. Professor Dasgupta.

Prerequisite: ENME 3113. Static flexural response of thin, elastic, rectangular, and circular plates. Exact (series) and approximate (Ritz) solutions. Circular cylindrical shells. Axisymmetric and non-axisymmetric membrane theory. Shells of arbitrary shape.

ENME E4215x Theory of vibrations

Lect: 3. 3 pts. Professor Betti.

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 E4332x Finite element analysis, I

Lect: 3. 3 pts. Professor Waisman.

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.

ENME E6220x Random processes in mechanics

Lect: 2.5. 3 pts. Professor Deodatis.

Prerequisite: ENME E4215 or the equivalent. Random variables, stationary and ergodic random processes, correlation functions, and power spectra. Input-output relations of linear systems; analysis of response of discrete and continuous structures to random loadings. Crossing rates, peak distributions, and response analysis of nonlinear structures to random loading. Simulation of stationary random processes.

ENME E6315x Theory of elasticity

Lect: 2.5. 3 pts. Instructor to be announced.

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

ENME E6333y Finite element analysis, II

Lect: 2.5. 3 pts. Professor Waisman.

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.

ENME E8320y Viscoelasticity and plasticity

Lect: 3. 4 pts. Professor Chen.

Prerequisite: ENME E6315 or the equivalent, or the instructor's permission. Constitutive equations of viscoelastic and plastic bodies. Formulation and methods of solution of the boundary value, problems of viscoelasticity and plasticity.

ENME E8323y Nonlinear vibrations

Lect: 2.5. 3 pts. Instructor to be announced.

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: \$300.

GRAP E2005y Computer-aided engineering graphics

Lect: 1.5. Lab: 2.5. 3 pts. Not given in 2009–2010.

Prerequisite: MATH V1105. 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 E3115y 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: \$300.

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.

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.

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www.compeng.columbia.edu



IN CHARGE
 Steven M. Nowick
 508 Computer Science

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 Stephen A. Edwards
 Associate Professor of Computer Science

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 Associate Professor of Computer Science
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 Professor of Computer Science
 Daniel Rubenstein
 Associate Professor of Computer Science

Simha Sethumadhavan
 Assistant Professor of Computer Science
 Kenneth L. Shepard
 Professor of Electrical Engineering
 Stephen H. Unger
 Professor Emeritus of Computer Science (and Electrical Engineering)
 Charles A. Zukowski
 Professor of Electrical Engineering

The computer engineering program is run jointly by the Computer Science and Electrical Engineering departments. It offers both B.S. and M.S. degrees.

The program covers some of engineering's most active, exciting, and critical areas, which lie at the interface between CS and EE. The focus of the major is on computer systems involving both digital hardware and software.

Some of the key topics covered are computer design (i.e., computer architecture); embedded systems (i.e., the design of dedicated hardware/software for cell phones, automobiles, robots, games, and aerospace); digital and VLSI circuit design; computer networks; design automation (i.e. CAD); and parallel and distributed systems (including architectures, programming, and compilers).

The undergraduate major includes one substantial senior design course, either designing an entire microprocessor (*EECS 4340*), or an embedded system (*CSEE 4840*) (including both software and hardware components), or

providing hands-on experience in designing and using a computer network (*CSEE 4140*).

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. Detailed lists of requirements can be found in the charts on the following pages, and on a checklist

posted at www.compeng.columbia.edu/pages/ugrad.

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*, *EECS E4340*, or *CSEE W4140*), 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

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

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3) ³
PHYSICS (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)	
CHEMISTRY	one-semester lecture (3–4) C1403 or C1404 or C3045 or C1604 Lab C1500 (3) either semester or physics lab C1493 (3)			
CORE REQUIRED COURSES	ELEN E1201 (3.5) Intro. to elec. eng. (either semester)		ELEN E3801 (3.5) Signals & systems	COMS W3137 (3) or W3139 (4) Data structures CSEE W3827 (3) Fund. of computer sys.
REQUIRED LABS			ELEN E3084 (1) Signals & systems lab	ELEN E3082 (1) Digital systems lab
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0)	➔ C1010 (3) Z1003 (0)	➔ C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES¹			HUMA C1001, COCI C1101, or Global Core (3–4) HUMA W1121 or W1123 (3) ¹	HUMA C1002, COCI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
COMPUTER SCIENCE	COMS W1004 (3) ²	COMS W1007 (3) or W1009	W3203 (3) Discrete math.	
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

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

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

³ APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2010.

COMPUTER ENGINEERING: THIRD AND FOURTH YEARS EARLY-STARTING STUDENTS

		SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
CORE REQUIRED COURSES		IEOR E3658 (3) Probability	ELEN E3331 (3) Electronic circuits	COMS W4118 (3) Operating systems	COMS W4115 (3) Programming lang.
		COMS W3157 (3) Advanced programming	COMS W3261 (3) Computer sci. theory		
		ELEN E3201 (3.5) Circuit analysis	CSEE W4823 (3) or CSEE W4119 (3) Advanced logic design Computer networks		
REQUIRED LABS		ELEN E3081 (1) Circuit analysis lab	ELEN E3083 (1) Electronic circuits lab	EECS E4340 (3) Computer hardware design or CSEE W4840 (3) Embedded sys. design or CSEE W4140 (4) Networking lab	
ELECTIVES	TECH	15 points required; see details on pages 103–105			
	NONTECH	Complete 27-point requirement; see page 11 or www.seas.columbia.edu for details (administered by the advising dean)			
TOTAL POINTS¹		16.5	17	15	15

For a discussion about programming languages used in the program, please see www.compeng.columbia.edu. Check the late-starting student chart for footnotes about various courses.

¹"Total points" assumes that 20 points of nontechnical electives and other courses are included.

outside the departments with adviser approval. Courses at the 3000 level or higher in other areas of engineering, math, and science can be considered for approval, as long as they do not significantly overlap with other required or elective courses. Economics courses cannot be used as technical electives.

Starting Early

Students are strongly encouraged to begin taking core computer engineering courses as sophomores. They start with *ELEN E1201: Introduction to electrical engineering* in the second semester of their first year and may continue with other core courses one semester after that. For sample "early-starting" programs, see the charts on the following two pages. It must be emphasized that these charts, as well as the "late-start-

ing" charts that follow, present examples only; actual schedules may be customized in consultation with academic advisers.

GRADUATE PROGRAM

The Computer Engineering Program offers a course of study leading to the degree of Master of Science (M.S.). The basic courses in the M.S. program come from the Electrical Engineering and Computer Science Departments. Students completing the program are prepared to work (or study further) in such fields as digital computer design, digital communications, and the design of embedded computer systems.

Applicants are generally expected to have a bachelor's degree in computer engineering, computer science, or electrical engineering with at least a 3.2 GPA in technical courses. The Graduate

Record Examination (GRE), General Test only, is required of all applicants.

Students must take at least 30 points of courses at Columbia University at or above the 4000 level. These must include at least 15 points from the courses listed below that are deemed core to computer engineering. At least 6 points must be included from each department. CSEE and EECS courses can count toward either department minimum. Other courses may be chosen with the prior approval of a faculty adviser in the Computer Engineering Program.

CORE COMPUTER ENGINEERING COURSES

COMS W4115: Programming language and translators

COMS W4118: Operating systems, I

CSEE W4119: Computer networks

CSEE W4140: Networking lab

CSEE W4180: Network security

CSEE W4823: Advanced logic design

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

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3) ³
PHYSICS (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)	
CHEMISTRY	one-semester lecture (3–4) C1403 or C1404 or C3045 or C1604 Lab C1500 (3) either semester or physics lab C1493 (3)			
CORE REQUIRED COURSES	ELEN E1201 (3.5) ² Intro. to elec. eng. (either semester)			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	→ C1010 (3) → Z1003 (0)	→ C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES			HUMA C1001, COCI C1101, or Global Core (3–4) HUMA W1121 or W1123 (3)	HUMA C1002, COCI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
COMPUTER SCIENCE	COMS W1004 (3) ¹	COMS W1007 (3) or W1009	W3203 (3) ² Discrete math.	
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

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

²Transfer 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.

³APMA 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
CORE REQUIRED COURSES		IEOR E3658 (3) ¹ Probability	COMS W3157 (3) Advanced programming	COMS W4118 (3) Operating systems	COMS W4115 (3) Programming lang.
		COMS W3137 (3) or W3139 (4) Data structures	ELEN E3331 (3) Electronic circuits	CSEE W4119 (3) Computer networks	or CSEE W4823 (3) Advanced logic design
		ELEN E3201 (3.5) Circuit analysis	COMS W3261 (3) ³ Models of comp.		
		ELEN E3801 (3.5) Signals & systems	CSEE W3827 (3) Fund. of computer systems		
REQUIRED LABS		ELEN E3081 (1) ² Circuit analysis lab	ELEN E3083 (1) ² Electronic circuits lab	EECS E4340 (3) Computer hardware design or CSEE W4840 (3) Embedded sys. design or CSEE W4140 Networking lab	
		ELEN E3084 (1) ² Signals & systems lab	ELEN E3082 (1) ² Digital systems lab		
ELECTIVES	TECH	15 points required; see details on pages 103–105 ⁴			
	NONTECH	Complete 27-point requirement; see page 11 or www.seas.columbia.edu for details (administered by the advising dean)			
TOTAL POINTS⁵		15	17	15	18

For a discussion about programming languages used in the program, please see www.compeng.columbia.edu.

¹SIEO W3600, SIEO W4105, STAT W4105, and SIEO W4150 can be used instead of IEOE E3658, 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 IEOE E3658 and augment it with STAT W1211.

²If possible, ELEN E3081 and ELEN E3084 should be taken along with ELEN E3201 and ELEN 3801 respectively, and ELEN E3083 and ELEN E3082 taken with ELEN E3331 and CSEE W3827 respectively.

³COMS W3261 can be taken one semester later than pictured.

⁴The total points of technical electives is reduced to 12 if APMA E2101 has been replaced by MATH E1210 and either APMA E3101 or MATH V2010.

⁵Assuming technical electives taken Semesters VII and VIII, and 9 points of nontechnical electives taken Semesters VI, VII, and VIII.

CSEE W4824: Computer architecture
CSEE W4825: Digital systems design*
CSEE W4840: Embedded systems design
COMS E6118: Operating systems, II*
CSEE E6180: Modeling and performance
COMS E6181: Advanced internet services
CSEE E6824: Parallel computer architecture
CSEE W6831: Sequential logic circuits*
CSEE W6832: Topics in logic design theory*
CSEE E6847: Distributed embedded systems
CSEE W6861: Computer-aided design of digital systems
ELEN E4321: Digital 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 E4896: Music signal processing*
ELEN E6321: Advanced digital electronic circuits
ELEN E6488: Optical interconnects and interconnection networks
ELEN E6761: Computer communication networks, I
ELEN E6762: Computer communication networks, II*
ELEN E6850: Visual information systems
ELEN E6860: Advanced digital signal processing

The overall program must include at least 15 points of 6000-level *ELEN*, *EECS*, *CSEE*, or *COMS* courses (exclusive of seminars). No more than 9 points of research may be taken for credit. No more than 3 points of a nontechnical elective (at or above the 4000 level) may be included. A minimum GPA of at least 2.7 must be maintained, and all degree requirements must be completed within five years of the beginning of the first course credited toward the degree.

*Occasionally offered.

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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-solving skills and the production expertise required in the efficient processing of information. Computer scientists, therefore, function in a wide variety of roles, ranging from pure theory

and design to programming and marketing.

The computer science curriculum at Columbia places equal emphasis on theoretical computer science and mathematics and on experimental computer technology. A broad range of upper-level courses is available in such areas as artificial intelligence, computational complexity and the analysis of algorithms, combinatorial methods, computer architecture, computer-aided digital design, computer communications, databases, mathematical models for computation, optimization, and software systems.

Laboratory Facilities

The department has well-equipped lab areas for research in computer graphics,

computer-aided digital design, computer vision, databases and digital libraries, data mining and knowledge discovery, distributed systems, mobile and wearable computing, natural-language processing, networking, operating systems, programming systems, robotics, user interfaces, and real-time multimedia.

The computer facilities include a shared infrastructure of Sun and Linux multiprocessor file servers, NetApp file servers, a student interactive teaching and research lab of high-end multimedia workstations, a Microsoft programming laboratory with 15 Windows XP workstations, a Unix/Linux laboratory with 63 Linux workstations, a large vonware system for teaching, a large cluster of

Linux servers for computational work, and a cluster of Sun servers. The research infrastructure includes hundreds of workstations and PCs running Solaris, Windows XP, Linux, and Mac OSX; 7 terabytes of disk space are backed up by a 48TB Sun Thumper and a Sun StorEdge LT02 with 100-tape library unit.

Research labs contain Puma 500 and IBM robotic arms; a UTAH-MIT dexterous hand; an Adept-1 robot; three mobile research robots; a real-time defocus range sensor; PC interactive 3-D graphics workstations with 3-D position and orientation trackers; prototype wearable computers, wall-sized stereo projection systems; see-through head-mounted displays; a networking testbed with three Cisco 7500 backbone routers, traffic generators, Ethernet switches, Sun Ray thin clients, and a 17-node (34CPU) IBM Netfinity cluster. The department uses a 3COM SIP IP phone system. The protocol was developed in the department.

The servers are connected on a gigabit network; all have remote consoles and remote power for easy maintenance after hours. The rest of the department's computers are connected via a switched 100 Mb/s Ethernet network, which has direct connectivity to the campus OC-3 Internet and Internet2 gateways. The campus has 802.11a/b wireless LAN coverage.

The research facility is supported by a full-time staff of professional system administrators and programmers, aided by a number of part-time student system administrators.

UNDERGRADUATE PROGRAM

Computer science majors at Columbia study an integrated curriculum, partially in areas with an immediate relationship to the computer, such as programming languages, operating systems, and computer architecture, and partially in theoretical computer science and mathematics. Thus, students obtain the background to pursue their interests both in applications and in theoretical developments.

Practical experience is an essential component of the computer science program. Undergraduate students are often involved in advanced faculty research projects using state-of-the-art computing facilities. Qualified majors sometimes serve as consultants at the Computer Center, which operates several labs with microcomputers and terminals available at convenient locations on the campus.

Upper-level students in computer science may assist faculty members with research projects, particularly in the development of software. Ongoing faculty projects include algorithmic analysis, computational complexity, software tool design, distributed computation, modeling and performance evaluation, computer networks, computer architecture, CAD for digital systems, computer graphics, programming environments, expert systems, natural language processing, computer vision, robotics, multicomputer design, user interfaces, VLSI applications, artificial intelligence, 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.

For further information on the undergraduate computer science program, please see the home page at www.cs.columbia.edu/education/undergrad and the Quick Guide at www.cs.columbia.edu/education/undergrad/seasguide.

Technical Electives

All technical electives except those noted in each track must be approved by the adviser. In every case, the technical elective course must be at the 3000 level or higher. All technical electives should be taken in computer science. With the adviser's approval, however, courses in other departments may be taken as technical electives; in every such case, the subject of the course must have a strong and obvious 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."

COMPUTER SCIENCE PROGRAM: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	COMS W3210 (3)
PHYSICS (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 CHEM W3081 (2) or CHEM C1500 (3) or CHEM C3085 (4)	
CHEMISTRY (choose one course)	one-semester lecture (3–4) C1403 or C1404 or C3045 or C1604 either semester			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	→ C1010 (3) → Z1003 (0)	→ C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES	ECON W1105 (4) and W1105 recitation (0) either semester		HUMA C1001, COCI C1101, or Global Core (3–4)	HUMA C1002, COCI C1102, or Global Core (3–4)
			HUMA C1121 or C1123 (3) either semester	
REQUIRED TECH ELECTIVES	Professional-level course (3) (see page 12) either semester			
COMPUTER SCIENCE	COMS W1004 (3) Intro. to computer science either semester		COMS W1009 (3) or COMS W1007 (3) Object-oriented programming and COMS W3203 (3) Discrete math	COMS W3137 (4) or COMS W3139 (4) Data structures and COMS W3157 (4) Adv. programming
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

An advanced version of each track is available by invitation for qualified students who wish an extra opportunity for advanced learning.

The following courses are required as a preparation for all tracks: *COMS W1004*, *W1007* (or *W1009*), *W3137* (or *W3139*), *W3157*, *W3203*, *W3210*, *W3251*, *W3261*, *CSEE W3827*, and *SIEO W4150* (*SIEO W3600* is an accepted substitute for *W4150*). Collectively these courses are called the CS Core Curriculum.

Students who pass the Computer Science Advanced Placement (AP)

Exam, either A or AB, with a 4 or 5 will receive 3 points of credit and exemption from *COMS W1004*.

Note: A maximum of one course passed with a grade of D may be counted toward the major or minor.

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

CSOR W4231: Analysis of algorithms

COMS W4236: Introduction to computational complexity

COMS W4241: Numerical algorithms and complexity

COMPUTER SCIENCE: THIRD AND FOURTH YEARS

		SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES		COMS W3251 (3) Computational lin. algebra COMS W3261 (3) Computer sci. theory CSEE W3827 (3) Fund. of computer sys.	SIEO W4150 (3) or SIEO W3600 (4) Prob. & stat.		
ELECTIVES	NONTECH	3 points	6 points	3 points	
	TECH	3 points	6 points	12 points	9 points
TOTAL POINTS		15	15–16	15	9

The primary programming languages for the undergraduate major are C and Java, and students are expected to learn both at an early stage. The language for COMS W1004/W1007/W1009/W3137/W3139 is Java. COMS W1004 is waived for students who have had AP computer science in high school.

BREADTH: 2 courses

Any COMS 3000- or 4000-level courses except those countable toward the CS core or foundations of CS track

ELECTIVES: any 5 courses from the following list

COMS W4203: Graph theory
COMS W4205: Combinatorial theory
COMS W4252: Computational learning theory
COMS W4261: Introduction to cryptography
COMS W4281: Quantum computing
COMS W4444: Programming and problem solving
COMS W4771: Machine learning
COMS W4772: Advanced machine learning
COMS W4995: Math foundations of machine learning

COMS E6232: Analysis of algorithms, II
COMS E6261: Advanced cryptography
COMS E6717: Information theory
COMS E6998: Approximation algorithms

Track 2: Systems Track

The systems track is for students interested in the implementation of software and/or hardware systems. Register for track course *COMS E0002*.

REQUIRED: 3 courses

COMS W4115: Programming languages and translators
COMS W4118: Operating systems
CSEE W4119: Networking

BREADTH: 2 courses

Any COMS 3000- or 4000-level course except those countable for the CS core or systems track

ELECTIVES: any 5 courses from the following list

Any COMS W41xx course

Any COMS W48xx 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*, *COMS E6901*) 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 topics I (with adviser approval; may be repeated)

COMS W4996: Special topics 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: Introduction to databases

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 W4172: 3D user interface design

COMS W4701: Artificial intelligence

COMS W4733: Computational aspects of robotics

COMS W4735: Visual interfaces to computers

COMS W4771: Machine learning

COMS W4995: Video game technology and design

COMS W3902: Undergraduate thesis

COMS W3998: Undergraduate projects in computer science

or **COMS W4901:** Projects in computer science
COMS W4995-W4996: Special topics in computer science, I and II (with adviser approval)

COMS E6901: Projects in computer science

Any **COMS E691x** course (with adviser approval)

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

Track 6: Advanced

The advanced track of the B.S. in Computer Science provides extra opportunity for advanced learning. It comprises accelerated versions of the other five tracks. Entry is only by collective faculty invitation, extended to students who have already completed the core courses and the required courses for one of those tracks.

REQUIRED TRACK COURSES

A student designates one of the five other track areas and completes the set of required track courses for that track, prior to entry into the Advanced Track. There are two or three courses, depending on the designated area.

BREADTH REQUIREMENT

Two breadth courses of the designated track.

ELECTIVES

At least two 4000-level lecture courses from the menu for the designated track, plus two 6000-level courses in the designated track area.

THESIS

There is a required 6-point senior thesis.

INVITATION

Only the top 20% of computer science majors in course performance in computer science courses will be considered for invitation during the junior year. (A student in the advanced track who does not maintain this status may be required to return to his or her previously selected track area.)

GRADUATE PROGRAMS

The Department of Computer Science offers graduate programs leading to the degree of Master of Science, the professional degree of Computer Systems Engineer and the degree of Doctor of Philosophy. Both the Aptitude Test and Advanced Tests of the Graduate Record Examination (GRE) are required for admission to the department's graduate programs. Applicants for September admission should take the GREs by October of the preceding year. Applicants for January admission should take these exams by April of the preceding year.

The course requirements in all pro-

grams are flexible, and each student is urged to design his or her own program under the guidance of a faculty adviser. The student's program should focus on a particular field of computer science. Among the fields of graduate study in computer science are analysis of algorithms, artificial intelligence, expert systems, natural language understanding, computer vision, multicomputer design, VLSI applications, combinatorial modeling, combinatorial optimization, computational complexity, computer architecture and design, computer communications networks, computer graphics, database machines and systems, microprocessors, parallel computation, programming environments, programming languages, robotics, user interfaces, software design, computational biology, computer security, and machine learning.

Graduate students are encouraged actively to pursue research. Faculty members of the Department of Computer Science are engaged in experimental and theoretical research in most of the fields in which courses are offered. The degree of doctor of philosophy requires a dissertation based on the candidate's original research, which is supervised by a faculty member.

The professional degree program also provides the student with the opportunity to specialize beyond the level of the Master of Science program. The program leading to the degree of Computer Systems Engineer is particularly suited to those who wish to advance their professional development after a period of industrial employment.

COURSES IN COMPUTER SCIENCE

COMS W1001x and y Introduction to information science

Lect: 3. 3 pts. Professor Cannon.

Basic introduction to concepts and skills in information sciences: human-computer interfaces, representing information digitally, organizing and searching information on the World Wide Web, principles of algorithmic problem solving, introduction to database concepts, introduction to programming in Python.

COMS W1003x or y Introduction to computer science and programming in C

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

A general introduction to computer science concepts, algorithmic problem-solving capabilities, and programming skills in C. Columbia University

students may receive credit for only one of the following three courses: W1003, W1004, or W1005.

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

Lect: 3. 3 pts. Professor Cannon.

A general introduction to computer science for science and engineering students interested in majoring in computer science or engineering. Covers fundamental concepts of computer science, algorithmic problem-solving capabilities, and introductory Java programming skills. Assumes no prior programming background. Columbia University students may receive credit for only one of the following three courses: W1003, W1004, or W1005.

COMS W1005x and y Introduction to computer science and programming in MATLAB

Lect: 3. 3 pts. Paul Blaar.

A general introduction to computer science concepts, algorithmic problem-solving capabilities, and programming skills in MATLAB. Assumes no prior programming background. Columbia University students may receive credit for only one of the following three courses: W1003, W1004, or W1005.

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

Lect: 3. 3 pts. Professor Kender.

Prerequisites: COMS W1004 or AP Computer Science with a grade of 4 or 5. The second course for majors in computer science. A rigorous treatment of object-oriented concepts using Java as an example language. Development of sound programming and design skills, problem solving and modeling of real-world problems from science, engineering, and economics using the object-oriented paradigm.

COMS W1009x Honors introduction to computer science

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

Prerequisite: COMS W1004 or AP computer science with a grade of 4 or 5. An honors-level introduction to computer science, intended primarily for students considering a major in computer science. Computer science as a science of abstraction. Creating models for reasoning about and solving problems. The basic elements of computers and computer programs. Implementing abstractions using data structures and algorithms. Taught in Java.

ECBM E3060x Introduction to genomic information science and technology

Lect: 3. 3 pts. Professor Anastassiou.

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

COMS W3101x and y Programming languages

Lect: 1. 1 pt. Instructors to be announced.

Prerequisite: Fluency in at least one programming language. Introduction to a programming language. Each section is devoted to a specific language. Intended only for those who are already fluent in at least one programming language. Sections may meet for one hour per week for the whole term, for three hours per week for the first third of the term, or for two hours per week for the first six weeks. May be repeated for credit if different languages are involved.

COMS W3133x or y Data structures in C

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

Prerequisite: COMS W1003 or knowledge of C. Not intended for computer science majors. Data types and structures: arrays, stacks, singly and doubly linked lists, queues, trees, sets, and graphs. Programming techniques for processing such structures: sorting and searching, hashing, garbage collection. Storage management. Rudiments of the analysis of algorithms. Taught in C. Note: Due to significant overlap, students may receive credit for only one of the following four courses: COMS W3133, W3134, W3137, or W3139.

COMS W3134x and y Data structures in Java

Lect: 3. 3 pts. Professor Hershkop.

Prerequisite: COMS W1004 or knowledge of Java. Not intended for computer science majors. Data types and structures: arrays, stacks, singly and doubly linked lists, queues, trees, sets, and graphs. Programming techniques for processing such structures: sorting and searching, hashing, garbage collection. Storage management. Rudiments of the analysis of algorithms. Taught in Java. Note: Due to significant overlap, students may receive credit for only one of the following four courses: COMS W3133, W3134, W3137, or W3139.

COMS W3137x and y Data structures and algorithms

Lect: 3. 4 pts. x: Professor Allen; y: Instructor to be announced.

Prerequisite: COMS W1007. Corequisite: COMS W3203. Data types and structures: Arrays, stacks singly and doubly linked lists, queues, trees, sets, and graphs. Programming techniques for processing such structures: sorting and searching, hashing, garbage collection. Storage management. Design and analysis of algorithms. Taught in Java. Note: Due to significant overlap, students may receive credit for only one of the following four courses: COMS W3133, W3134, W3137, or W3139.

COMS W3139y Honors data structures and algorithms

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

Prerequisite: COMS 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 and y Advanced programming

Lect: 4. 4 pts. Professor Schulzrinne.

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 and 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 Papageorgiou.

Prerequisite: Two terms of calculus. Computational linear algebra, solution of linear systems, sparse linear systems, least squares, eigenvalue problems, and numerical solution of other multivariate problems as time permits.

COMS W3261x and y Computer science theory

Lect: 3. 3 pts. Professor Pasik.

Prerequisites: COMS W3137 and W3203. Regular languages: deterministic and nondeterministic, finite automata, regular expressions. Context-free languages: context-free grammars, push-down automata. Turing machines, the Chomsky hierarchy, and the Church-Turing thesis. Introduction to complexity theory and NP completeness.

CSEE W3827x and y Fundamentals of computer systems

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

Prerequisite: An introductory programming course. Fundamentals of computer organization and digi-

tal 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 and 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 and y Undergraduate projects in computer science

1 to 3 pts. Instructor to be announced.

Prerequisite: Approval by a faculty member who agrees to supervise the work. Consult the department for section assignment. Independent project involving laboratory work, computer programming, analytical investigation, or engineering design. May be repeated for credit, but not for a total of more than 3 points of degree credit.

ECBM E4060x Introduction to genomic information science and technology

Lect: 3. 3 pts. Professor Anastassiou.

Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function, and manipulation of the biomolecular sequences of nucleic acids and proteins. The role of enzymes and gene regulatory elements in natural biological functions as well as in biotechnology and genetic engineering. Recombination and other macromolecular processes viewed as mathematical operations with simulation and visualization using simple computer programming. This course shares lectures with ECBM E3060, but the work requirements differ somewhat.

COMS W4101x or y Topics in computer science technology

1.5 pts. Instructor to be announced.

Prerequisites: Fluency in at least one programming language and familiarity with computer systems. Introduction to current topics in computer science technology. Each section will be devoted to a specific technology. Sections may meet for

1.5 hours per week for the whole term or 3 hours per week for a half term. May be repeated for credit if different technologies are involved.

COMS W4111x and y Introduction to databases

Lect: 3. 3 pts. Professor Gravano.

Prerequisites: COMS W3137 or W3134, fluency in Java; or the instructor's permission. The fundamentals of database design and application development using databases: entity-relationship modeling, logical design of relational databases, relational data definition and manipulation languages, SQL, XML, query processing, physical database tuning, transaction processing, security. Programming projects are required.

COMS W4112y Database system implementation

Lect: 2.5. 3 pts. Professors Gravano or Ross

Prerequisites: COMS W4111; fluency in Java or C++. COMS W3827 is recommended. The principles and practice of building large-scale database management systems. Storage methods and indexing, query processing and optimization, materialized views, transaction processing and recovery, object-relational databases, parallel and distributed databases, performance considerations. Programming projects are required.

COMS W4115x and y Programming languages and translators

Lect: 3. 3 pts. x: Professor Edwards; y: Professor Aho.

Prerequisites: COMS W3137 or the equivalent, W3261, and 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. Instructor to be announced.

Prerequisite: COMS W4115 or the instructor's permission. Continuation of COMS W4115, with broader and deeper investigation into the design and implementation of contemporary language translators, be they compilers or interpreters. Topics include: parsing, semantic analysis, code generation and optimization, run-time environments, and compiler-compilers. A programming project is required.

COMS W4118x Operating systems, I

Lect: 3. 3 pts. Professor Keromytis.

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.

CSEE W4119x and y Computer networks

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

Corequisite: SIEO W3600 or W3658 or equivalent. Introduction to computer networks and the technical foundations of the Internet, including applications, protocols, local area networks, algorithms for routing and congestion control, security, elementary performance evaluation. Several programming assignments and a lab project may be required.

CSEE W4140x or y Networking laboratory

Lect: 3. 4 pts. Professor Stavrou.

Pre/corequisites: CSEE W4119 or equivalent coursework; students need one of the pre/corequisites or the instructor's permission. In this hands-on networking lab course, students will learn how to put "principles into practice." The course will cover the technologies and protocols of the Internet using equipment currently available to large Internet service providers such as CISCO routers and end systems. A set of laboratory experiments will provide hands-on experience with engineering wide-area networks and will familiarize students with the Internet Protocol (IP), Address Resolution Protocol (ARP), Internet Control Message Protocol (ICMP), User Datagram Protocol (UDP) and Transmission Control Protocol (TCP), the Domain Name System (DNS), routing protocols (RIP, OSPF, BGP), network management protocols (SNMP), and application-level protocols (FTP, TELNET, SMTP).

COMS W4156x or y Advanced software engineering

Lect: 3. 3 pts. Professor Kaiser.

Prerequisites: Any one or more of COMS W4111, W4115, W4118, or W4444. Assumes substantial prior software development experience in one or more of C++, Java, or C#, as well as basic familiarity with using SQL. Focuses primarily on component model frameworks (EJB, .NET/COM+, Web Services) and quality assurance (code inspection, unit and integration testing, stress testing). Introduction to UML. Surveys other software life-cycle topics as time permits. Centers on an intense semester-long multi-iteration team project building an N-tier application.

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 imple-

mentation is required: the final project involves writing an interactive 3D video game in OpenGL.

COMS W4162x or y Advanced computer graphics

Lect: 3. 3 pts. Professor 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. 3 pts. Professor Grinspun.

Prerequisites: COMS W3137 or W3139, and W4156 is recommended. Previous familiarity with C is recommended. Intensive introduction to computer animation, including fundamental theory and algorithms for computer animation, keyframing, kinematic rigging, simulation, dynamics, free-form animation, behavioral/procedural animation, particle systems, postproduction; small groups implement a significant animation project; advanced topics as time permits.

COMS W4170x User interface design

Lect: 3. 3 pts. Professor Feiner.

Prerequisite: COMS W3137. Introduction to the theory and practice of computer user interface design, emphasizing the software design of graphical user interfaces. Topics include basic interaction devices and techniques, human factors, interaction styles, dialogue design, and software infrastructure. Design and programming projects are required.

COMS W4172y 3D user interfaces and augmented reality

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 soft-

ware 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 Bellare.

Prerequisite: COMS W3137 or W3139, and W4119, or the instructor's permission.

Introduction to network security concepts and mechanisms; measures employed in countering such threats. Concepts and tools available in order to assume an appropriate security posture. Foundations of network security and an in-depth review of commonly used security mechanisms and techniques; security threats and network-based attacks, applications of cryptography, authentication, access control, intrusion detection and response, security protocols (IPsec, SSL, Kerberos), denial of service attacks and defenses, viruses and worms, software vulnerabilities, Web security, wireless security, and privacy.

COMS W4187x or y Security architecture and engineering

Lect: 3. 3 pts. Professor Bellare.

Prerequisites: COMS W4118; W4180 and/or W4119 recommended. Secure programming. Cryptographic engineering and key handling. Access controls. Tradeoffs in security design. Design for security.

COMS W4203y Graph theory

Lect: 3. 3 pts. Professor Gross.

Prerequisite: COMS W3203. General introduction to graph theory. Isomorphism testing, algebraic specification, symmetries, spanning trees, traversability, planarity, drawings on higher-order surfaces, colorings, extremal graphs, random graphs, graphical measurement, directed graphs, Burnside-Polya counting, voltage graph theory.

COMS W4205x Combinatorial theory

Lect: 3. 3 pts. Professor Gross.

Prerequisites: 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.

CSOR 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. Woźniakowski.

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.

ECS W4340x Computer hardware design

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

Prerequisites: ELEN E3331 and CSEE W3827. Practical aspects of computer hardware design

through the implementation, simulation, and prototyping of a PDP-8 processor. High-level and assembly languages, I/O, interrupts, datapath and control design, pipelining, busses, memory architecture. Programmable logic and hardware prototyping with FPGAs. Fundamentals of VHDL for register-transfer level design. Testing and validation of hardware. Hands-on use of industry CAD tools for simulation and synthesis. Lab required.

COMS W4444x Programming and problem solving
Lect: 3. 3 pts. Professor Ross.

Prerequisites: COMS W3137 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 W4560x Introduction to computer applications in health care and biomedicine
Lect: 3. 3 pts. Professor Chiang.

Prerequisites: Experience with computers and a passing familiarity with medicine and biology. Undergraduates in their senior or junior years may take this course only if they have adequate background in mathematics and receive permission from the instructor. An overview of the field of biomedical informatics, combining perspectives from medicine, computer science, and social science. Use of computers and information in health care and the biomedical sciences, covering specific applications and general methods, current issues, capabilities and limitations of biomedical informatics. Biomedical informatics studies the organization of medical information, the effective management of information using computer technology, and the impact of such technology on medical research, education, and patient care. The field explores techniques for assessing current information practices, determining the information needs of health care providers and patients, developing interventions using computer technology, and evaluating the impact of those interventions.

COMS W4701x or y Artificial intelligence

Lect: 3. 3 pts. x: Professor McKeown; y: Professor Stolfo.

Prerequisite: COMS W3137. 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, or W3137,

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, or W3137, 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. 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. Visual input as data and for control of computer systems. Survey and analysis of architecture, algorithms, and underlying assumptions of commercial and research systems that recognize and interpret human gestures, analyze imagery such as fingerprint or iris patterns, generate natural language descriptions of medical or map imagery. Explores foundations in human psychophysics, cognitive science, and artificial intelligence.

COMS W4737x or y Biometrics

Lect: 3. 3 pts. Professor Belhumeur.

Prerequisite: A background at the sophomore level in computer science, engineering, or like discipline. In this course we will explore the latest advances in biometrics as well as the machine learning techniques behind them. Students will learn how these technologies work and how they are sometimes defeated. Grading will be based on homework assignments and a final project. There will be no midterm or final exam. This course shares lectures with COMS E6737. Students taking COMS E6737 are required to complete additional homework problems and undertake a more rigorous final project. Students will only be allowed to earn credit for COMS W4737 or COMS E6737 and not both.

CBMF W4761x or y Computational genomics

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

Prerequisites: Either (1) ECBM E4060 or (2) COMS W1003, W1004, or W1007 and SIEO W4150, or SIEO W3600. Computational techniques for analyzing and understanding genomic data, including DNA, RNA, protein and gene expression data. Basic concepts in molecular biology relevant to these analyses. Emphasis on techniques from artificial intelligence and machine learning. String-matching algorithms, dynamic programming, hidden Markov models, expectation-maximization, neural networks, clustering algorithms, support vector machines. Students with life sciences backgrounds who satisfy the prerequisites are encouraged to enroll.

COMS W4771y Machine learning

Lect: 3. 3 pts. Professor Jebara.

Prerequisites: Any introductory course in linear algebra and any introductory course in statistics are both required. Highly recommended: COMS W4701 or knowledge of artificial intelligence. Topics from generative and discriminative machine learning including least squares methods, support vector machines, kernel methods, neural networks, Gaussian distributions, linear classification, linear regression, maximum likelihood, exponential family distributions, Bayesian networks, Bayesian inference, mixture models, the EM algorithm, graphical models, and hidden Markov models. Algorithms implemented in Matlab.

COMS W4772x Advanced machine learning

Lect: 3. 3 pts. Professor Jebara.

Prerequisites: COMS W4771 or the instructor's permission; knowledge of linear algebra and introductory probability or statistics is required. An exploration of advanced machine learning tools for perception and behavior learning. How can machines perceive, learn from, and classify human activity computationally? Topics include appearance-based models, principal and independent components analysis, dimensionality reduction, kernel methods, manifold learning, latent models, regression, classification, Bayesian methods, maximum entropy methods, real-time tracking, extended Kalman filters, time series prediction, hidden Markov models, factorial HMMs, input-output HMMs, Markov random fields, variational methods, dynamic Bayesian networks, and Gaussian/Dirichlet processes. Links to cognitive science.

CSEE W4823x or y Advanced logic design

Lect: 3. 3 pts. Professor Nowick.

Prerequisite: CSEE W3827 or a half-semester introduction to digital logic, or the equivalent. An introduction to modern digital system design. Advanced topics in digital logic: controller synthesis (Mealy and Moore machines); adders and multipliers; structured logic blocks (PLDs, PALs, ROMs); iterative circuits. Modern design methodology: register transfer level modelling (RTL); 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 multi-level NAND and NOR gate circuits. Clocking schemes for one- and two-phase systems. Fault checking: scan method, built-in test. Survey of logic simulation methods. Other topics to be added as appropriate.

CSEE W4840y Embedded systems

Lect: 3. 3 pts. Professor Edwards.

Prerequisite: CSEE W4823. Embedded system design and implementation combining hardware and software, I/O, interfacing, and peripherals. Weekly laboratory sessions and term project on design of a microprocessor-based embedded system including at least one custom peripheral. Knowledge of C programming and digital logic required. Lab required.

COMS W4901x and 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 W4910x Curricular practical training

1 pt. Instructor to be announced.

Prerequisite: Obtained internship and the faculty adviser's permission. Only for M.S. students in the Department of Computer Science who need relevant work experience as part of their program of study. Final report required. This course may not be taken for pass/fail credit or audited.

COMS W4955x or y Special topics in computer science, I

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

Prerequisite: The instructor's permission. Special topics arranged as the need and availability arises. Topics are usually offered on a one-time basis. Since the content of this course changes each time it is offered, it may be repeated for credit. Consult the department for section assignment.

COMS W4966x 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 Java or the instructor's permission. Continuation of COMS W4111, the course covers latest trends in both database research and industry: information retrieval, Web search, data mining, data warehousing, OLAP, decision support, multimedia databases, and XML and databases. Programming projects 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, distribu-

tion, 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 E6174y Interaction design: a perceptual approach

Lect: 3. 3 pts. Professor Paley.

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 interfaces components, screen layouts, and interaction techniques for application-specific systems.

COMS E6176x 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 multi-processor 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 E6183x Advanced topics in network security

Lect: 3. 3 pts. Professor Keromytis.

Prerequisites: COMS W4180, W4119, and W4261 recommended. Review the fundamental aspects of security, including authentication, authorization, access control, confidentiality, privacy, integrity, and availability. Review security techniques and tools, and their applications in various problem areas. Study the state of the art in research. A programming project is required.

COMS E6184y Seminar on anonymity and privacy

Lect: 3. 3 pts. Professor Bellare.

Prerequisite: COMS W4261 or W4180 or CSEE W4119 or the instructor's permission. This course

will cover the following topics: legal and social framework for privacy; data mining and databases; anonymous commerce and internet usage; traffic analysis; policy and national security considerations. Classes are seminars, with students presenting papers and discussing them. Seminar focus changes frequently to remain timely.

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 E6253y Advanced topics in computational learning theory

Lect: 3. 3 pts. Professor Servedio.

Prerequisites: COMS W4231 or equivalent; COMS W4252 or W4236 helpful but not required. In-depth study of inherent abilities and limitations of computationally efficient learning algorithms. Algorithms for learning rich Boolean function classes in online, Probably Approximately Correct, and exact learning models. Connections with computational complexity theory emphasized. Substantial course project or term paper required.

COMS E6261x or y Advanced cryptography

Lect: 3. 3 pts. Professor Malkin.

Prerequisite: COMS W4261. A study of advanced cryptographic research topics, such as secure computation, zero knowledge, privacy, anonymity, cryptographic protocols. Concentration on theoretical foundations, rigorous approach, and prov-

able security. Contents varies between offerings. May be repeated for credit.

COMS E6291x or y Theoretical topics in computer science

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

Prerequisite: The instructor's permission. Concentration on some theoretical aspect of computer science. Content varies from year to year. May be repeated for credit.

COMS E6732x or y Computational imaging

Lect: 3. 3 pts. Professor Nayar.

Prerequisite: COMS W4731 or the instructor's permission. Computational imaging uses a combination of novel imaging optics and a computational module to produce new forms of visual information. Survey of the state of the art in computational imaging. Review of recent papers on omnidirectional 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.).

CSEE E6734y Computational photography

Lect: 3. 3 pts. Professor Belhumeur.

Prerequisite: COMS W4160, W4731, or a working knowledge of photography are recommended. Students should have knowledge in any of three core areas: computer vision, computer graphics, or photography. Computational techniques are used to produce a new level of images and visual representations. Topics include HDR imaging, feature matching using RANSAC, image mosaics, image-based rendering, motion magnification, camera lens arrays, programmable lighting, face detection, single- and multiview geometry, and more.

COMS E6735y Visual databases

Lect: 3. 3 pts. Professor Kender.

Prerequisites: COMS W3133, W3134, or W3137 required; COMS W4731 or COMS W4735 helpful but not required. Contact instructor if uncertain.

The analysis and retrieval of large collections of image and video data, with emphasis on visual semantics, human psychology, and user interfaces. Low-level processing: features and similarity measures; shot detection; key frame selection; machine learning methods for classification. Middle-level processing: organizational rules for videos, including unedited (home, educational), semiedited (sports, talk shows), edited (news, drama); human memory limits; progressive refinement; visualization techniques; incorporation of audio and text. High-level processing: extraction of thematic structures; ontologies, semantic filters, and learning; personalization of summaries and interfaces; detection of pacing and emotions. Examples and demonstrations from commercial and research systems throughout. Substantial course project or term paper required.

COMS E6737x or y Biometrics

Lect: 3. 3 pts. Professor Belhumeur.

Prerequisites: A background at the sophomore level in computer science, engineering, or like discipline. In this course we will explore the latest advances in biometrics as well as the machine learning techniques behind them. Students will learn how these technologies work and how they are sometimes defeated. Grading will be based on homework assignments and a final project. There will be no midterm or final exam. This course shares lectures with COMS W4737. Students taking COMS E6737 are required to complete additional homework problems and undertake a more rigorous final project. Students will only be allowed to earn credit for COMS W4737 or COMS E6737 and not both.

CSEE E6824y Parallel computer architecture

Lect: 3. 3 pts. Professor Sethumadhavan.

Prerequisite: CSEE W8424. Parallel computer principles, machine organization, and design of parallel systems, including parallelism detection methods, synchronization, data coherence, and interconnection networks. Performance analysis and special-purpose parallel machines.

CSEE 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.

CSEE E6832x or y Topics in logic design theory

Lect: 3. 3 pts. Professors Theobald and Ivancic.

Prerequisite: CSEE W3827 or any introduction to logic circuits. A list of topics for each offering of the course is available in the department office one month before registration. May be taken more than once if topics are different. Iterative logic circuits applied to pattern recognition. Finite state machines; alternative representations,

information loss, linear circuits, structure theory. Reliability and testability of digital systems.

CSEE E6847y Distributed embedded systems

Lect: 2. 3 pts. Professor Carloni.

Prerequisite: Any course numbered in the COMS4110s, CSEE4800s, or ELEN4300s, or the instructor's permission. An interdisciplinary 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.

CSEE E6861y Computer-aided design of digital systems

Lect: 2. 3 pts. Professor Nowick.

Prerequisites: (1) One semester of advanced digital logic (CSEE W4823 or the equivalent, or the instructor's permission); (2) a basic course in data structures and algorithms (COMS W3133, W3134, W3137, W3139, or W3157, or the equivalent) and familiarity with programming. Introduction to modern digital CAD synthesis and optimization techniques. Topics include modern digital system design (high-level synthesis, register-transfer level modeling, algorithmic state machines, optimal scheduling algorithms, resource allocation and binding, retiming), controller synthesis and optimization, exact and heuristic two-level logic minimization, advanced multilevel logic optimization, optimal technology mapping to library cells (for delay, power, and area minimization), advanced data structures (binary decision diagrams), SAT solvers and their applications, static timing analysis, and introduction to testability. Includes hands-on small design projects using and creating CAD tools. General Education Requirement: Quantitative and Deductive Reasoning (QUA).

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 12 points have been completed. No more than 12 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.

Henry Krumb School of Mines
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www.eee.columbia.edu



OUR MISSION

Earth and Environmental Engineering at the Henry Krumb School of Mines fosters excellence in education and research for the development and application of science and technology to maximize the quality of life for all, through the sustainable use and responsible management of Earth's resources.



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EARTH RESOURCES AND THE ENVIRONMENT

The Earth and Environmental Engineering program fosters education and research in the development and application of technology for the sustainable development, use, and integrated management of Earth's resources. Resources are identified as minerals, energy, water, air, and land, as well as the physical, chemical, and biological components of the environment. There is close collaboration with other engineering disciplines, the Lamont-Doherty Earth Observatory, the International Research Institute for Climate Prediction, the Center for Environmental Research and Conservation, and other Columbia Earth Institute units.

THE HENRY KRUMB SCHOOL OF MINES AT COLUMBIA UNIVERSITY

The School of Mines of Columbia University was established in 1864 and was the first mining and metallurgy

department in the U.S. It became the foundation for Columbia's School of Engineering and Applied Sciences and has been a pioneer in many areas of mining and metallurgy, including the first mining (Peele) and mineral processing (Taggart) handbooks, flotation, chemical thermodynamics and kinetics, surface and colloid chemistry, and materials science.

Nearly one hundred years after its formation, the School of Mines was renamed Henry Krumb School of Mines (HKSM) in honor of the generous Columbia benefactor of the same name. The Henry Krumb School of Mines (SEAS) supports three components:

- The **Department of Earth and Environmental Engineering (EEE)**, one of the nine departments of SEAS.
- Columbia's interdepartmental program in **Materials Science and Engineering (MSE)**. This program, administered by the Department of Applied Physics and Applied Mathematics, is described in another section of this bulletin.

- **The Earth Engineering Center.** The current research areas include energy, materials, and water resources.

EARTH AND ENVIRONMENTAL ENGINEERING (EEE)

Starting in 1996, the educational programs of Columbia University in mining and mineral engineering were transformed into the present program in Earth and Environmental Engineering (EEE). This program is concerned with the environmentally sound extraction and processing of primary materials (minerals, fuels, water), the management and development of land and water resources, and the recycling or disposal of used materials. EEE offers the Bachelor of Science (B.S.) in Earth and Environmental Engineering, the Master of Science (M.S.) in Earth Resources Engineering, the professional degrees of Engineer of Mines and Metallurgical Engineer, and the doctorate degrees (Ph.D., Eng.Sc.D.) in EEE.

The EEE program welcomes Combined Plan students. An EEE minor is offered to all Columbia engineering students who want to enrich their academic record by concentrating some of their technical electives on Earth/environment subjects. There is close collaboration between EEE and the Departments of Civil Engineering and Earth and Environmental Sciences, including several joint appointments.

EEE and the Earth Engineering Center are the contributions of The Fu Foundation School of Engineering and Applied Science to The Earth Institute of Columbia University, a major education and research initiative of the University. The Department of Earth and Environmental Engineering combines the longstanding and proud tradition of Columbia's School of Mines with forward-thinking courses and programs, innovative research, and a deep concern for the environment.

RESEARCH CENTERS ASSOCIATED WITH EARTH AND ENVIRONMENTAL ENGINEERING

Columbia Water Center. The Columbia Water Center, in collaboration with other Earth Institute units and external partners, is leading intellectual inquiry into an assessment, prediction, and solution of the potentially global crisis of freshwater scarcity. Goals are to:

- develop multiscale predictive capabilities (e.g., new data sets and modeling tools) for local, regional, and global water resource assessment, recognizing

changing climate, demographic, and usage dynamics

- target analyses toward public and private investment in future water resource development, local and regional ecosystem services provided by water and the essential life-support water needs of societies
- identify and test appropriate technologies for the storage, treatment, and conveyance of water to improve reliable, cost-efficient access
- identify and compare locally appropriate policy instruments that facilitate the implementation of selected incentives for higher-value, higher-efficiency water use, while promoting equity of use and life support functions
- test and demonstrate the applicability of the policy and technology developments in real-world settings, working with local institutions and private-sector developers or users in an open and public process
- develop and disseminate the knowledge base that results from our activities to support global water resource development and decision making, including the development of a forum, the Global Roundtable on Water (GROW), to facilitate international policy and technical action to improve our collective water future.

For more information: www.water.columbia.edu

Center for Life Cycle Analysis (LCA).

The Center for Life Cycle Analysis of Columbia University was formed in the spring of 2006 with the objective of conducting comprehensive life cycle analy-

ses of energy systems. LCA provides a framework for quantifying the potential environmental impacts of material and energy inputs and outputs of a process or product from "cradle to grave." The mission of the Center is to guide technology and energy policy decisions with data-based, well-balanced, and transparent descriptions of the environmental profiles of energy systems. For more information: www.seas.columbia.edu/clca

Center for Sustainable Use of Resources (SUR).

The Center for Sustainable Use of Resources builds on the strengths of past research at Columbia and North Carolina State on recycling, composting, waste-to-energy, and landfill engineering. Also, the Center will clearly define the impacts of all solid waste technologies and practices with regard to greenhouse gas emissions and will, on a case-by-case basis, establish and validate protocols that account for greenhouse gas emissions and savings that may be easily replicated and readily accepted. SUR will also identify technologies that can replace some virgin feedstock with appropriate local waste streams. Through its publications, meetings, and Web page, SUR will disseminate information on the best waste management technologies and methods that, on a life-cycle basis, will result in reducing the impacts of waste management on global climate change. An equally important objective of the Center is to provide graduate-level training, at the participating universities, in the ways and means of sustainable resource utilization to engineers and scientists from the U.S. and

around the world, in particular from the developing world, where the need for modern management of wastes is most acute. The Earth Engineering Center, in collaboration with the Department of Earth and Environmental Engineering, has already been engaged in this role, and some of our alumni are working in various parts of the waste management industry. There have been more than twenty theses written on various aspects of waste management, including in-depth studies of implementing advanced processes and methodologies in Chile, China, Greece, and India. For more information: www.surcenter.org

Earth Engineering Center. The mission of the Earth Engineering Center is to develop and promote engineering methodologies that provide essential material to humanity in ways that maintain the overall balance between the constantly increasing demand for materials, the finite resources of the Earth, and the need for clean water, soil, and air. The Center is dedicated to the advancement of industrial ecology, i.e., the reconfiguring of industrial activities and products with full knowledge of the environmental consequences. Research is being conducted on a variety of geoenvironmental issues with the intent to quantify, assess, and ultimately manage adverse human effects on the environment. Research areas include management of water and energy resources, hydrology and hydrogeology, numerical modeling of estuarine flow and transport processes, and integrated waste management. For more information: www.columbia.edu/cu/earth

Environmental Tracer Group. The Environmental Tracer Group uses natural and anthropogenic (frequently transient) tracers, as well as deliberately released tracers, to investigate the physics and chemistry of transport in environmental systems. The tracers include natural or anthropogenically produced isotopes (e.g., tritium or radioactive hydrogen, helium and oxygen isotopes, or radiocarbon), as well as noble gases and chemical compounds (e.g., CFCs and SF₆). The ETG analytical facilities include four mass spectrometric systems that can be used in the analysis of tritium and noble gases in water, sediments, and rocks. In addition to the mass spectrometric

systems, there are several gas chromatographic systems equipped with electron capture detectors that are used for measurements of SF₆ in continental waters and CFCs and SF₆ in the atmosphere. GC/MS capability is being added to the spectrum of analytical capabilities. For more information: www.ideo.columbia.edu/~nobleagas

Industry/University Cooperative Research Center for Advanced Studies in Novel Surfactants (IUCS).

IUCS was established in 1998 by the Henry Krumb School of Mines, Department of Chemical Engineering, and Department of Chemistry at Columbia University. The Center encompasses detailed structure-property assessment of several classes of surface-active molecules, including oligomeric, polymeric, and bio-molecules. The aim of IUCS is to develop and characterize novel surfactants for industrial applications such as coatings, dispersions, deposition, gas hydrate control, personal care products, soil decontamination, waste treatment, corrosion prevention, flotation, and controlled chemical reactions. The proposed research thus focuses on the design and development of specialty surfactants, characterization of their solution and interfacial behavior, and identification of suitable industrial applications for these materials.

The goals of IUCS are to perform industrially relevant research to address the technological needs in commercial surfactant and polymer systems; develop new and more efficient surface-active reagents for specific applications in the industry and methodologies for optimizing their performance; promote the use of environmentally benign surfactants in a wide array of technological processes; and build a resource center to perform and provide state-of-the-art facilities for characterization of surface-active reagents. For more information: www.columbia.edu/cu/iucrc

International Research Institute for Climate Prediction (IRI).

The IRI 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. For more information: iri.columbia.edu

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, biocolloids, microbial surfaces, and interfacial spectroscopy.

Lenfest Center for Sustainable Energy.

The mission of the Lenfest Center for Sustainable Energy is to develop technologies and institutions to ensure a sufficient supply of environmentally sustainable energy for all humanity. To meet this goal, the Center supports research programs in energy science, engineering, and policy across Columbia University to develop technical and policy solutions that will satisfy the world's future energy needs without threatening to destabilize the Earth's natural systems.

The mission of the Lenfest Center is shaped by two global challenges. First, the Center seeks to reduce the emission of carbon dioxide into the atmosphere and to forestall a disruption of global climate systems that would impose negative consequences for human welfare. Second, the Center seeks to create energy options that will meet the legitimate energy demands of a larger and increasingly wealthy world population. In order to meet these two challenges, the

Center seeks to develop new sources, technologies, and infrastructures.

The Lenfest Center focuses primarily on the technological and institutional development of the three energy resources sufficient to support the world's projected population in 2100 without increased carbon emissions: solar, nuclear, and fossil fuels combined with carbon capture and storage. Although each of these options can, in theory, be developed on a scale to satisfy global demand, they each face a combination of technological and institutional obstacles that demand research and development before they can be deployed.

The Center's main activities are based within the range of natural science and engineering disciplines. At the same time, it integrates technological research with analysis of the institutional, economic, and political context within which energy technologies are commercialized and deployed. For more information: www.energy.columbia.edu

Waste to Energy Research and Technology Council (WTERT). The Waste to Energy Research and Technology Council brings together engineers, scientists, and managers from industry, universities, and government with the objective of advancing the goals of sustainable waste management globally. The mission of WTERT is to identify the best available technologies for the treatment of various waste materials, conduct additional academic research as required, and disseminate this information by means of its publications, the WTERT Web, and annual meetings. In particular, WTERT strives to increase the global recovery of energy and materials from used solids and to advance the economic and environmental performance of waste-to-energy (WTE) technologies in the U.S. and worldwide. The guiding principle is that responsible management of wastes must be based on science and the best available technology and not what seems to be inexpensive now but can be very costly in the near future. For more information: www.seas.columbia.edu/earth/wtert

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. Graduates equipped with the necessary tools (mathematics, chemistry, physics, Earth sciences, and engineering science) will understand and implement the underlying principles used in the engineering of processes and systems.

2. Graduates will be able to pursue careers in industry, government agencies, and other organizations concerned with the environment and the provision of primary and secondary materials and energy, as well as continue their education as graduate students in related disciplines.
3. Graduates will possess the basic skills needed for the practice of Earth and environmental engineering, including measurement and control of material flows through the environment; assessment of environmental impact of past, present, and future industrial activities; and analysis and design of processes for remediation, recycling, and disposal of used materials.
4. Graduates will practice their profession with excellent written and communication skills and with professional ethics and responsibilities.

The Curriculum

The first two years of the EEE program are similar to those of other engineering programs. Students are provided with a strong foundation in basic sciences and mathematics, as well as the liberal arts core. Specific to the EEE program is an early and sustained introduction to Earth science and environmental engineering, and options for a number of science courses to meet the specific interests of each student. The junior and senior years of the program consist of a group of required courses in engineering science and a broad selection of technical electives organized into three distinct concentrations, representing major areas of focus within the department.

Several Columbia departments, such as Civil Engineering, Mechanical Engineering, and Earth and Environmental Sciences (Lamont-Doherty Earth Observatory), as well as the Mailman School of Public Health, contribute courses to the EEE program. EEE students are strongly encouraged to work as summer interns in industry or agencies on projects related to Earth and environmental engineering. The department helps students get summer internships.

Technical Elective Concentrations

Students majoring in Earth and environmental engineering select one of the

following three preapproved technical elective concentrations. Note that the eight-course sequence for each preapproved concentration includes two science courses during sophomore year (fall semester) and six technical elective courses during junior and senior years.

Any deviations from a preapproved concentration must be approved by an undergraduate faculty adviser. Alternatives for junior/senior electives within each concentration are listed, and others may be considered among 3000- to 4000-level courses of any SEAS department, as well as courses listed in the section "Courses in Other Divisions" in this bulletin. However, at least four of the six junior/senior electives must consist of engineering topics. Alternatives for sophomore-year science courses are shown in the EEE course table.

A student may also choose to develop an individual concentration conforming to his/her specific interests, provided that it satisfies ABET engineering accreditation criteria. Therefore, this must be developed in close consultation with and approved by a faculty adviser.

Water Resources and Climate Risks Concentration

Preapproved course sequence:

- PHYS C1403:** Introduction to classical and quantum waves (SEM III)
EESC V2100: Climate system (SEM III)
EAEE E4006: Field methods for environmental engineering (SEM VI)
EAEE E4009: GIS for resource, environmental, and infrastructure management (SEM VII)
EAEE E4350: Planning and management of urban hydrologic systems (SEM VII)
EAEE E4257: Environmental data analysis and modeling (SEM VIII)
ECIA W4100: Management and development of water systems (SEM VIII)
CIEE E4257: Contaminant transport in subsurface systems (SEM VIII)

Alternatives for junior/senior electives:

- EAEE E4001:** Industrial ecology of Earth resources
CIEE E4260: Urban ecology studio
CIEE E4163: Environmental engineering: wastewater
CIEN E4250: Waste containment design and practice
CIEN E4255: Flow in porous media
APPH E4200: Physics of fluids
EESC W4008: Introduction to atmospheric science
EESC W4401: Quantitative models of climate-sensitive natural and human systems

EESC W4404: Regional dynamics, climate and climate impacts

Sustainable Energy and Materials Concentration

Preapproved course sequence:

- CHEM C3443:** Organic chemistry (SEM III)
EESC V2200: Solid earth system (SEM III)
MECE E3311: Heat transfer (SEM VI)
EAEE E4001: Industrial ecology of Earth resources (SEM VII)
EAEE E4900: Applied transport and chemical rate phenomena (SEM VII)
MECE E4302: Advanced thermodynamics (SEM VIII)
EESC W3015: The Earth's carbon cycle (SEM VIII)
MECE E4211: Energy: sources and conversion (SEM VIII)

Alternatives for junior/senior electives:

- CHEN E3110:** Transport phenomena I
CHEN E3120: Transport phenomena II
EAEE E3101: Earth resource production systems
MSAE E3103: Elements of materials science
CHEM C3071: Introduction to organic chemistry
CHEM G4230: Statistical thermodynamics
EAEE E4550: Catalysis for emissions control
EESC W4008: Introduction to atmospheric science
EAEE E4560: Particle technology

Environmental Health Engineering Concentration

Preapproved course sequence:

- CHEM C3443:** Organic chemistry (SEM III)
EESC V2100: Climate system (SEM III)
EAEE E4006: Field methods for environmental engineering (SEM VI)
EAEE E4009: GIS for resource, environmental and infrastructure management (SEM VII)
EHSC P6300: Environmental health sciences (SEM VII)
EAEE E4257: Environmental data analysis and modeling (SEM VIII)
EAEE E4150: Air pollution prevention and control (SEM VIII)
EHSC P6309: Biochemistry basic to environmental health (SEM VIII)

Alternatives for junior/senior electives:

- EAEE E4001:** Industrial ecology of Earth resources
EAEE E4900: Applied transport and chemical rate phenomena
EAEE E4950: Environmental biochemical processes
CIEE E4257: Contaminant transport in subsurface systems

GRADUATE PROGRAMS

M.S. in Earth Resources Engineering (MS-ERE)

The MS-ERE program is designed for engineers and scientists who plan to pursue, or are already engaged in, envi-

ronmental management/development careers. The focus of the program is the environmentally sound mining and processing of primary materials (minerals, energy, and water) and the recycling or proper disposal of used materials. The program also includes technologies for assessment and remediation of past damage to the environment. Students can choose a pace that allows them to complete the MS-ERE requirements while being employed.

MS-ERE graduates are specially qualified to work for engineering, financial, and operating companies engaged in mineral processing ventures, the environmental industry, environmental groups in all industries, and for city, state, and federal agencies responsible for the environment and energy/resource conservation. At the present time, the U.S. environmental industry comprises nearly 30,000 big and small businesses with total revenues of over \$150 billion. Sustainable development and environmental quality has become a top priority of government and industry in the United States and many other nations.

This M.S. program is offered in collaboration with the Departments of Civil Engineering and Earth and Environmental Sciences. Many of the teaching faculty are affiliated with Columbia's Earth Engineering Center.

For students with a B.S. in engineering, at least 30 points (ten courses) are required. For students with a nonengineering B.S. or a B.A., preferably with a science major, up to 48 points (total of sixteen courses) may be required for makeup courses. All students are required to carry out a research project and write a thesis worth 3–6 points. A number of areas of study are available for the MS-ERE, and students may choose courses that match their interest and career plans. The areas of study include:

- alternative energy and carbon management
- climate risk assessment and management
- environmental health engineering
- integrated waste management
- natural and mineral resource development and management
- novel technologies: surficial and 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 cogeneration, district heating, and distributed generation of energy. Classes will discuss technologies for efficiency improvement in the generation and consumption sector; energy recovery from solid wastes; alternatives to fossil fuels, including solar and wind energy, and nuclear fission and fusion; and technologies for addressing the environmental concerns over the use of fossil fuels and nuclear energy. Classes on climate change, air quality, and health impacts focus on the consequences of energy use. Policy and its interactions with environmental sciences and energy engineering will be another aspect of the concentration. Additional specialization may consider region specific energy development.

Integrated Waste Management (IWM)

Humanity generates nearly 2 billion tons of municipal solid wastes (MSW) annually. Traditionally, these wastes have been discarded in landfills that have a finite

lifetime and then must be replaced by converting more greenfields to landfills. This method is not sustainable because it wastes land and valuable resources. Also, it is a major source of greenhouse gases and of various 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.

EARTH AND ENVIRONMENTAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3) or Honors Math I (4)	MATH V1102 (3) Honors Math II (4)	MATH V1201 (3)	APMA E2101 (3) MATH E1210 (3) ODE
PHYSICS	C1401 (3) or C1601 (3.5) or C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	CHEM C3443 (3.5) or PHYS C1403 (3) or PHYS C2601 (3.5) or BIOL C2005 (4)	
CHEMISTRY	C1403 (3.5) and Lab C1500 (3) either semester or C1604 (3.5) or C3045 (3.5)	C1404 (3.5) C2507 (3) C3046 (3.5) and Lab C2507 (3)		
REQUIRED NONTECHNICAL ELECTIVES	C1010 (3) or Z1003 (4) or ALP0006 (0)	C1010 (3) Z1003 (4)	HUMA C1001, COCI C1101, or Global Core (3-4) or C1010 (3)	HUMA C1002, COCI C1102, or Global Core (3-4) ECON W1105 (4) and W1155 recitation (0) HUMA C1121 or C1123 (3)
	REQUIRED PROFESSIONAL AND TECHNICAL ELECTIVES	EAAE E1100 (3) A better planet by design or other departmental professional-level course	EESC W4001 (4) or EESC V2100 (4.5) or EESC V2200 (4.5) EAAE E2002 (3) Alternative energy sources	
COMPUTER SCIENCE	Computer language: COMS W1003 (3) or W1004 (3) any semester			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

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

EARTH AND ENVIRONMENTAL ENGINEERING PROGRAM: THIRD AND FOURTH YEARS

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES	EAAE E3103 (3) Energy, minerals, and material systems	CIEE E3255 (3) Environmental control and pollution reduction systems	EAAE E3998 (2) Undergraduate design project	EAAE E3999 (2) Undergraduate design project
	CIEE E4252 (3) Environmental engineering	CIEE E3250 (3) Hydrosystems engineering	EAAE E4003 (3) Aquatic chemistry	EAAE E4160 (3) Solid and hazardous waste management
	ENME E3161 (4) Fluid mechanics or MECE E3100 (3) Introduction to mechanics of fluids	SIEO W3600 (4) Introduction to probability and statistics	EAAE E3801 (2) Earth and environmental engineering lab, II	
	CHEE E3010 (4) Principles of chemical engineering thermodynamics or MSAE E3111 (3) Thermodynamics, kinetic theory, and statistical mechanics or MECE E3301 (3) Thermodynamics	EAAE E3800 (2) Earth and environmental engineering lab, I EAAE E3901 (3) Environmental microbiology		
TECHNICAL ELECTIVES		3 points	6 points	9 points
NONTECHNICAL ELECTIVES	3 points		3 points	3 points
TOTAL POINTS	15–17	18	16	17

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 Tuncel Yegulalp at 212-854-2984 or by e-mail to yegulalp@columbia.edu.

Doctoral Programs

EEE offers two doctoral degrees:

(1) the Eng.Sc.D. degree, administered by The Fu Foundation School of Engineering and Applied Science; and (2) the Ph.D. degree, administered by the Graduate School of Arts and Sciences. Qualifying examinations and

all other intellectual and performance requirements for these degrees are the same. All applicants should use the School of Engineering forms. The scope includes the design and use of sensors for measurement at molecular scale; the understanding of surface, colloid, aqueous, and high-temperature phenomena; the integrated management of multiple resources and the mitigation of natural and environmental hazards, at regional to global scales. The management of the interaction between human activities, Earth resources, and ecosystems is of primary interest.

The engineering objectives of EEE research and education include:

- **provision and disposal of materials:** environmentally sustainable extraction and processing of primary materials; manufacturing of derivative products;

recycling of used materials; management of industrial residues and used products; materials-related application of industrial ecology.

- **management of water resources:** understanding, prediction, and management of the processes that govern the quantity and quality of water resources, including the role of climate; development/operation of water resource facilities; management of water-related hazards.
- **energy resources and carbon management:** mitigation of environmental impacts of energy production; energy recovery from waste materials; advancement of energy efficient systems; new energy sources; development of carbon sequestration strategies.
- **sensing and remediation:** understanding of transport processes at

different scales and in different media; containment systems; modeling flow and transport in surface and subsurface systems; soil/water decontamination and bioremediation.

The Professional Degrees

The department offers the professional degrees of Engineer of Mines (E.M.) and Metallurgical Engineer (Met.E.). In order to gain admission to both degree programs, students must have an undergraduate degree in engineering and complete at least 30 credits of graduate work beyond the M.S. degree, or 60 credits of graduate work beyond the B.S. degree. These programs are planned for engineers who wish to do advanced work beyond the level of the M.S. degree but who do not desire to emphasize research.

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

EAEE E1100y A better planet by design

Lect.: 3. 3 pts. Professors Lall and Park.

Development of the infrastructure for providing safe and reliable resources (energy, water, and other materials, transportation services) to support human societies while attaining environmental objectives. Introduction of a typology of problems by context and common frameworks for addressing them through the application of appropriate technology and policy. An interdisciplinary perspective that focuses on the interaction between human and natural systems is provided. Alternatives for resource provision and forecasts of their potential environmental impacts through a context provided by real world applications and problems.

EAEE E2002x Alternative energy resources

Lect: 3. 3 pts. Professors Walker and Lackner. Unconventional, alternative energy resources. Technological options and their role in the world energy markets. Comparison of conventional and unconventional, renewable and nonrenewable energy resources and analysis of the consequences of various technological choices and constraints. Economic considerations, energy availability, and the environmental consequences of large-scale, widespread use of each particular technology. Introduction to carbon dioxide capture and carbon dioxide disposal as a means of sustaining the fossil fuel option.

EAEE 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.

EAEE E3103x Energy, minerals and materials systems

Lect: 3.3 pts. Professors Lackner and Yegulalp. Prerequisite: MSAE E3111 or MECE E3301 and ENME E3161 or MECE E3100 or the equivalent. Overview of energy resources, resource management from extraction and processing to recycling and final disposal of wastes. Resource availability and resource processing in the context of the global natural and anthropogenic material cycles; thermodynamic and chemical conditions including nonequilibrium effects that shape the resource base; extractive technologies and their impact on the environment and the biogeochemical cycles; chemical extraction from mineral ores, and 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.

EAEE E3112y Introduction to rock mechanics

Lect: 3. 3 pts. Not given in 2009–2010.

Prerequisites: EAEE E3101 and ENME E3111, or their equivalents. Rock as an engineering material, geometry and strength of rock joints, geotechnical classification of rock masses, strength and failure of rock, field investigations prior to excavation in rock, rock reinforcement, analysis and support of rock slopes and tunnels, and case histories.

MSAE E3141y Processing of metals and semiconductors

Lect: 3. 3 pts. Professor Duby.

Prerequisites: MSAE E3103 or equivalent. Synthesis and production of metals and semiconductors with engineered microstructures for desired properties. Includes high-temperature, aqueous, and electrochemical processing; thermal and mechanical processing of metals and alloys; casting and solidification; diffusion, microstructural evolution, and phase transformations; modification and processing of surfaces and interfaces; deposition and removal of thin films. Processing of Si and other materials for elemental and compound semiconductor-based electronic, magnetic, and optical devices.

EAEE E3185y Summer fieldwork for Earth and environmental engineers

0.5 pts. Instructor to be announced.

Undergraduates in Earth and environmental engineering may spend up to 3 weeks in the field under staff direction. The course consists of mine, landfill, plant, and major excavation site visits and brief instruction of surveying methods. A final report is required.

EAEE E3221x Environmental geophysics

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

Introduction to applied and environmental geophysics methods. Overview of principles of geophysics, geophysical methods and techniques (seismic, ground penetrating radar, resistivity, frequency em, and magnetics), and theory and practical aspects of data processing and inversion. Examination of geophysical case studies for engineering and environmental purposes.

CIEE E3250x 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 E3800y Earth and environmental engineering laboratory, I

Lect: 1. Lab: 3. 2 pts. Professors Duby, Chandran, and Castaldi.

Prerequisite: CHEE E3010. Corequisite: EAAE E3255. Experiments on fundamental aspects of Earth and environmental engineering with emphasis on the applications of chemistry, biology, and thermodynamics to environmental processes: energy generation, analysis and purification of water, environmental biology, and biochemical treatment of wastes. Students will learn the laboratory procedures and use analytical equipment firsthand, hence demonstrating experimentally the theoretical concepts learned in class.

EAAE E3801x Earth and environmental engineering laboratory, II

Lect: 1. Lab: 3. 2 pts. Professors Duby, Chandran, and Castaldi.

Prerequisite: EAAE E3800. Corequisite: EAAE E4003. A continuation of EAAE E3800, with emphasis on the principles underlying water analysis for inorganic, organic, and bacterial contaminants.

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

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 E3901y Environmental microbiology

Lect: 3. 3 pts. Professor Chandran.

Prerequisite: CHEM C1404 or the equivalent. Fundamentals of microbiology, genetics and molecular biology, principles of microbial nutrition, energetics and kinetics, application of novel and state-of-the-art techniques in monitoring the structure and function of microbial communities in the environment, engineered processes for biochemical waste treatment and bioremediation, microorganisms and public health, global microbial elemental cycles.

EAAE E3998x-E3999y Undergraduate design project

Lect: 1. Lab: 2. 2 pts (each semester). The staff.

Prerequisite: Senior standing. Students must enroll for both E3998x and E3999y during their senior year. Selection of an actual problem in Earth and environmental engineering, and design of an engineering solution including technical, economic, environmental, ethical, health and safety, and social issues. Use of software for design, visualization, economic analysis, and report preparation. Students may work in teams. Presentation of results in a formal report and public presentation.

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. Instructor to be announced.

Industrial ecology examines how to reconfigure industrial activities so as to minimize the adverse environmental and material resource effects on the planet. Engineering applications of methodology of industrial ecology in the analysis of current processes and products and the selection or design of environmentally superior alternatives. Home assignments of illustrative quantitative problems.

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 2009–2010.

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 2009–2010.

Geophysical methods as applicable to engineering problems. Principles of geophysics and noninvasive imaging techniques (inversion technology) and benefits and pitfalls of geophysics vs. direct imaging methods. Discussion of theory of each method. Discussion of data acquisition, processing and interpretation for each method. Treatment of several case studies. Class-wide planning and execution of small-scale geophysical survey.

EAAE E4006y Field methods for environmental engineering

Lect: 1.5. Lab: 2. 3 pts. Professor McGillis.

Principles and methods for designing, building, and testing systems to sense the environment. Monitoring the atmosphere, water bodies and boundary interfaces between the two. Sensor systems for monitoring heat and mass flows, chemicals, and biota. Measurements of velocity, temperature, flux and concentration in the field. The class will involve planning and execution of a study to sense a local environmental system.

EAAE E4007y Environmental geophysics field studies

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

Application of geophysical methods to noninvasive assessment of the near surface. First part consists of series of two-hour lectures of physics and math involved in instrumental methods and data acquisition and processing. In the field (nine field days) students plan surveys; collect and analyze geophysical data in teams; learn how to integrate geophysical data with invasive data, hydrological, geological, engineering, and contaminant transport models; and develop a comprehensive and justifiable model of the subsurface. Geophysical methods include GPR (Ground Penetrating Radar), conductivity, and magnetic and seismic methods. Field applications include infrastructure/environmental assessment, archeological studies, and high resolution geology.

EAAE E4009x Geographic information systems (GIS) for resource, environmental, and infrastructure management

Lect: 3. 3 pts. Professor Gorokhovich.

Prerequisite: The instructor's permission. Basic concepts of geomatics, spatial data representation and organization, and analytical tools that comprise GIS are introduced and applied to a variety of problems including watershed protection, environmental risk assessment, material mass balance, flooding, asset management, and emergency response to natural or man-made hazards. Technical content includes geography and map projections, spatial statistics, database design and use, interpolation and visualization of spatial surfaces and volumes from irregularly spaced data, and decision analysis in an applied setting. Taught in a laboratory setting using ArcGIS. Access to New York City and other standard databases. Term projects emphasize information synthesis toward the solution of a specific problem.

EAAE E4011y Industrial ecology for manufacturing

Lect: 3. 3 pts. Not given in 2009–2010.

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 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.

CIEE E4163x Environmental engineering: wastewater

Lect: 3. 3 pts. Professor Becker.

Prerequisites: Introductory chemistry (with lab) and fluid mechanics. Fundamentals of water pollution and wastewater characteristics. Chemistry, microbiology, and reaction kinetics. Design of primary, secondary, and advanced treatment systems. Small community and residential systems.

EAAE E4190x Photovoltaic systems engineering and sustainability

Lect: 3. 3 pts. Professor Fthenakis.

Prerequisite: Senior Standing or the instructor's permission. A systems approach for intermittent renewable energy involving the study of resources, generation, demand, storage, transmission, economics, and politics. Study of current and emerging photovoltaic technologies, with focus on basic sustainability metrics (e.g., cost, resource availability, and life-cycle environmental impacts). The status and potential of first- and second-generation photovoltaic technologies (e.g., crystalline and amorphous Si, CdTe, CIGS) and emerging third-generation ones. Storage options to overcome the intermittency constraint. Large scales of renewable energy technologies and plug-in hybrid electric cars.

EAAE E4200y Production of inorganic materials

Lect: 3. 3 pts. Professor Duby.

Prerequisite: CHEN E3010 or the equivalent. Production and recycling of inorganic materials in aqueous and high-temperature systems. Industrial and environmental applications of hydrometallurgy, pyrometallurgy, and electrometallurgy. Reactor systems for, e.g., leaching, precipitation, and solvent extraction, bath and flash smelting reactors, rotary kilns, and fluid bed reactors. Thermodynamic and kinetic factors and material/energy balances involved in the design and performance of such reactors in typical applications.

EAAE E4241x Solids handling and transport systems

Lect: 3. 3 pts. Not given in 2009–2010.

Analysis and design of transportation systems for

bulk solids in tunnels, mines, and large excavations. Design of hoisting, cable transport, rail and trackless haulage systems, conveyor belts, selection of loaders, excavators, off-highway trucks, and draglines for large excavations.

CHEE E4252x Introduction to surface and colloid chemistry

Lect: 3. 3 pts. Professor Somasundaran.

Prerequisite: Elementary physical chemistry. Thermodynamics of surfaces, properties of surfactant solutions and surface films, electrostatic and electrokinetic phenomena at interfaces, adsorption; interfacial mass transfer and modern experimental techniques.

CIEE E4252y Environmental engineering

Lect: 3. 3 pts. Professor Gong.

Prerequisites: CHEM C1403, or the equivalent; ENME E3161 or the equivalent. Engineering aspects of problems involving human interaction with the natural environment. Review of fundamental principles that underlie the discipline of environmental engineering, i.e., constituent transport and transformation processes in environmental media such as water, air, and ecosystems. Engineering applications for addressing environmental problems such as water quality and treatment, air pollution emissions, and hazardous waste remediation. Presented in the context of current issues facing the practicing engineers and government agencies, including legal and regulatory framework, environmental impact assessments, and natural resource management.

CIEE E4257y Groundwater contaminant transport and remediation

Lect: 3. 3 pts. Professor Mutch.

Prerequisite: CIEE E3250 or the equivalent. Single- and multiple-phase transport in porous media; contaminant transport in variably saturated heterogeneous geologic media; physically based numerical models of such processes.

EAAE E4257y (section 001) Environmental data analysis and modeling

Lect: 3. 3 pts. Professors Yegulalp, Lall, and Gorokhovich.

Prerequisite: SIEO W3600 or SIEO W4250, or the equivalent. Statistical methods for the analysis of the space and time structure in environmental data. Application to problems of climate variation and change; hydrology; air, water, and soil pollution dynamics; disease propagation; ecological change; and resource assessment. Applications are developed using the ArcView Geographical Information System (GIS), integrated with currently available statistical packages. Team projects that lead to publication-quality analyses of data in various environmental fields of interest. An interdisciplinary perspective is emphasized in this applications-oriented class.

EAAE E4350x Planning and management of urban hydrologic systems

Lect: 3. 3 pts. Professor Rangarajan.

Prerequisite: ENME E3161 or the equivalent. Introduction to runoff and drainage systems in an urban setting, including hydrologic and hydraulic analyses, flow and water quality monitoring, common regulatory issues, and mathematical modeling. Applications to problems of climate variation, land use changes, infrastructure operation and receiving water quality, developed using statistical packages, public-domain models, and Geographical Information Systems (GIS). Team projects that can lead to publication of quality analyses in relevant fields of interest. Emphasis on the unique technical, regulatory, fiscal, policy, and other interdisciplinary issues that pose a challenge to effective planning and management of urban hydrologic systems.

EAAE E4361y Economics of Earth resource industries

Lect: 3. 3 pts. Professor Yegulalp.

Prerequisite: EAAE E3101 or the instructor's permission. Definition of terms. Survey of Earth resource industries: resources, reserves, production, global trade, consumption of mineral commodities and fuels. Economics of recycling and substitution. Methods of project evaluation: estimation of operating costs and capital requirements, project feasibility, risk assessment, and environmental compliance. Cost estimation for reclamation/remediation projects. Financing of reclamation costs at abandoned minesites and waste-disposal postclosure liability.

CHEE E4530y Corrosion of metals

Lect: 3. 3 pts. Professor Duby.

Prerequisite: CHEN E3010 or the equivalent.

The theory of electrochemical corrosion, corrosion tendency, rates, and passivity. Application to various environments. Cathodic protection and coatings. Corrosion testing.

EAAE E4550x Catalysis for emissions control

Lect: 3. 3 pts. Professors Castaldi and Farrauto.

Prerequisites: ENME E3161 and MSAE E3111 or the equivalent. Fundamentals of heterogeneous catalysis, including modern catalytic preparation techniques. Analysis and design of catalytic emissions control systems. Introduction to current industrial catalytic solutions for controlling gaseous emissions. Introduction to future catalytically enabled control technologies.

EACE E4560x Particle technology (section 1)

Lect: 3. 3 pts. Professor Park.

Prerequisites: ENME E3161 and MSAE E3111 or the equivalent. Introduction to engineering processes involving particulates and powders. The fundamentals of particle characterization, multiphase flow behavior, particle formation, processing and utilization of particles in various engineering applications with examples in energy and environment related technologies. Engineering of functionalized particles and design of multiphase reactors and processing units with emphasis on fluidization technology. Particle technology is an interdisciplinary field. Due to the complexity of

particulate systems, particle technology is often treated as art rather than science. In this course, the fundamental principles governing the key aspects of particle science and technology will be introduced, along with various industrial examples.

EAAE 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. Professor Chandran.

Basic microbiological principles; microbial metabolism; identification and interactions of microbial populations responsible for the biotransformation of pollutants; mathematical modeling of microbially mediated processes; biotechnology and engineering applications using microbial systems for pollution control.

EAAE E4950x Environmental biochemical processes

Lect: 3. 3 pts. Professor Chandran.

Prerequisites: EAAE E4901 or CIEE E4252 or EAAE E4003 or the instructor's approval. Qualitative and quantitative considerations in engineered environmental biochemical processes. Characterization of multiple microbial reactions in a community and techniques for determining associated kinetic and stoichiometric parameters. Engineering design of several bioreactor configurations employed for biochemical waste treatment. Mathematical modeling of engineered biological reactors using state-of-the-art simulation packages.

EAAE E4980 Urban environmental technology and policy

Lect: 3. 3 pts. Not given in 2009–2010.

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 2009–2010.

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 E6150y Industrial catalysis

Lect: 3. 3 pts. Professor Farrauto.

Prerequisite: EAAE E4550 or the equivalent, or the instructor's permission. Fundamental principles of kinetics, characterization and preparation of catalysts for production of petroleum products for conventional transportation fuels, specialty chemicals, polymers, food products, hydrogen and fuel cells, and the application of catalysis in biomass conversion to fuel. Update of the ever-changing demands and challenges in environmental applications, focusing on advanced catalytic applications as described in modern literature and patents. All students are required to prepare and present a literature review project to improve their presentation skills related to the application of catalysis.

EAAE E6151y Applied geophysics

Lect: 3. 3 pts. Not given in 2009–2010.

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 2009–2010.

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. Not given in 2009–2010.

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 Gong.

Prerequisite: Engineering hydrology or the equivalent. Spatial/temporal dynamics of the hydrologic cycle and its interactions with landforms and vegetation. Hydroclimatology at regional to planetary scales, focusing on mechanisms of organization and variation of water fluxes as a function of season, location, reservoir (ocean, atmosphere, land), and time scale. Land-atmosphere interaction and the role of vegetation and soil moisture. Topography as an organizing principle for land-water fluxes. Geomorphology and the evolution of river networks. Sedimentation, erosion, and hill slope hydrology. Dynamics of water movement over land, in rivers, and in the subsurface, with an emphasis on modeling interfaces. Integrated models and the scale problem. Emphasis on data-based spatial/temporal modeling and exploration of outstanding theoretical challenges.

CHEE E6252y Applied surface and colloid chemistry

Lect: 2. Lab: 3. 3 pts. Professors Somasundaran and Farinato.

Prerequisite: CHEE E4252. Applications of surface chemistry principles to wetting, flocculation, flotation, separation techniques, catalysis, mass transfer, emulsions, foams, aerosols, membranes, biological surfactant systems, microbial surfaces, enhanced oil recovery, and pollution problems. Appropriate individual experiments and projects. Lab required.

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

Lect: 3. 3 pts. Not given in 2009–2010.

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. Professor Duby.

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 12 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 Noyan.

MSAE E3103x Elements of materials science

Lect: 3. 3 pts. Professor Noyan.

MSAE E3104y Laboratory in materials science

Lect: 1. Lab. 4. 3 pts. Instructor to be announced.

MSAE E3111x Thermodynamics, kinetic theory, and statistical mechanics

Lect: 3. 3 pts. Professor Billinge.

MSAE E3141y Processing of metals and semiconductors

Lect: 3. 3 pts. Professor Duby.

MSAE E3142y Processing of ceramics and polymers

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

MSAE E3156x-E3157y Design project

3 pts. Members of the faculty.

MSAE E3900x and y Undergraduate research in materials science

0 to 4 pts. Members of the faculty.

MSAE E4090x Nanotechnology

Lect: 3. 3 pts. Offered in alternate years. Professor Herman.

MSAE E4101x Structural analysis of materials

Lect: 3. 3 pts. Professor Chan.

MSAE E4132y Fundamentals of polymers and ceramics

Lect: 3. 3 pts. Not given in 2009–2010.

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 Marianetti.

MSAE E4207y Lattice vibrations and crystal defects

Lect: 3. 3 pts. Professor Chan.

MSAE E4215y Mechanical behavior of materials

Lect: 3. 3 pts. Professor Noyan.

MSAE E4250x Ceramics and composites

Lect: 3. 3 pts. Offered in alternate years. Professor Guha.

MSAE E4301x and y Materials science laboratory

1 to 3 pts. Instructor to be announced.

MSAE E4990x and y Special topics in materials science and engineering

Lect: 3. 3 pts. Instructors to be announced.

MSAE E6020y Electronic ceramics

Lect: 3. 3 pts. Offered in alternate years. Not given in 2009–2010.

MSAE E6081x Solid state physics, I

Lect: 3. 3 pts. Professor Pinczuk.

MSAE E6082y Solid state physics, II

Lect: 3. 3 pts. Professor Kim.

MSAE E6091y Magnetism and magnetic materials

Lect: 3. 3 pts. Offered in alternate years. Not given in 2009–2010.

MSAE E6120x Grain boundaries and interfaces

Lect: 2. 3 pts. Offered in alternate years. Not given in 2009–2010.

MSAE E6220x Crystal physics

Lect: 3. 3 pts. Offered in alternate years. Not given in 2009–2010.

MSAE E6221x Introduction to dislocation theory

Lect: 3. 3 pts. Offered in alternate years. Not given in 2008–2009.

MSAE E6225y Techniques in x-ray and neutron diffraction

Lect: 3. 3 pts. Offered in alternate years. Not given in 2009–2010.

MSAE E6229x Energy and particle beam processing of materials

Lect: 3. 3 pts. Not given in 2009–2010.

MSAE E6230x Kinetics of phase transformations

Lect: 3. 3 pts. Offered in alternate years. Not given in 2009–2010.

MSAE E6251y Thin films and layers

Lect: 2. 3 pts. Professor Chan.

MSAE E6273x and y, and s Materials science reports

0 to 6 pts. Members of the faculty.

MSAE E8235x and y Selected topics in materials science

Lect: 3. 3 pts. Instructors to be announced.

MSAE E8236y Anelastic relaxations in crystals

Lect: 3. 3 pts. Offered in alternate years. Not given in 2009–2010.

MSAE E9000x and y Materials science and engineering colloquium

0 pts. Members of the faculty.

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

Lect: 1. 1 pt. Members of the faculty.

MSAE E9301x and y, and s Doctoral research

0 to 15 pts. Members of the faculty.

MSAE E9309x and y, and s Proposal of research for the doctorate

0 to 3 pts. Members of the faculty.

MSAE 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.

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ASSOCIATE RESEARCH
SCIENTIST
Vladimir Sokolov

POSTDOCTORAL
RESEARCH
SCIENTISTS/FELLOWS
Yee Him Cheung
Cory Dean
Nadia Pervez
Siddharth Ramakrishnan

Contemporary electrical engineering is a broad discipline that encompasses a wide range of activities. A common theme is the use of electrical and electromagnetic signals for the generation, transmission, processing, storage, conversion, and control of information and energy. An equally important aspect is the human interface and the role of individuals as the sources and recipients of information. The rates at which information is transmitted today range from megabits per second to gigabits per second and in some cases, as high as terabits per second. The range of frequencies over which these processes are studied extends from direct current (i.e., zero frequency), to

microwave and optical frequencies.

The need for increasingly faster and more sophisticated methods of handling information poses a major challenge to the electrical engineer. New materials, devices, systems, and network concepts are needed to build the advanced communications and information handling systems of the future. Previous innovations in electrical engineering have had a dramatic impact on the way in which we work and live: the transistor, integrated circuits, computers, radio and television, satellite transmission systems, lasers, fiber optic transmission systems, and medical electronics.

The faculty of the Electrical Engineering Department at Columbia University

is dedicated to the continued development of further innovations through its program of academic instruction and research. Our undergraduate academic program in electrical engineering is designed to prepare the student for a career in industry or business by providing her or him with a thorough foundation of the fundamental concepts and analytical tools of contemporary electrical engineering. A wide range of elective courses permits the student to emphasize specific disciplines such as telecommunications, microelectronics, digital systems, or photonics. 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.

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; micro-electronic circuits, integrated systems and computer-aided design; systems biology; and electromagnetics and plasmas. Details on all of these areas can be found at 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 semi conductor light sources such as LEDs and injection lasers, fabrication and analysis of quantum confined structures, photo conductors, pin diodes, avalanche photodiodes, optical interconnects, and quantum optics. A major effort is the picosecond optoelectronics program, focusing on the development of new devices and their applications to high-speed optoelectronic measurement systems, photonic switching, and optical logic. In addition, research is being performed in detection techniques for optical communications and radar. Members of the photonics group play a leading role in a multi-university consortium: The National Center for Integrated Photonics Technology.

Integrated systems research involves the analysis and design of analog, digital, and mixed-signal microelectronic circuits and systems. These include novel signal processors and related systems, data converters, radio frequency circuits, low noise and low power circuits, and fully integrated analog filters that share the same chip with digital logic. VLSI architectures for parallel computation, packet switching, and signal processing are also under investigation. Computer-aided design research involves the development of techniques for the analysis and design of large-scale integrated circuits and systems.

Electromagnetics research ranges from the classical domains of microwave generation and transmission and wave propagation in various media to modern applications involving lasers, optical fibers, plasmas, and solid-state devices. Problems relevant to controlled thermo-

nuclear fusion are under investigation.

Laboratory Facilities

Current research activities are fully supported by more than a dozen well-equipped research laboratories run by the Department. Specifically, laboratory research is conducted in the following laboratories: Multimedia Networking Laboratory, Lightwave Communications Laboratory, Systems Laboratory, Image and Advanced Television Laboratory, Laser Processing Laboratory, Molecular Beam Epitaxy Laboratory, Surface Analysis Laboratory, Microelectronics Fabrication Laboratory, Device Measurement Laboratory, Ultrafast Optoelectronics Laboratory, Columbia Integrated Systems Laboratory (CISL), Lightwave Communications Laboratory, Photonics Laboratory, Plasma Physics Laboratory (in conjunction with the Department of Applied Physics).

Laboratory instruction is provided in the Introduction to Electrical Engineering Laboratory, Marcellus-Hartley Electronics Laboratory, Microprocessor Laboratory, Microwave Laboratory, Optical Electronics Laboratory, Solid-State Laboratory, VLSI Design Laboratory, and Student Projects Laboratory, all on the twelfth floor of the S. W. Mudd Building.

UNDERGRADUATE PROGRAM

The undergraduate program in electrical engineering at Columbia University has five formal educational objectives:

- A. Produce graduates with a strong foundation in the basic sciences and mathematics that will enable them to identify and solve electrical engineering problems.
- B. Provide our students with a solid foundation in electrical engineering that prepares them for life-long careers and professional growth in fields of their choice.
- C. Provide our students with the basic skills to communicate effectively and to develop the ability to function as members of multi-disciplinary teams.
- D. Provide our students with a broad-based education so that they can appreciate diversity of opinion, better understand ethical issues, and develop a perspective of our profession.
- E. Provide our students with a relevant

engineering design experience that is integrated across the four year curriculum. Through these experiences, our students will develop an understanding of the relationship between theory and practice.

The B.S. program in electrical engineering at Columbia University seeks to provide a broad and solid foundation in the current theory and practice of electrical engineering, including familiarity with basic tools of math and science, an ability to communicate ideas, and a humanities background sufficient to understand the social implications of engineering practice. Graduates should be qualified to enter the profession of engineering, to continue toward a career in engineering research, or to enter other fields in which engineering knowledge is essential. Required nontechnical courses cover civilization and culture, philosophy, economics, and a number of additional electives. English communication skills are an important aspect of these courses. Required science courses cover basic chemistry and physics, whereas math requirements cover calculus, differential equations, probability, and linear algebra. Basic computer knowledge is also included, with an introductory course on using engineering workstations and two rigorous introductory computer science courses. Core electrical engineering courses cover the main components of modern electrical engineering and illustrate basic engineering principles. Topics include a sequence of two courses on circuit theory and electronic circuits, one course on semiconductor devices, one on electromagnetics, one on signals and systems, one on digital systems, and one on communications or networking. Engineering practice is developed further through a sequence of laboratory courses, starting with a first-year course to introduce hands-on experience early and to motivate theoretical work. Simple creative design experiences start immediately in this first-year course. Following this is a sequence of lab courses that parallel the core lecture courses. Opportunities for exploring design can be found both within these lab courses and in the parallel lecture courses, often coupled with experimentation and computer simulation, respectively. The culmination of the

laboratory sequence and the design experiences introduced throughout earlier courses is a senior design course (capstone design course), which includes a significant design project that ties together the core program, encourages creativity, explores practical aspects of engineering practice, and provides additional experience with communication skills in an engineering context. Finally, several technical electives are required, chosen to provide both breadth and depth in a specific area of interest. More detailed program objectives and outcomes are posted at www.ee.columbia.edu/academics/undergrad.

The program in electrical engineering leading to the B.S. degree is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

There is a strong interaction between the Department of Electrical Engineering and the Departments of Computer Science, Applied Physics and Applied Mathematics, Industrial Engineering and Operations Research, Physics, and Chemistry.

EE Core Curriculum

All electrical engineering (EE) students must take a set of core courses, which collectively provide the student with fundamental skills, expose him/her to the breadth of EE, and serve as a springboard for more advanced work, or for work in areas not covered in the core. These courses are shown on the charts on the following pages, along with all program requirements. A full curriculum checklist is also posted at www.ee.columbia.edu/academics/undergrad.

Technical Electives

The 18-point technical elective requirement for the electrical engineering program consists of three components: depth, breadth, and other. A general outline is provided here, and more specific course restrictions can be found at www.ee.columbia.edu/academics/undergrad. For any course not clearly listed there, adviser approval is necessary.

The *depth* component must consist of at least 6 points of electrical engineering courses in one of four defined areas: (a) photonics, solid-state devices, and electromagnetics; (b) circuits and elec-

tronics; (c) signals and systems; and (d) communications and networking. The depth requirement provides an opportunity to pursue particular interests and exposure to the process of exploring a discipline in depth—an essential process that can be applied later to other disciplines, if desired.

The *breadth* component must consist of at least 6 additional points of engineering courses that are outside of the chosen depth area. These courses can be from other departments within the school. The breadth requirement precludes overspecialization. Breadth is particularly important today, as innovation requires more and more of an interdisciplinary approach, and exposure to other fields is known to help one's creativity in one's own main field. Breadth also reduces the chance of obsolescence as technology changes.

Any remaining technical elective courses, beyond the minimum 12 points of depth and breadth, do not have to be engineering courses (except for students without *ELEN E1201* or approved transfer credit for *ELEN E1201*) but must be technical. Generally, math and science courses that do not overlap with courses used to fill other requirements are allowed.

Starting Early

The EE curriculum is designed to allow students to start their study of EE in their first year. This motivates students early and allows them to spread 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; schedules may vary depending on student preparation and interests.

Transfer Students

Transfer students coming to Columbia as juniors with sufficient general background can complete all requirements for the B.S. degree in electrical engineering. Such students fall into one of two categories:

Plan 1: Students coming to Columbia without having taken the equivalent of *ELEN E1201* must take this course in their junior year. This requires postponing the core courses in circuits and electronics until the senior year, and thus does not allow taking electives in that area; thus, such students cannot choose circuits and electronics as a depth area.

Plan 2: This plan is for students who have taken a course equivalent to *ELEN E1201* at their school of origin, including a laboratory component. See the bulletin for a description of this course. Many pre-engineering programs and physics departments at four-year colleges offer such courses. Such students can start taking circuits at Columbia immediately, and thus can choose circuits and electronics as a depth area.

It is stressed that *ELEN E1201* or its equivalent is a key part of the EE curriculum. The preparation provided by this course is essential for a number of other core courses.

Sample programs for both Plan 1 and Plan 2 transfer students can be found at www.ee.columbia.edu/academics/undergrad.

B.S./M.S. Program

The B.S./M.S. degree program is open to a select group of undergraduate students. This double degree program makes possible the earning of both the Bachelor of Science and Master of Science degrees simultaneously. Up to 6 points may be credited to both degrees, and some graduate classes taken in the senior year may count toward the M.S. degree. Both degrees may be conferred at the same time. Interested students can find further information at www.ee.columbia.edu/academics/undergrad and discuss options directly with their faculty adviser. Students must be admitted prior to the start of their seventh semester at SEAS.

Students in the 3-2 Combined Plan undergraduate program are not eligible for admission to this program.

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 www.ee.columbia.edu/academics/masters.

Master of Science Degree

Candidates for the M.S. degree in electrical engineering must complete 30 points of credit beyond the bachelor's degree. A minimum of 15 points of credit must be at the 6000 level or higher. No credit will be allowed for undergraduate courses (3000 or lower). At least 15 points must be taken in EE courses (i.e.,

courses listed by the Electrical Engineering Department) or courses designated COMS, of which at least 10 points must be EE courses. Courses to be credited toward the M.S. degree can be taken only upon prior approval of a faculty adviser in the Department of Electrical Engineering. This applies to the summer session as well as the autumn and spring terms. Certain 4000-level courses will not be credited toward the M.S. degree, and no more than 6 points of research may be taken for credit. Up to 3 points of credit for approved graduate courses outside of engineering and science may be allowed. The general school requirements listed earlier in this bulletin, such as minimum GPA, must also be satisfied. All degree requirements must be completed within five years of the beginning of the first course credited toward the degree. More details and a checklist for adviser approvals can be found at www.ee.columbia.edu/academics/masters.

Professional Degree

The professional degree in electrical engineering is intended to provide specialization beyond the level of the M.S. degree, in a focused area of electrical engineering selected to meet the professional objectives of the candidate. A minimum of 30 points of credit is required. The prospective E.E. candidate follows a program of study formulated in consultation with, and approved by, a faculty adviser. At least three courses will be in a specific, focused area of electrical engineering, and at least two-thirds of the entire program will be in electrical engineering or computer science. No thesis is required, but the program may optionally include a seminar or project or research for which a report is produced; up to 6 points of such projects may be credited toward the degree. The level of the courses will generally be higher than is typical of a master's degree program, although courses at the 4000 level may be included to prepare for more advanced work. A candidate is required to maintain a grade-point average of at least 3.0. All degree requirements must be completed within five years of the beginning of the first course credited toward the degree.

Doctoral Degree

The requirements for the Ph.D. and Eng.Sc.D. degrees are identical. Both require a dissertation based on the candidate's original research, conducted under the supervision of a faculty member. The work may be theoretical or experimental or both. Students who wish to become candidates for the doctoral degree in electrical engineering have the option of applying for admission to the Eng.Sc.D. program or the Ph.D. program. Students who elect the Eng.Sc.D. degree register in the School of Engineering and Applied Science; those who elect the Ph.D. degree 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 www.ee.columbia.edu/academics/phd.

Optional M.S. Concentrations

Students in the electrical engineering M.S. program often choose to use some of their electives to focus on a particular field. Students may pick one of a number of optional, formal concentration templates or design their own M.S. program in consultation with an adviser. These concentrations are not degree requirements. They represent suggestions from the faculty as to how one might fill one's programs so as to focus on a particular area of interest. Students may wish to follow these suggestions, but they need not. The degree requirements are quite flexible and are listed in the Master of Science Degree section, above. All students, whether following a formal concentration template or not, are expected to include breadth in their program. Not all of the elective courses listed here are offered every year. For the latest information on available courses, visit the Electrical Engineering home page at www.ee.columbia.edu.

Concentration in Multimedia Networking

Advisers: Prof. Henning Schulzrinne, Prof. Predrag Jelenkovic

1. Satisfy M.S. degree requirements.
2. Both *ELEN E6711: Stochastic signals and noise* and *ELEN E6761: Computer communication networks, I*.
3. Either *COMS W4118: Operating systems* or *COMS W4111: Database systems*.
4. *COMS E6181: Advanced Internet services*.

With an adviser's approval, any of the courses above can be replaced by the following closely related subjects: *CSEE E4140: Networking laboratory*; *CSEE W4119: Computer networks*; *COMS W4180: Network security*; *ELEN E6762: Computer communication networks, II*; *ELEN E6850: Visual information systems*; *ELEN E6950: Wireless and mobile networking, I*; *ELEN E6951: Wireless and mobile networking, II*.

Concentration in Telecommunications Engineering

Advisers: Prof. Henning Schulzrinne, Prof. Predrag Jelenkovic, Prof. Ed Coffman, Prof. Nicholas Maxemchuk, Prof. Gil Zussman

1. Satisfy the M.S. degree requirements.
2. One basic hardware or software course such as: *ELEN E4321: Digital VLSI circuits*; *ELEN E4411: Fundamentals of photonics*; *COMS W4118: Operating systems, I*; *COMS W4111: Database systems*.
3. One basic systems course such as: *ELEN E4702: Communication theory*; *ELEN E4703: Wireless communications*; *CSEE W4119: Computer networks*; *ELEN E6761: Computer communication networks, I*.
4. At least two approved courses from a focus area such as Signal/Image Processing and Telecommunications/Multimedia Networks.

Concentration in Media Engineering

Advisers: Prof. Shi-Fu Chang, Prof. Dan Ellis, Prof. Xiaodong Wang

1. Satisfy the basic M.S. degree requirements.
2. Both *ELEN E4810: Digital signal processing* and *ELEN E4830: Digital image processing*.

3. Either *ELEN E6761: Computer communication networks, I* or *CSEE W4119: Computer networks*.
4. At least two approved advanced courses such as: *ELEN E4896: Music signal processing*; *ELEN E6820: Speech and audio processing and recognition*; *ELEN E6850: Visual information systems*; *ELEN E6860: Advanced digital signal processing*; *ELEN E688x: Topics in signal processing*; *ELEN E6762: Computer communication networks, II*; *ELEN E6717: Information theory*; *COMS E6181: Advanced internet services*; *ELEN E6950: Wireless and mobile networking, I*; or *ELEN E6001-E6002: Advanced projects in electrical engineering* with an appropriate project. A cross-disciplinary project in areas related to new media technology is especially encouraged.

Concentration in Lightwave (Photonics) Engineering

Advisers: Prof. Keren Bergman, Prof. Paul Diamant, Prof. Richard Osgood, Prof. Amiya Sen, Prof. Tony Heinz

1. Satisfy the M.S. degree requirements.
2. Take both *ELEN E4411: Fundamentals of photonics* and *ELEN E6403: Classical electromagnetic theory* (or an equivalent, such as *APPH E4300: Applied electrodynamics* or *PHYS G6092: Electromagnetic theory*).
3. One more device/circuits/photonics course such as: *ELEN E4401: Wave transmission and fiber optics*; *ELEN E6412: Lightwave devices*; *ELEN E6413: Lightwave systems*; *ELEN E4405: Classical nonlinear optics*; *ELEN E6414: Photonic integrated circuits*; *ELEN E4314: Communication circuits*; *ELEN E4501: Electromagnetic devices and energy conversion*.
4. At least two approved courses in photonics or a related area.

Concentration in Wireless and Mobile Communications

Adviser: Prof. Gil Zussman

1. Satisfy M.S. degree requirements.
2. One basic circuits course such as: *ELEN E4312: Analog electric circuits*; *ELEN E4314: Communication circuits*; *ELEN E6314: Advanced communication circuits*; *ELEN E6312: Advanced analog ICs*.

3. Two communications or networking courses such as: CSEE W4119: *Computer networks*; ELEN E4702: *Digital communications*; ELEN E4703: *Wireless communications*; ELEN E6711: *Stochastic signals and noise*; ELEN E4810: *Digital signal processing*; ELEN E6950: *Wireless and mobile networking, I*; ELEN E6951: *Wireless and mobile networking, II*; ELEN E6761: *Computer communication networks, I*; ELEN E6712: *Communication theory*; ELEN E6713: *Topics in communications*; ELEN E6717: *Information theory*.
4. At least two approved courses in wireless communications or a related area.

Concentration in Microelectronic Circuits

Advisers: Prof. Yannis Tsvividis, Prof. Charles Zukowski, Prof. Kenneth Shepard, Prof. Peter Kinget

1. Satisfy M.S. degree requirements.
2. One digital course: ELEN E4321: *Digital VLSI circuits* or ELEN E6321: *Advanced digital electronic 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 E6211: *Circuit theory*; ELEN E6261: *Computational methods of circuit analysis*; ELEN E6304: *Topics in electronic circuits*; ELEN E6318: *Microwave circuit design*.
5. At least two additional approved courses in circuits or a related area.

Concentration in Microelectronic Devices

Advisers: Prof. Wen Wang, Prof. Richard Osgood, Prof. Ioannis (John) Kymissis

1. Satisfy M.S. degree requirements.
2. One basic course such as: ELEN E4301: *Introduction to semiconductor devices* or ELEN E4411: *Fundamentals of photonics*.
3. One advanced course such as: ELEN E4193: *Modern display science and technology*; 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*; ELEN E6945: *Nanoscale fabrication and devices*.

4. At least two approved courses in devices or a related area.

Concentration in Systems Biology

Advisers: Prof. Dimitris Anastassiou, Prof. Pedrag Jelenkovic, Prof. Aurel Lazar, Prof. Kenneth Shepard, Prof. Xiaodong Wang, Prof. Charles Zukowski

1. Satisfy 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*; CHBC W4510: *Molecular systems biology, I*; CHBC W4511: *Molecular systems biology, II*; BIST P8139: *Theoretical genetic modeling (Biostatistics)*; ELEN E6010: *Systems biology*; EEBM E6020: *Methods in computational neuroscience*; BMEE E6030: *Neural modeling and neuro-engineering*; APMA E4400: *Introduction to biophysical modeling*; CHEN E4700: *Principles of genomic technologies*; ELEN E4312: *Analog electronic circuits*.
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*; EEBM E6090: *Topics in computational neuroscience and neuroengineering*; ELEN E6261: *Computational methods of circuit analysis*.

COURSES IN ELECTRICAL ENGINEERING

ELEN E1101x or y The digital information age
Lect: 3. 3 pts. Professor Vallancourt.
 An introduction to information transmission and storage, including technological issues. Binary

numbers; elementary computer logic; digital speech and image coding; basics of compact disks, telephones, modems, faxes, UPC bar codes, and the World Wide Web. Projects include implementing simple digital logic systems and Web pages. Intended primarily for students outside the School of Engineering and Applied Science. The only prerequisite is a working knowledge of elementary algebra.

ELEN E1201y Introduction to electrical engineering

Lect: 3. Lab: 1. 3.5 pts. Professor Vallancourt.
 Prerequisite: MATH V1101. Basic concepts of electrical engineering. Exploration of selected topics and their application. Electrical variables, circuit laws, nonlinear and linear elements, ideal and real sources, transducers, operational amplifiers in simple circuits, external behavior of diodes and transistors, first order RC and RL circuits. Digital representation of a signal, digital logic gates, flipflops. A lab is an integral part of the course. Required of electrical engineering and computer engineering majors.

ELEN E3043x Solid state, microwave, and fiber optics laboratory

Lect: 1. Lab: 6. 3 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. Professor Zukowski.
 Prerequisite: ELEN E1201 or the equivalent.
 Corequisite: ELEN E3201. Companion lab course for ELEN E3201. Experiments cover such topics as: use of measurement instruments; HSPICE simulation; basic network theorems; linearization of nonlinear circuits using negative feedback; 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

ELECTRICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS EARLY-STARTING STUDENTS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3) ³
PHYSICS (three tracks, choose one)	C1401 (3) —————> C1601 (3.5) —————> C2801 (4.5) —————>	C1402 (3) C1602 (3.5) C2802 (4.5)		
CHEMISTRY	one-semester lecture (3–4) C1403 or C1404 or C3045 or C1604			
CORE REQUIRED COURSES	ELEN E1201 (3.5) Introduction to electrical engineering (either semester)		ELEN E3201 (3.5) Circuit analysis ELEN E3801 (3.5) Signals & systems	ELEN E3331 (3) Electronic circuits CSEE E3827 (3) Fund. of computer sys.
REQUIRED LABS			ELEN E3081 (1) ² Circuit analysis lab ELEN E3084 (1) ² Signals & systems lab	ELEN E3083 (1) ² Electronic circuits lab ELEN E3082 (1) ² Digital systems lab
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) —————> Z0006 (0) —————>	C1010 (3) Z1003 (0)	C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES	HUMA C1001, C0CI C1101, or Major Cultures (3–4); HUMA W1121 or W1123 (3); HUMA C1002, C0CI C1102, or Global Core (3–4); 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.			
COMPUTER SCIENCE	COMS W1007 (3) any semester ¹			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹COMS W1007 may be replaced by COMS W1003, W1004, or W1009, but impact on later options should be considered (see www.ee.columbia.edu/academics/undergrad).

²If possible, these labs should be taken along with their corresponding lecture courses.

³APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2010.

circuits; programmable logic devices. The lab generally meets on alternate weeks.

ELEN E3083y Electronic circuits laboratory

Lab: 3. 1 pt. Professor Vallancourt.

Prerequisite: ELEN E3081. Corequisite: ELEN E3331. Companion lab course for ELEN E3331. Experiments cover such topics as macromodeling of nonidealities of opamps using HSPICE; Schmitt triggers and astable multivibrators 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 the-

ory of solids. Carrier concentration and transport in semiconductors. P-n junction and junction transistors. Semiconductor surface and MOS transistors. Optical effects and optoelectronic devices.

ELEN E3201x Circuit analysis

Lect: 3. Recit: 1. 3.5 pts. Professor Zukowski.

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.

ELECTRICAL ENGINEERING: THIRD AND FOURTH YEARS EARLY-STARTING STUDENTS

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
PHYSICS (tracks continued)	C1403 (3) C2601 (3.5) Lab W3081 (2)	Lab C1494 (3) ¹ Lab C2699 (3)		
EE CORE REQUIRED COURSES	ELEN E3106 (3.5) Solid-state devices & materials	ELEN E3401 (4) Electromagnetics ELEN E3701 (3) ² Intro. to communication systems or CSEE W4119 (3) ² Computer networks		
EE REQUIRED LABS			ELEN E3043 (3) Solid state, microwave, & fiber optics lab ELEN E3399 (1) EE practice	One capstone design course ³ (ELEN E3390, ELEN E4332, EECS E4340, or CSEE W4840)
OTHER REQUIRED COURSES	IEOR E3658 or STAT 4105 ⁴ ; and COMS W3137 (or 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)			
ELECTIVES	EE DEPTH TECH	At least two technical electives in one depth area. The four depth areas are (a) photonics, solid-state devices, and electromagnetics; (b) circuits and electronics; (c) signals and systems; and (d) communications and networking (For details, see www.ee.columbia.edu/academics/undergrad)		
	BREADTH TECH	At least two technical electives outside the chosen depth area; must be engineering courses (see www.ee.columbia.edu/academics/undergrad)		
	OTHER TECH	Additional technical electives (consisting of more depth or breadth courses, or further options listed at www.ee.columbia.edu/academics/undergrad) as required to bring the total points of technical electives to 18 ⁵		
	NONTECH	Complete 27-point requirement; see page 11 or www.seas.columbia.edu for details (administered by the advising dean)		
TOTAL POINTS⁶	16.5	17	16	18

¹Chemistry lab (CHEM 1500) may be substituted for physics lab, although this is not generally recommended.

²These courses can be taken in the sophomore year if the prerequisites/corequisites are satisfied.

³The 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.

⁴SIEO W3600 and W4150 cannot generally be used to replace IEOR E3658 or STAT W4105.

⁵The total points of technical electives is reduced to 15 if APMA E2101 has been replaced by MATH E1210 and either APMA E3101 or MATH V2010.

⁶"Total points" assumes that 20 points of nontechnical electives and other courses are included.

ELEN E3331y Electronic circuits

Lect: 3. 3 pts. Professor Vallancourt.

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. Professor Vallancourt.

Prerequisites: ELEN E3082, E3083, E3331, E3401, and E3801. Advanced circuit design laboratory. Students work in teams to specify, design, implement, and test an engineering prototype. The work involves technical as well as nontechnical consider-

ations, such as manufacturability, impact on the environment, and economics. The project is chosen by the instructor and may change from year to year.

ELEN E3399x Electrical engineering practice 1 pt.

Design project planning, written and oral technical communication, practical aspects of engineering

ELECTRICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS LATE-STARTING STUDENTS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101(3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3) ³
PHYSICS (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) ⁴ Lab C2699 (3)
CHEMISTRY	one-semester lecture (3–4) C1403 or C1404 or C3045 or C1604			
ELECTRICAL ENGINEERING	ELEN E1201 (3.5) either semester ¹			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	C1010 (3) Z1003 (0)	C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES			HUMA C1001, C0CI C1101, or Global Core (3–4) HUMA W1121 or W1123 (3)	HUMA C1002, C0CI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
COMPUTER SCIENCE	COMS W1007 (3) either semester ²			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹Transfer 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.

²COMS W1007 may be replaced by COMS W1003, W1004, or W1009, but impact on later options should be considered (see www.ee.columbia.edu/academics/undergrad).

³APMA E2101 may be replaced by MATH E1210 and either APMA E3101 or MATH V2010.

⁴Chemistry lab (CHEM C1500) may be substituted for physics lab, although this is not generally recommended.

as a profession, such as career development and societal and environmental impact.

ELEN E3401y Electromagnetics

Lect: 3. 4 pts. Professor Diamant.

Prerequisites: 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 quasistatic 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: IEOR E3658. 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 W3827x and y Fundamentals of computer systems

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

Prerequisite: An introductory programming course. Fundamentals of computer organization and digital logic. Boolean algebra, Karnaugh maps, basic gates and components, flipflops and latches, counters and state machines, basics of combinational and sequential digital design. Assembly language, instruction sets, ALUs, single-cycle and multi-cycle processor design, introduction to pipelined processors, caches, and virtual memory.

ELEN E3998x and y Projects in electrical engineering

0 to 3 pts.

May be repeated for credit, but no more than 3 total points may be used for degree credit. Prerequisite: approval by a faculty member who agrees to supervise the work. Independent project involving laboratory work, computer programming, analytical investigation, or engineering design.

ELECTRICAL ENGINEERING: THIRD AND FOURTH YEARS¹ LATE-STARTING STUDENTS

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
EE CORE REQUIRED COURSES	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) Electronic circuits ELEN E3401 (4) Electromagnetics ELEN E3701 (3) Intro. to communication systems or CSEE W4119 (3) Computer networks		
EE REQUIRED LABS	ELEN E3081 (1) ² Circuit analysis lab ELEN E3084 (1) ² Signals & systems lab	ELEN E3083 (1) ² Electronic circuits lab ELEN E3082 (1) ² Digital systems lab	ELEN E3043 (3) Solid state, microwave, & fiber optics lab ELEN E3399 (1) EE practice	One capstone design course ³ (ELEN E3390, ELEN E4332, EECS E4340, or CSEE W4840)
OTHER REQUIRED COURSES	IEOR E3658 or STAT W4105 ⁴ ; and COMS W3137 (or W3133, W3134, or W3139) (Some of these courses are <i>not</i> offered both semesters)			
ELECTIVES	EE DEPTH TECH	At least two technical electives in one depth area. The four depth areas are (a) photonics, solid-state devices, and electromagnetics; (b) circuits and electronics; (c) signals and systems; and (d) communications and networking (For details, see www.ee.columbia.edu/academics/undergrad)		
	BREADTH TECH	At least two technical electives outside the chosen depth area; must be engineering courses (see www.ee.columbia.edu/academics/undergrad)		
	OTHER TECH	Additional technical electives (consisting of more depth or breadth courses, or further options listed at www.ee.columbia.edu/academics/undergrad) as required to bring the total points of technical electives to 18 ⁵		
	NONTECH	Complete 27-point requirement; see page 11 or www.seas.columbia.edu for details (administered by the advising dean)		
TOTAL POINTS⁶	15.5	18	16	18

¹This 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.

²If possible, these labs should be taken along with their corresponding lecture courses.

³The 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.

⁴SIEO W3600 and W4150 cannot generally be used to replace IEOE E3658 or STAT W4105.

⁵The total points of technical electives is reduced to 15 if APMA E2101 has been replaced by MATH E1210 and either APMA E3101 or MATH V2010.

⁶"Total points" assumes that 9 points of nontechnical electives are included.

BMEB W4011x Computational neuroscience: Circuits in the brain

Lect: 3. 3 pts. Professors Lazar and Yuste.

Prerequisite: ELEN E3801 or BIOL W3004.

Biophysics of computation, the Hodgkin-Huxley

neuron, modeling and analysis of ion channels, basic dendritic integration. Integrate-and-fire and other spiking neuron models, stimulus representation and the neural code, time encoding and stimulus recovery, information representation with time

encoding machines, fast algorithms for stimulus recovery, elements of spike processing and neural computation. Modeling synapses and synaptic transmission, synaptic plasticity and learning algorithms. Projects in Matlab.

ECBM E4060x Introduction to genomic information science and technology

Lect: 3. 3 pts. Professor Anastassiou.

Introduction to the information system paradigm of molecular biology. Representation, organization, structure, function, and manipulation of the biomolecular sequences of nucleic acids and proteins. The role of enzymes and gene regulatory elements in natural biological functions as well as in biotechnology and genetic engineering. Recombination and other macromolecular processes viewed as mathematical operations with simulation and visualization using simple computer programming. This course shares lectures with ECBM E3060, but the work requirements differ somewhat.

CSEE W4119x and y Computer networks

Lect: 3. 3 pts. Professors Misra and Rubenstein

Corequisite: IEBR E3658 or SIEO W3600, or the equivalent. Introduction to computer networks and the technical foundations of the Internet, including applications, protocols, local area networks, algorithms for routing and congestion control, security, elementary performance evaluation. Several written and programming assignments required.

CSEE W4140x or y Networking laboratory

Lect: 3. 4 pts.

Prerequisite: CSEE W4119 or the equivalent. In this course, students will learn how to put "principles into practice," in a hands-on networking lab course. The technologies and protocols of the Internet will be covered, using equipment currently available to large Internet service providers such as CISCO routers and end systems. A set of laboratory experiments will provide hands-on experience with engineering wide-area networks and will familiarize students with the Internet Protocol (IP), Address Resolution Protocol (ARP), Internet Control Message Protocol (ICMP), User Datagram Protocol (UDP), Transmission Control Protocol (TCP), the Domain Name System (DNS), routing protocols (RIP, OSPF, BGP), network management protocols (SNMP), and application-level protocols (FTP, TELNET, SMTP).

ELEN E4193x Modern display science and technology

Lect: 3. 3 pts. Professor Kymissis.

Prerequisites: Linear algebra, differential equations, and basic semiconductor physics. Introduction to modern display systems in an engineering context. The basis for visual perception, image representation, color space, metrics of illumination. Physics of luminescence, propagation and manipulation of light in anisotropic media, emissive displays, and spatial light modulators. Fundamentals of display addressing, the Alt-Pleshko theorem, multiple line addressing. Large area electronics, fabrication, and device integration of commercially important display types. A series of short laboratories will reinforce material from the lectures. Enrollment may be limited.

ELEN E4301y Introduction to semiconductor devices

Lect: 3. 3 pts. Professor Laibowitz.

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.

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.

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. Professor Shepard.

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 E4411x Fundamentals of photonics

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

Prerequisite: ELEN E3401 or the equivalent. Planar resonators. Photons and photon streams. Photons and atoms: energy levels and band structure; interactions of photons with matter; absorption, stimulated and spontaneous emission; thermal light, luminescence light. Laser amplifiers: gain, saturation, and phase shift; rate equations; pumping. Lasers: theory of oscillation; laser output characteristics. Photons in semiconductors: generation, recombination, and injection; heterostructures; absorption and gain coefficients. Semiconductor photon sources: LEDs; semiconductor optical amplifiers; homojunction and heterojunction laser diodes. Semiconductor photon detectors: p-n, p-i-n, and heterostructure photodiodes; avalanche photodiodes.

ELEN E4488x Optical systems

Lect: 3. 3 pts. Professor Bergman.

Prerequisite: ELEN E3401 or the equivalent. Introduction to optical systems based on physical design and engineering principles. Fundamental geometrical and wave optics with specific emphasis on developing analytical and numerical tools used in optical engineering design. Focus on applications that employ optical systems and networks, including examples in holographic imaging, tomography, Fourier imaging, confocal microscopy, optical signal processing, fiber optic communication systems, optical interconnects, and networks.

ELEN E4501x Electromagnetic devices and energy conversion

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

Prerequisite: ELEN 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 electro-mechanical 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 EEME 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 or y Digital communications

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

Prerequisite: ELEN E3701 or the equivalent. Digital communications for both point-to-point and switched applications is further developed. Optimum receiver structures and transmitter signal shaping for both binary and M-ary signal transmission. An introduction to block codes and convolutional codes, with application to space communications.

ELEN E4703y Wireless communications

Lect: 3. 3 pts. Professor Diamant.

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 E4810x Digital signal processing

Lect: 3. 3 pts. Professor Ellis.

Prerequisite: ELEN E3801. Digital filtering in time and frequency domain, including properties of discrete-time signals and systems, sampling theory, transform analysis, system structures, IIR and FIR filter design techniques, the Discrete Fourier Transform, Fast Fourier Transforms.

ELEN E4815y Random signals and noise

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

Prerequisite: IEOR E3658 or the equivalent. Characterization of stochastic processes as models of signals and noise; stationarity, ergodicity, correlation functions, and power spectra. Gaussian processes as models of noise in linear and nonlinear systems; linear and nonlinear transformations of random processes; orthogonal series representations. Applications to circuits and devices, to communication, control, filtering, and prediction.

CSEE W4823x or y Advanced logic design

Lect: 3. 3 pts. Professor Nowick.

Prerequisite: CSEE W3827 or the equivalent. An introduction to modern digital system design. Advanced topics in digital logic: controller synthesis (Mealy and Moore machines); adders and multipliers; structured logic blocks (PLDs, PALs, ROMs); iterative circuits. Modern design methodology: register transfer level modeling (RTL); algorithmic state machines (ASMs); introduction to hardware description languages (VHDL or Verilog); system-level modeling and simulation; design examples.

CSEE W4824x or y Computer architecture

Lect: 3. 3 pts. Professor Carloni.

Prerequisite: CSEE W3287 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.

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 W4823 or the equivalent. Embedded system design and implementation combining hardware and software. I/O, interfacing, and peripherals. Weekly laboratory sessions and term project on design of a microprocessor-based embedded system including at least one custom peripheral. Knowledge of C programming and digital logic required. Lab required.

ELEN E4896y Music signal processing

Lect: 3. 3 pts. Professor Eleftheriadis.

Prerequisite: A course on discrete-time signal processing (at the level of ELEN E3801 or, preferably, E4810). An introductory course on the applications of signal processing to music, suitable to seniors and first-year graduate students in electrical engineering, computer science, or music. Emphasis is placed on the signal processing operations in both recording and live environments. Topics covered include audio and room acoustics; microphones and loudspeakers; A/D conversion, dithering, and digital audio formats; analog and digital audio mixers; audio effects algorithms; sequencers, samplers, and Digital Audio Workstations (DAW); mastering for CD and DVD production; and sound synthesis algorithms. Throughout the course case studies of real systems will be examined in detail. The course includes a site visit to a state-of-the-art professional recording facility.

ELEN E4998x and y Intermediate projects in electrical engineering

0 to 3 pts.

Prerequisite: The instructor's permission. May be repeated for credit, but no more than 3 total points may be used for degree credit. Substantial independent project involving laboratory work, computer programming, analytical investigation, or engineering design.

ELEN E6001x-E6002y Advanced projects in electrical engineering

1 to 4 pts.

May be repeated for up to 6 points of credit. Graduate-level projects in various areas of electrical engineering and computer science. In consultation with an instructor, each student designs his or her project depending on the student's previous training and experience. Students should consult with a professor in their area for detailed arrangements no later than the last day of registration.

ELEN E6010y Systems biology: Design principles for biological circuits

Lect: 3. 4.5 pts. Instructor to be announced.

Prerequisite: ECBM E4060 or the instructor's permission. Beyond bioinformatics, cells as systems. Metabolic networks, transcription regulatory networks, signaling networks. Deterministic and stochastic kinetics. Mathematical representation of reconstructed networks. Network motifs. Signal transduction and neuronal networks. Robustness. Bacterial chemotaxis and patterning in fruit fly development. Kinetic proofreading. Optimal gene circuit design. Rules for gene regulation. Random networks and multiple time scales. Biological information processing. Numerical and simulation techniques. Major project(s) in Matlab.

EEBM E6020y Methods of computational neuroscience

Lect: 3. 4.5 pts. Professor Lazar.

Prerequisite: BMEB W4011 or the instructor's permission. Formal methods in computational neuroscience, including methods of signal processing, communications theory, information theory, systems and control, system identification and machine learning. Molecular models of transduction pathways. Robust adaptation and integral feedback. Stimulus representation and groups. Stochastic and dynamical systems models of spike generation. Neural diversity and ensemble encoding. Time encoding machines and neural codes. Stimulus recovery with time decoding machines. MIMO models of neural computation. Synaptic plasticity and learning algorithms. Major project(s) in Matlab.

BMEE E6030y Neural modeling and neuroengineering

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

Prerequisites: APMA E3101, ELEN E3801, and BMEB W4011, or the equivalent, or the 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.

ELEN E6080-6089x or y Topics in systems biology

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

Prerequisite: The instructor's permission. Selected advanced topics in systems biology. Content varies from year to year, and different topics rotate through the course numbers 6080-6089.

EEBM E6090-6099x or y Topics in computational neuroscience and neuroengineering

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

Prerequisite: The instructor's permission.

Selected advanced topics in computational neuroscience and neuroengineering. Content varies from year to year, and different topics rotate through the course numbers 6090-6099.

CSEE E6180x or y Modeling and performance evaluation

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

Prerequisites: COMS W4118 and SIEO W4150 or permission of the instructor. Introduction to queueing analysis and simulation techniques. Evaluation of time-sharing and multiprocessor systems. Topics include priority queueing, buffer storage, disk access, interference and bus contention problems, and modeling of program behaviors.

ELEN E6201x Linear system theory

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

Prerequisites: ELEN E3801 and APMA E3101, or the equivalents. Abstract objects, the concepts of state. Definition and properties of linear systems. Characterization of linear continuous time and 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.

Prerequisite: ELEN E4312. Integrated circuit device characteristics and models; temperature- and supply-independent biasing; IC operational amplifier analysis and design; feedback amplifiers, stability and frequency compensation techniques; noise in circuits; low-noise design. Computer-aided analysis techniques are extensively used. An extensive design project is an integral part of the course.

ELEN E6314x Advanced communication circuits

Lect: 3. 4.5 pts. Instructor to be announced.

Prerequisites: ELEN E4314 and E6312. Overview of communication systems, modulation and detection schemes. Receiver and transmitter architectures. Noise, sensitivity, and dynamic range. Nonlinearity and distortion. Low-noise amplifiers, mixers, and oscillators. Phase-locked loops and frequency synthesizers. Power 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. 4.5 pts. Professor Shepard.

Prerequisite: ELEN E4321. Advanced topics in the design of digital integrated circuits. Clocked and nonclocked combinational logic styles. Timing circuits: latches and flip-flops, phase-locked loops, delay-locked loops. SRAM and DRAM memory circuits. Modeling and analysis of on-chip 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 E6412y Lightwave devices

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

Prerequisite: ELEN E4411. Electro-optics: princi-

ples; electro-optics of liquid crystals and photo-refractive materials. Nonlinear optics: second-order nonlinear optics; third-order nonlinear optics; pulse propagation and solitons. Acousto-optics: interaction of light and sound; acousto-optic devices. Photonic switching and computing: photonic switches; all-optical switches; bistable optical devices. 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.

ELEN E6488y Optical interconnects and interconnection networks

Lect: 2. 3 pts. Professor Bergman

Prerequisite: ELEN E4411 or E4488, or an equivalent photonics course. Introduction to optical interconnects and interconnection networks for digital systems. Fundamental optical interconnects technologies, optical interconnection network design, characterization, and performance evaluation. Enabling photonic technologies, including free-space structures, hybrid and monolithic integration platforms for photonic on-chip, chip-to-chip, backplane, and node-to-node interconnects, as well as photonic networks on-chip.

EEME E6601x Introduction to control theory

Lect: 3. 3 pts. Professor Longman.

Prerequisite: MATH E1210. A graduate-level 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_∞ , linear robust control, predictive control. Learning control, repetitive control, adaptive control. Liapunov and Popov stability. Nonlinear adaptive control, nonlinear robust control, sliding mode control.

ELEN E6711x Stochastic models in information systems

Lect: 3. 4.5 pts. Instructor to be announced.
 Prerequisite: IEOR E3658. 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: communication networks (queueing systems), biological networks (hidden Markov models), Bayesian restoration of images (Gibbs fields), and electric networks (random walks).

ELEN E6712x Communication theory

Lect: 3. 3 pts. Instructor to be announced.
 Prerequisite: ELEN E4815 or the equivalent, or the instructor's permission. Representation of band-limited signals and systems. Coherent and incoherent communications over Gaussian channels. Basic digital modulation schemes. Intersymbol interference channels. Fading multipath channels. Carrier and clock synchronization.

ELEN E6717x Information theory

Lect: 2. 3 pts. Instructor to be announced.
 Prerequisite: IEOR E3658 or a course in stochastic processes. Corequisite: ELEN E4815. 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: IEOR E3658. 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: IEOR E3658 and CSEE W4119, or the equivalent, or the instructor's permission. Focus on architecture protocols and performance evaluation of geographically distributed and local area data networks. Emphasis on layered 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 E6770-6779x or y Topics in telecommunication networks

Lect: 2. 3 pts. Instructor to be announced.
 Further study of areas such as communication protocols and architectures, flow and congestion control in data networks, performance evaluation

in integrated networks. Content varies from year to year, and different topics rotate through the course numbers 6770 to 6779.

ELEN E6820y Speech and audio processing and recognition

Lect: 3. 4.5 pts. Professor Ellis.
 Prerequisite: ELEN E4810 or the instructor's 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 E6824y Parallel computer architecture

Lect: 3. 3 pts. Professor Sethumadhavan.
 Prerequisite: CSEE W8424. Parallel computer principles, machine organization, and design of parallel systems, including parallelism detection methods, synchronization, data coherence, and interconnection networks. Performance analysis and special-purpose parallel machines.

CSEE E6847y Distributed embedded systems

Lect: 2. 3 pts. Professor Carloni.
 Prerequisite: Any course numbered in the COMS4110s, CSEE4800s, or ELEN4300s, or the instructor's permission. An interdisciplinary 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.

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.

CSEE E6861y Computer-aided design of digital systems

Lect: 2. 3 pts. Professor Nowick.
 Prerequisites: (1) One semester of advanced digital logic (CSEE W4823 or the equivalent, or the instructor's permission); (2) a basic course in data structures and algorithms (COMS W3133, W3134, W3137, W3139, or W3157, or the equivalent) and familiarity with programming. Introduction to modern digital CAD synthesis and optimization techniques. Topics include modern digital system design (high-level synthesis, register-transfer level modeling, algorithmic state machines, optimal scheduling algorithms, resource allocation and binding, retiming), controller synthesis and optimization, exact and heuristic two-level logic minimization, advanced multilevel logic optimization, optimal technology mapping to library cells (for delay, power, and area minimization), advanced data structures (binary decision diagrams), SAT solvers and their applications, static timing analysis, and introduction to testability. Includes hands-on small design projects using and creating CAD tools. General Education Requirement: Quantitative and Deductive Reasoning (QUA).

ELEN E6880-6889x or y Topics in signal processing

Lect: 2. 3 pts. Instructor to be announced.
 Prerequisite: ELEN E4810. Advanced topics in signal processing, such as multidimensional 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, and different topics rotate through the course numbers 6880-6889.

ELEN E6900-6909x or y Topics in electrical and computer engineering

Lect: 2. 3 pts. Instructor to be announced.
 Prerequisite: the instructor's permission. Selected topics in electrical and computer engineering. Content varies from year to year, and different topics rotate through the course numbers 6900-6909.

ELEN E6945x or y Device nanofabrication

Lect: 3. 3 pts. Professor Wind.
 Prerequisites: ELEN E3106 and E3401, or the equivalents. Recommended: ELEN E4944. This course provides an understanding of the methods used for structuring matter on the nanometer

length; thin-film technology; lithographic 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. 3 pts. Instructor to be announced.

Prerequisite: CSEE W4119, ELEN E6761, or the instructor's permission. Third-generation packet switched systems, wireless LANs, mobile computing and communications. Study of some current research topics. Quantitative homework assignments may require use of a mathematical software package. A project based on readings from the literature will be required. Lab required.

ELEN E6999 Curricular practical training

1 to 3 pts.

May be repeated for up to 3 points of total credit. Prerequisites: Obtained internship and approval from a faculty adviser. Only for electrical engineering and computer engineering graduate students who include relevant off-campus work experience as part of their approved program of study. Final report required. May not be taken for pass/fail credit or audited.

EEME E8601x Advanced topics in control theory

Lect: 3. 3 pts. Professor Longman.

See EEME E6601x (page 186).

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: submission of an outline of the proposed research for the approval of the faculty member who is to supervise the work of the student.

ELEN E9800x and y, and s Doctoral research instruction

3, 6, 9, or 12 pts. Instructor to be announced.

A candidate for the Eng.Sc.D. degree in electrical engineering must register for 12 points of doctoral research instruction. Registration in ELEN E9800 may not be used to satisfy the minimum residence requirement for the degree.

ELEN E9900x and y, and s Doctoral dissertation

0 pts. Instructor to be announced.

A candidate for the doctorate may be required to register for this course every term after the student's course work has been completed, and until the dissertation has been accepted.

Courses in Electrical Engineering Offered Occasionally

ELEN E3000x Introduction to circuits, systems, and electronics

Lect: 3. Recit: 1. 3.5 pts.

Introductory course in electrical circuits, systems, electronics, and digital information processing for non-electrical engineers.

EEHS E3900y History of telecommunications: from the telegraph to the Internet

Lect: 3. 3 pts.

Historical development of telecommunications from the 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 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 E4405x Classical nonlinear optics

Lect: 3. 3 pts.

Prerequisite: ELEN E4401. Waves in anisotropic media. Maxwell's equations and constitutive relations. Fresnel equations. Optical waves in anisotropic crystals. Birefringence. Waves in nonlinear 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 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 E4720y Networking laboratory

Lab: 3. 3 pts.

Prerequisites: Knowledge of computer programming plus CSEE W4119 or the equivalent. Covers practical experience in network programming and systems. Weekly laboratory sessions on network programming and systems leading to a term project on design, implementation, debugging, and integration of network protocols on IP routers. Emphasis on practical experience with (1) networking equipment, including Intel IXP network processor-based routers, PC-based routers, and commercial routers; and (2) the ns-2 simulator. Laboratory topics include socket programming, setting up a commercial router/PC-routers and wireless networks, setting routing tables, programming network processors, deploying network algorithms, and debugging UDP and TCP protocols.

ELEN E471x Introduction to biological sensory systems

Lect: 3. 3 pts.

Corequisite: IEOR E3658. 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, Schlaer, 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.

CSEE W4825y Digital systems design

Lect: 3. 3 pts.

Prerequisite: CSEE W3827. Dynamic logic, field programmable gate arrays, logic design languages, multipliers. Special techniques for multilevel NAND and NOR gate circuits. Clocking schemes for one- and two-phase systems. Fault checking: scan method, built-in test. Survey of logic simulation methods. Other topics to be added as appropriate.

EEHS E4900y History of telecommunications: from the telegraph to the Internet

Lect: 3. 3 pts.

Historical development of telecommunications from the telegraphy of the mid-1800s to the Internet at present. Included are the technologies of telephony, radio, and computer communications. The coverage includes both the technologies themselves and the historical events that shaped, and in turn were shaped by, the technologies. The historical development, both the general context and the particular events concerning communications, is presented chronologically. The social needs that elicited new technologies and the consequences of their adoption are examined. Throughout the course, relevant scientific and engineering principles are explained as needed. These include, among others, the concept and effective use of spectrum, multiplexing to improve capacity, digital coding, and networking principles. There are no prerequisites, and no prior scientific or engineering knowledge is required. SEAS students may not include this as a technical elective. This course shares lectures with EEHS E3900, but the work requirements differ somewhat.

ELEN E4944x Principles of device microfabrication

Lect: 3. 3 pts.

Science and technology of conventional and advanced microfabrication techniques for electronics, integrated and discrete components. Topics include diffusion; ion implantation, thin-film growth including oxides and metals, molecular beam and liquid-phase epitaxy; optical and advanced lithography; and plasma and wet etching.

ELEN E6140x Gallium arsenide materials processing

Lect: 3. 3 pts.

Prerequisite: ELEN E4301 or the instructor's permission. Materials and device aspects of GaAs

and compound technologies, electronic properties of GaAs, growth techniques (bulk and epitaxial), surface and etching properties, implantation, MESFETS, transferred electron devices, Impatt diodes, HEMTs, HBTs.

ELEN E6151y Surface physics and analysis of electronic materials

Lect: 2. 3 pts.

Prerequisite: 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. 3 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: immitance 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. 3 pts.

Prerequisite: The instructor's permission. State-of-the-art techniques in integrated circuits. Topics may change from year to year.

ELEN E6316x or y Analog systems in VLSI

Lect: 3. 3 pts.

Prerequisite: ELEN E6312. Analog-digital inter

faces in very large-scale integrated circuits. Precision sampling; A/D and D/A converter architectures; switched capacitor circuits; system considerations.

ELEN E6403y Classical electromagnetic theory

Lect: 3. 4.5 pts.

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 E6414y Photonic integrated circuits

Lect: 3. 3 pts.

Photonic integrated circuits are important subsystem components for telecommunications, optically controlled radar, optical signal processing, and photonic local area networks. This course will introduce the student to the devices and the design of these circuits. Principle and modeling of dielectric waveguides (including silica on silicon- and InP-based materials), waveguide devices (simple and star couplers), and surface diffractive elements. Numerical techniques for modelling circuits will be discussed, including beam propagation and finite difference codes. Design of other devices will be discussed: optical isolators, demultiplexers.

EEME E6610x Optimal control theory

Lect: 3. 3 pts.

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.

Prerequisites: EEME E6601 or ELEN E6201 and an undergraduate controls course. Fundamental properties of nonlinear systems; qualitative analysis of nonlinear systems; nonlinear controllability and observability; nonlinear stability; zero dynamics and inverse systems; feedback stabilization and linearization; sliding control theory; nonlinear observers; describing functions.

ELEN E6713y Topics in communications

Lect: 3. 3 pts.

Prerequisite: ELEN E6712 or E4702 or E4703, or the equivalent, or the instructor's permission. Advanced topics in communications, such as turbo codes, LDPC codes, multiuser communications, network coding, cross-layer optimization, cognitive radio. Content may vary from year to year to reflect the latest development in the field.

ELEN E6731y Satellite communication systems*Lect: 2. 3 pts.*

Prerequisite: ELEN E4702. Introduction to satellite communication, with emphasis on characterization and systems engineering of the transmission channel. Power budgets, antennas, transponders, multiple access, and frequency reuse techniques. Noise, intermodulation, interference, and propagation effects. Modulation methods, earth terminals, and standards. Digital transmission and advanced systems.

ELEN E6762y Computer communications networks, II*Lect: 2. 3 pts.*

Prerequisite: ELEN E6761. Broadband ISDN—Services and protocols; ATM. Traffic characterization and modeling: Markov-modulated Poisson and Fluid Flow processes; application to voice, video, and images. Traffic management in ATM networks: admission and access control, flow control. ATM switch architectures; input/output queueing. Quality of service (QoS) concepts.

ELEN E6763y Digital circuit switched networks*Lect: 2. 3 pts.*

Prerequisite: ELEN E6761 or the instructor's permission. Current topics in digital circuit switching: introduction to circuit switching, comparison with packet switching, elements of telephone traffic engineering, space and time switching, call processing in digital circuit-switched systems, overload control mechanisms, nonhierarchical routing, common channel signaling, introduction to integrated services digital networks. Examples of current systems are introduced throughout. Emphasis on modeling and quantitative performance analysis. Queueing models introduced where possible.

ELEN W6781y Topics in modeling and analysis of random phenomena*Lect: 3. 3 pts.*

Prerequisite: ELEN E6711. Recommended preparation: a course on real analysis and advanced probability theory. Current methodology in research in stochastic processes applied to communication, control, and signal processing. Topics vary from year to year to reflect student interest and current developments in the field.

CSEE E6831y Sequential logic circuits*Lect: 3. 3 pts.*

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.

CSEE E6832x Topics in logic design theory*Lect: 3. 3 pts.*

Prerequisite: CSEE W3827 or any introduction to logic circuits. A list of topics for each offering of the course is available in the department office one month before registration. May be taken more than once if topics are different. Iterative logic circuits applied to pattern recognition. Finite state machines; alternative representations, information loss, linear circuits, structure theory. Reliability and testability of digital systems.

ELEN E6920x or y Topics in VLSI systems design*Lect: 2. 3 pts.*

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. 3 pts.*

Prerequisite: ELEN E6711 or the equivalent. Recommended preparation: a course in measure theory or advanced probability theory. Probability and point processes. Random intensity rate, martingales, and the integral representation of point process martingales. Recursive estimation, the theory of innovations, state estimate for queues. Markovian queueing networks. Hypothesis testing, the separation between filtering and detection. Mutual information and capacity for the Poisson-type channel. Stochastic control, dynamic programming for intensity control.

ELEN E9060x or y Seminar in systems biology*Lect: 2. 3 pts.*

Open to doctoral candidates, and to qualified M.S. candidates with the instructor's permission. Study of recent developments in the field of systems biology.

EEBM E9070x or y Seminar in computational neuroscience and neuroengineering*Lect: 2. 3 pts.*

Open to doctoral candidates and qualified M.S. candidates with the instructor's permission. Study of recent developments in computational neuroscience and neuroengineering.

ELEN E9101y Seminar in physical electronics*Sem: 2. 3 pts.*

Prerequisite: Quantum electronics and ELEN E4944, or the instructor's permission. Advanced topics in classical and quantum phenomena that are based on ion and electron beams, gas discharges, and related excitation sources. Application to new laser sources and microelectronic fabrication.

ELEN E9201x or y Seminar in circuit theory*Sem: 2. 3 pts.*

Open to doctoral candidates, and to qualified M.S. candidates with the instructor's permission. Study of recent developments in linear, nonlinear, and distributed circuit theory and analysis techniques important to the design of very large-scale integrated circuits.

ELEN E9301y Seminar in electronic devices*Sem: 2. 3 pts.*

Open to doctoral candidates, and to qualified M.S. candidates with the instructor's permission. Theoretical and experimental studies of semiconductor physics, devices, and technology.

ELEN E9303x or y Seminar in electronic circuits*Sem: 2. 3 pts.*

Open to doctoral candidates, and to qualified M.S. candidates with the instructor's permission. Study of recent developments in electronic circuits.

ELEN E9402x and y Seminar in quantum electronics*Sem: 2. 3 pts.*

Open to doctoral candidates, and to qualified M.S. candidates with the instructor's permission. Recent experimental and theoretical developments in various areas of quantum electronics research. Examples of topics that may be treated include novel nonlinear optics, lasers, transient phenomena, and detectors.

ELEN E9403x Seminar in photonics*Sem: 2. 3 pts.*

Prerequisite: ELEN E4411. Open to doctoral candidates, and to qualified M.S. candidates with the instructor's permission. Recent experimental and theoretical developments in 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.

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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.

Engineering management systems is a multidisciplinary field in industrial engineering, operations research, contemporary technology, business, economics, and management. It provides a foundation for decision making and managing risks in complex systems.

Financial engineering is a multidisciplinary field integrating financial theory with economics, methods of engineering, tools of mathematics, and practice of programming. The field provides training in the application of engineering methodologies and quantitative methods to finance.

Current Research Activities

In industrial engineering, research is conducted in the area of logistics, routing, scheduling, production and supply chain management, inventory control, revenue management, and quality control.

In operations research, new developments are being explored in mathematical programming, combinatorial optimization, stochastic modeling, computational and mathematical finance, queueing theory, reliability, simulation, and both deterministic and stochastic network flows.

In engineering and management systems, research is conducted in the areas of logistics, supply chain optimization, and revenue and risk management.

In financial engineering, research is being carried out in portfolio management; option pricing, including exotic and real options; computational finance, such as Monte Carlo simulation and numerical methods; as well as data mining and risk management.

Projects are sponsored and supported by leading private firms and government agencies. In addition, our students and faculty are involved in the work of two research and educational centers: the Center for Applied Probability (CAP), the Center for Financial Engineering (CFE), and the Computational and Optimization Research Center (CORC). These centers are supported principally by grants from the National Science Foundation.

The Center for Applied Probability (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.

The Center for Financial Engineering (CFE) at Columbia University encourages interdisciplinary research on financial engineering and mathematical modeling in finance and promoting collaboration between Columbia faculty and financial institutions, through the organization of research seminars, workshops, and the dissemination of research done by members of the Center.

Computational Optimization Research Center (CORC) at Columbia

University is an interdisciplinary group of researchers from a variety of departments on the Columbia campus. Its permanent members are Professors Daniel Bienstock, Don Goldfarb, Garud Iyengar, Jay Sethuraman, and Cliff Stein, from the Industrial Engineering and Operations Research Department, and Professor David Bayer, from the Department of Mathematics at Barnard College.

Researchers at CORC specialize in the design and implementation of state-of-the-art algorithms for the solution of large-scale optimization problems arising from a wide variety of industrial and commercial applications.

UNDERGRADUATE PROGRAMS

B.S. in 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; and
4. to instill in our students an understanding of ethical issues and professional and managerial responsibilities.

B.S. in 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.

B.S. in Operations Research: Engineering Management Systems

This operations research option is designed to provide students with an understanding of contemporary technology and management. It is for students who are interested in a technical-management background rather than one in a traditional engineering field. It consists of required courses in industrial engineering and operations research, economics, business, and computer science, intended to provide a foundation for dealing with engineering and management systems problems. Elective courses are generally intended to provide a substantive core in at least one technology area and at least one management area.

Due to the flexibility of this option, it can incorporate the varied educational needs of preprofessional students interested in law, medicine, business, and finance. In addition, most students are encouraged to add a minor in economics or computer science to their standard course schedules.

B.S. in Operations Research: Financial Engineering

The operations research concentration in financial engineering is designed to provide students with an understanding of the application of engineering methodologies and quantitative methods to finance. Financial engineering is a multidisciplinary field integrating financial theory with economics, methods of engineering, tools of mathematics, and practice of programming. Students graduating with this concentration are prepared to enter careers in securities, banking, financial management, and consulting industries, and fill quantitative roles in corporate treasury and finance departments of general manufacturing and service firms.

Students who are interested in pursuing the rigorous concentration in financial engineering must demonstrate proficiency in calculus, computer programming, linear algebra, ordinary differential equations, probability, and statistics. Applications to the concentration will be accepted during the fall semester of the sophomore year, and students will be notified of the departmental decision by the end of that spring semester. The department is seeking students who demonstrate strength and consistency in all the above-mentioned areas. Application to this concentration is available online: www.ieor.columbia.edu/pages/undergraduate/financial_eng/bsfe_app.html.

Undergraduate Advanced Track

The undergraduate advanced track is designed for advanced undergraduate students with the desire to pursue further higher education after graduation. Students with a minimum cumulative GPA of 3.4 and faculty approval have the opportunity to participate. Students are invited to apply to the track upon the completion of their sophomore year. Advanced track students are required to take higher-level IEOR courses, including the following:

IEOR E4004 instead of *IEOR E3608*
IEOR E4106 instead of *IEOR E3106*
IEOR E4403 instead of *IEOR E4003*
 and *MATH V2500*

Students successfully completing the requirements of the undergraduate

advanced track will receive recognition on their academic record.

Minors

A number of minors are available for students wishing to add them to their programs. These minors are described starting on page 186 of this bulletin.

IEOR program students may want to consider minors in economics or computer science. In addition, operations research and engineering and management systems majors may elect to minor in industrial engineering, and industrial engineering majors may elect to minor in operations research.

The department does not offer a minor in engineering management systems or financial engineering.

Major in Economics— Operations Research

Students in Columbia College and the School of General Studies may register for a major in economics and operations research. This degree provides a student with a foundation in economic theory comparable to that provided by the general economics major while at the same time introducing the student to the field of operations research. The program is recommended for students with strong quantitative skills who are contemplating graduate studies in economics, operations research, or business.

For more information on the major in economics and operations research, students should contact the departmental advisers: In Economics, Professor Susan Elmes, 1018 International Affairs Building, 212-854-3680, and in IEOR, Professor Donald Goldfarb, 313 S. W. Mudd, 212-854-8011.

Required courses

This program requires a total of 50.5 points: 23 points in economics, 11 points in mathematics, 13.5 points in industrial engineering and operations research, and 3 points in computer science.

ECONOMICS

ECON W1105: Principles of economics
ECON W3211: Intermediate microeconomics
ECON W3213: Intermediate macroeconomics
ECON W3412: Introduction to econometrics
one seminar
two electives (one must be above the 2000

level). At least one of the electives must have **W3211** or **W3213** as a prerequisite.

OPERATIONS RESEARCH

SIEO W3600 or **SIEO W4150:** Introduction to probability and statistics
IEOR E3106 or **IEOR E4106:** Introduction to operations research: stochastic models
IEOR E3608: Introduction to mathematical programming (or **IEOR E4004:** Introduction to operations research: deterministic models)
one elective with the IEOR designation

Note: It is important to take *SIEO W3600*, *IEOR E3608*, and *IEOR E3106* as early as feasible; they are prerequisites for most other courses in the program.

MATHEMATICS

V1101, **V1102**, and **V1201** (Calculus I, II, and III),
V2010 (Linear algebra)

COMPUTER SCIENCE

COMS W1004 or **W1007:** Introduction to computer programming
 or
 another approved computer science course that involves substantial work in programming.

GRADUATE PROGRAMS

The Department of Industrial Engineering and Operations Research offers courses and M.S. programs in (1) engineering management systems, (2) financial engineering, (3) industrial engineering, and (4) operations research. Graduate programs leading to a Ph.D. or Eng.Sc.D. in industrial engineering or operations research, as well as one leading to the professional degree of Industrial Engineer, are also available. In addition, the department and the Graduate School of Business offer combined M.S./M.B.A. degree programs in industrial engineering, in financial engineering, and in operations research.

All degree program applicants are required to take the Aptitude Tests of the Graduate Record Examination. M.S./M.B.A. candidates are also required to take the Graduate Management Admissions Test.

A minimum grade point average of 3.0 (B) in an undergraduate engineering program is required for admission to the M.S. and professional degree programs. Students are expected, on entry, to have completed courses in ordinary differential equations, in linear algebra, and in a programming language such as C or Java.

M.S. in Engineering Management Systems

The Master of Science program in engineering management systems (EMS) provides students with a 30-point (33 points if no background in probability and statistics) that emphasizes both technology and management perspectives in solving problems, making decisions, and managing risks in complex systems. Students pursuing this degree program are provided with a rigorous exposure to deterministic optimization and stochastic modeling, a basic coverage of applications in the areas of operations engineering and management, and an in-depth coverage of applications.

Graduates from this program are expected to assume positions as business analysts in logistics, supply chain, revenue management, and consulting firms, and as financial analysts in risk-management departments of investment banks, hedge funds, and credit-card and insurance firms.

The department requires that MSEMS students achieve grades of B– or higher in each of the fundamental core courses (*IEOR E4004* and *IEOR E4106*). Poor performance in these courses is indicative of inadequate preparation and is very likely to lead to serious problems in completing the program. In addition, students must maintain a cumulative GPA equivalent to a B– during every term enrolled. Students failing to meet these criteria may be asked to withdraw from the program.

M.S. in Financial Engineering

The department offers a full-time M.S. in financial engineering. This program is intended to provide a unique technical background for students interested in pursuing career opportunities in financial analysis and risk management. In addition to the basic requirements for graduate study, students are expected, on entry, to have attained a high level of mathematical and computer programming skills, particularly in probability, statistics, linear algebra, and the use of a programming language such as C or JAVA. Work experience is desirable but not required. For the Class of 2009–2010, the MSFE program requires the completion of 36 points on a full-time

M.S. in Engineering Management Systems (30 points)¹

Required Core Courses (9 points)	Management Electives (minimum 6 points) ²	Engineering/Technical Electives (minimum 6 points) ²
<p>The department recommends that students complete these core courses during their first term of study:</p> <p>IEOR E4004 Intro to operations research: deterministic models</p> <p>IEOR E4106 Intro to operations research: stochastic models</p> <p>IEOR E4111 Operations consulting</p> <p>(SIEO W4150 Intro to probability and statistics <i>must be taken if students have not taken the equivalent previously</i>)</p>	<p>Choose from:</p> <p>ECIE W4280 Corporate finance</p> <p>FINC B6302 Capital markets & investments</p> <p>FINC B8301 Advanced corporate finance</p> <p>IEME E4310 The manufacturing enterprise</p> <p>IEOR E4201 Engineering of management</p> <p>IEOR E4202 Engineering of management II</p> <p>IEOR E4505 Operations research in public policy</p> <p>IEOR E4510 Project management</p> <p>IEOR E4550 Entrepreneurial business creation for engineers</p> <p>IEOR E4705 Studies in operations research</p> <p>IEOR E4998 Managing technological innovation & entrepreneurship</p>	<p>Choose from:</p> <p>IEOR E4000 Production management</p> <p>IEOR E4210 Supply chain management</p> <p>IEOR E4220 Demand and supply analytics</p> <p>IEOR E4403 Advanced engineering & corporate economics</p> <p>IEOR E4404 Simulation</p> <p>IEOR E4405 Production scheduling</p> <p>IEOR E4407 Game theoretic models of operations</p> <p>IEOR E4418 Logistics and transportation management</p> <p>IEOR E4601 Dynamic pricing and revenue optimization</p>

¹All courses listed are 3 points each unless otherwise specified.

²The remaining electives can be selected from IEOE, the School of International and Public Affairs, the Business School, and the Departments of Economics, Mathematics, and Statistics. At least 18 points out of 30 (or 33, if taking SIEO W4150) must be taken in IEOE.

basis only. Students start with an eight-week part I summer session (July 6 to August 28, 2009), and continue through the 2009–2010 academic year. Students may complete the program in May 2010, August 2010, or December 2010.

The Department requires that students achieve grades of B– or higher in each of the three fundamental core courses offered in the first summer. Poor performance in these courses is indicative of inadequate preparation and is very likely to lead to serious problems in completing the program. As a result, students failing to meet this criterion will be asked to withdraw from the program.

M.S. in Industrial Engineering

The Master of Science program in industrial engineering (30 points) is

intended to enable students with engineering undergraduate degrees to enhance their training in special fields, including production planning, inventory control, scheduling, and industrial economics.

MSIE degree candidates are required to satisfy a core program of graduate courses:

SIEO W4150: Introduction to probability and statistics

IEOR E4000: Production management

IEOR E4004: Intro to operations research: deterministic models

IEOR E4106: Intro to operations research: stochastic models

All students must take at least 18 points of graduate work in the IEOE Department (denoted by courses with the IEOE designation) and at least 30 points of graduate studies at Columbia.

In addition to courses within the Engineering School, students can also take electives from various schools within the University, such as the Business School, the School of International and Public Affairs, the Graduate School of Arts and Sciences, and the Law School.

MSIE students may choose concentrations in the following areas:

Production and operations management (www.ieor.columbia.edu/pages/graduate/ms_industrial_eng/pom.html)

Regulated industries (www.ieor.columbia.edu/pages/graduate/ms_industrial_eng/ri.html)

The MSIE program 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.

The department requires that MSIE students achieve grades of B– or higher in each of the fundamental core courses (*IEOR E4004* and *IEOR E4106*). Poor performance in these courses is indicative of inadequate preparation and is very likely to lead to serious problems in completing the program. In addition, students must maintain a cumulative GPA equivalent to a B– during every term enrolled. Students failing to meet these criteria may be asked to withdraw from the program.

M.S. in Operations Research

The Master of Science program in operations research (30 points) is designed to enable students to concentrate their studies in methodological areas such as mathematical programming, stochastic models, and simulation. The department offers a variety of domain-specific courses in areas that include logistics, supply chain management, revenue management, risk management, and financial engineering.

All students must take at least 18 points of graduate work in the IEOR Department (denoted by courses with the IEOR designation) and at least 30 points of graduate studies at Columbia. In addition to courses within the Engineering School, students can also take electives from various schools with-

M.S. in Financial Engineering—May 2010 Completion (36 points) ¹		
Summer Semester (7.5 points) ²	Fall Semester (15 points) ²	Spring Semester (13.5 points) ²
<p>Required core courses:</p> <p>IEOR E4701 Stochastic models for financial engineering</p> <p>IEOR E4702 Statistical inference for financial engineering (1.5)</p> <p>IEOR E4706 Foundations of financial engineering</p>	<p>Required core courses:</p> <p>IEOR E4007 Optimization for financial engineering</p> <p>IEOR E4703 Monte Carlo simulation</p> <p>IEOR E4707 Continuous time finance</p> <p>IEOR E4709 Data analysis for financial engineering</p> <p>Elective</p>	<p>Choose four from the courses below, plus one other course in consultation with faculty adviser:³</p> <p>IEOR E4500 Applications programming for financial engineering</p> <p>IEOR E4602 Quantitative risk management</p> <p>IEOR E4630 Asset allocation</p> <p>IEOR E4708 Seminar on important papers in financial engineering</p> <p>IEOR E4710 Term structure modeling</p> <p>IEOR E4718 Intro to implied volatility smile</p> <p>IEOR E4731 Credit risk and credit derivatives</p> <p>DRAN B8835 Security pricing models</p>

¹Students may conclude the program in May, August, or December 2010. Please visit the departmental Web site (www.ieor.columbia.edu/pages/graduate/ms_financial_eng/index.html) for more information.

²All courses listed are for 3 credits, unless stated otherwise.

³Other courses include experimental finance, foreign exchange and related derivative instruments, hedge fund management, structured products, etc. Specific offerings may vary each term.

in the University, such as the Business School, the School of International and Public Affairs, the Graduate School of Arts and Sciences, and the Law School.

The MSOR program 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.

The Department requires that MSOR students achieve grades of B– or higher in each of the fundamental core courses (*IEOR E4004* and *IEOR E4106*). Poor performance in these courses is indicative of inadequate preparation and is very likely to lead to serious problems in completing the program. In addition, students must maintain a cumulative GPA equivalent to a B– during every term enrolled. Students failing to meet these criteria may be asked to withdraw from the program.

Joint M.S. and M.B.A.

The joint M.S. and M.B.A. degree program offered by The Fu Foundation School of Engineering and Applied Science and the Graduate School of Business trains students interested in combining business and engineering careers. This option is available for students in the financial engineering, industrial engineering, and operations research programs.

Admission for the combined program requires filling out separate applications from both schools, meeting the requirements of both schools; admission requirements are the same as those for the regular M.S. programs and for the M.B.A. Students in the program will have advisers assigned from both schools.

For more information, please visit the department or see the departmental Web site at www.ieor.columbia.edu.

Doctoral Studies

The requirements for the Ph.D. in industrial engineering and operations research are identical. Both require the student to pass two qualifying examinations—respectively covering stochastic and deterministic models—as well as submit and defend a dissertation based on the candidate's original research, conducted under the supervision of a faculty member. The dissertation work may be theoretical or computational or both. Doctoral students are also required to select a concentration for their studies and complete a certain amount of course work in one of the following fields: applied probability, mathematical programming, financial engineering, or supply chain management and logistics. Doctoral candidates must obtain a minimum of 60 points of formal course credit beyond the bachelor's degree. A master's degree from an accredited institution may be accepted as equivalent to 30 points. A minimum of 30 points beyond the master's degree must be earned while in residence in the doctoral program. Detailed information regarding the requirements for the doctoral degree may be obtained in the department office or online at www.ieor.columbia.edu.

COURSES IN INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

For up-to-date course offerings, please visit www.ieor.columbia.edu.

IEOR E3106x Introduction to operations research: stochastic models

Lect: 3. 3 pts. Professor Sigman.

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: queuing, reliability, inventory, and finance.

IEOR E3402y Production-inventory planning and control

Lect: 3. Rec: 1. 4 pts. The faculty.

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

M.S. in Operations Research (30 points)			
Required Core Courses (9 points)	SIEO W4150 Intro to Probability and Statistics (3) IEOR E4004 Intro to OR: Deterministic Models (3) IEOR E4106 Intro to OR: Stochastic Models (3) IEOR E4004 Simulation (3)		
Electives (18 points)	The department suggests a number of elective courses depending on areas of focus. The areas of focus include optimization, applied probability, and financial and managerial applications of operations research.		
Optimization The department recommends taking at least three of the following elective courses:	IEOR E4000 Production and operations management IEOR E4210 Supply chain management IEOR E4405 Production scheduling IEOR E4418 Logistics and transportation management IEOR E4600 Applied integer programming IEOR E4630 Asset allocation		
Applied Probability The department recommends taking at least three of the following elective courses:	IEOR E4000 Production and operations management IEOR E4210 Supply chain management IEOR E4220 Demand and supply analytics IEOR E4407 Game theoretic models of operation IEOR E4601 Dynamic pricing and revenue management IEOR E4602 Quantitative risk management IEOR E4700 Intro to financial engineering		
Students interested in financial and managerial applications of operations research should consider taking:	Corporate Finance Courses	Derivatives Pricing Courses	Management Courses
	IEOR E4403 Advanced engineering & corporate economics <i>And at least one of:</i> FINC B6302 Capital markets & investments FINC B8301 Advanced corporate finance ECIE W4280 Corporate finance	IEOR E4700 Intro to financial engineering <i>And at least one of:</i> IEOR E4602 Quantitative risk management IEOR E4630 Asset allocation IEOR E4620 Pricing models	<i>At least one of:</i> IEOR E4510 Project management IEOR E4550 Entrepreneurial business creation for engineers IEOR E4998 Managing technological innovation IEOR E4505 OR in public policy IEOR E4705 Studies in OR

integrated production-inventory systems. Production scheduling. Term project.

SIEO W3600y Introduction to probability and statistics

Lect: 3. Rec: 1. 4 pts. Professor Sigman.

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.

IEOR E3608x Introduction to mathematical programming

Lect: 3. Rec: 1. 4 pts. Professor Chudnovsky.

Prerequisite: Linear algebra (MATH V2010 or APMA E3101) and data structures. Introduction to mathematical programming models and computational techniques. Linear programming and the simplex method, dynamic programming, production planning applications.

IEOR E3658x Probability

Lect: 3. 3 pts. The faculty.

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 E3900x, y, and s Undergraduate research or project

1 to 3 pts. The faculty.

Prerequisite: Approval by a faculty member who agrees to supervise the work. Independent work involving experiments, computer programming, analytical investigation, or engineering design.

IEOR E4000x Production management

Lect: 3. 3 pts. The faculty.

Prerequisites or corequisites: SIEO W4105 and IEOR E4004. An introduction to production management for students not having an industrial engineering bachelor's degree. Topics include deterministic inventory models, aggregate production planning, material requirements planning, forecasting, stochastic inventory models, and supply chain management. Emphasis is on modeling and its implications for managerial decisions.

IEOR E4001y Design and management of production and service systems

Lect: 3. 3 pts. Professor Riccio.

Prerequisite: IEOR E4000 or E3402. Design and management problems in production and service systems: process design and capacity management, inventory system design and management, aggregate planning, staff scheduling, and quality control system design.

IEOR E4003x Industrial economics

Lect: 3. 3 pts. Professor Kachani.

Prerequisites or corequisites: SIEO W3600 (or W4150) and IEOR E3608 (or E4004). Introduction to the economic evaluation of industrial projects. Economic equivalence and criteria. Deterministic approaches to economic analysis. Multiple projects and constraints. Analysis and choice under risk and uncertainty.

IEOR E4004x and y Introduction to operations research: deterministic models

Lect: 3. 3 pts. Professors Goldfarb and Chudnovsky.

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 E4007x Optimization models and methods for financial engineering

Lect: 3. 3 pts. s: Professor Iyengar.

Prerequisite: Linear algebra (MATH V2010 or APMA E3101). Linear, quadratic, nonlinear, dynamic, and stochastic programming. Some discrete optimization techniques will also be introduced. The theory underlying the various optimization methods is covered. The emphasis is on modeling and the choice of appropriate optimization

methods. Applications from financial engineering will be discussed.

IEOR E4106x and y Introduction to operations research: stochastic models

Lect: 3. 3 pts. Professors Yao and White.

For graduate and undergraduate advanced track students only. Prerequisite: SIEO W3600 or W4150. Some of the main stochastic models used in engineering and operations research applications: discrete-time Markov chains, Poisson processes, birth and death processes and other continuous Markov chains, renewal reward processes. Applications: queueing, reliability, inventory, and finance.

SIEO W4150x Introduction to probability and statistics

Lect: 3. 3 pts. Professor Gallego.

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. The faculty.

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. Professor Riccio.

Prerequisite: ECON W2261. Management control via the budgeting and financial processes. Topics include the preparation, evaluation, and implementation of operating and capital budgets and review of their performance. Examples from contemporary practice.

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.

INDUSTRIAL ENGINEERING: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	→ Linear algebra (3) ¹
PHYSICS (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
CHEMISTRY (choose one course)	C1403 (3) or C1404 (3) or C1604 (3.5) or C3045 (3.5)			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	→ C1010 (3) Z1003 (0)	→ C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES	ECON W1105 (4) and W1155 recitation (0) either semester		HUMA C1001, COCI C1101, or Global Core (3–4)	HUMA C1002, COCI C1102, or Global Core (3–4)
			HUMA W1121 or W1123 (3) either semester	
FIRST- AND SECOND-YEAR DEPT. REQUIREMENTS	Professional-level course (3) (see pages 12–13)		ENGI E2261 (3)	SIEO W3600 (4)
COMPUTER SCIENCE			COMS W1004 (Java) (3) or COMS W1007 (Java) (3) ² and COMS W3134 (3) or COMS W3137 (4) ²	
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.

IEOR E4403x Advanced engineering and corporate economics

Lect: 3. 3 pts. Professor Kachani.

Prerequisites: SIEO W3600 (or W4150) and IEOR E3608 (or E4004). Key measures and analytical tools to assess the financial performance of a firm and perform the economic evaluation of industrial projects. Deterministic mathematical programming models for capital budgeting. Concepts in utility theory, game theory, and real options analysis.

IEOR E4404x and y Simulation

Lect: 3. Rec. 1. 4 pts. x: Professor Blanchet; y: The faculty.

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 E4004, and a working knowledge of computer programming. Job shop scheduling: parallel machines, machines in series; arbitrary job shops. Algorithms, complexity, and worst-case analysis. Effects of randomness: machine breakdowns, random processing time. Term project.

IEOR E4406x Facilities location, routing, and network design

Lect: 3. 3 pts. Professor Luss.

Prerequisites: IEOR E3608 or E4004. Facility location problems in application areas such as telecommunications networks, product distribution systems and emergency services. Emphasis on applications, algorithmic approaches, routing, and network design problems.

IEOR E4407x Game theoretic models of operations

Lect: 3. 3 pts. Professor Sethuraman.

Prerequisites: IEOR E4004 (or E3608), E4106 (or E3106), and familiarity with differential equations and a programming language; or the instructor's permission. A mathematically rigorous study of game theory and auctions, and their application to operations management. Topics include introductory game theory, private value auction, revenue equivalence, mechanism design, optimal auction, multiple-unit auctions, combinatorial auctions, incentives, and supply chain coordination with contracts. No previous knowledge of game theory is required.

INDUSTRIAL ENGINEERING: THIRD AND FOURTH YEARS

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES¹	MATH E1210 (3) Ordinary diff. equations IEOR E3608 (4) Mathematical prog. IEOR E3106 (3) Stochastic models COMS W4111 (3) Database sys.	IEOR E3402 (4) Production planning IEOR E4404 (4) Simulation	IEOR E4201 (3) Eng. of management, I IEOR E4003 (3) Industrial econ. IEOR E4207 (3) Human factors	IEOR E4202 (3) Eng. of management, II IEOR E4405 (3) Prod. scheduling IEOR E4412 (3) Quality control & management
TECHNICAL ELECTIVES	Choose one (3 pts.): Please consult the list on the departmental Web site: www.ieor.columbia.edu			
NONTECH ELECTIVES	Complete 27-point requirement. See page 11 or www.engineering.columbia.edu for details			

¹Taking required courses later than the prescribed semester is not permitted.

IEOR E4412y Quality control and management

Lect: 3. 3 pts. Professor Latzko.

Prerequisite: SIEO W3600 or W4150. Statistical methods for quality control and improvement: graphical methods, introduction to experimental design and reliability engineering, and the relationships between quality and productivity. Contemporary methods for product and process design, production, and delivery of products and services.

IEOR E4416y Capacity planning: models, algorithms and applications

Lect: 3. 3 pts. Professor Luss.

Prerequisite: IEOR E3608 or E4004. Capacity planning problems are of significant importance in capital-intensive service and manufacturing industries, including telecommunications networks, power generation and transport, transportation networks, and heavy process industries. We will explore a large variety of capacity planning models with emphasis on timing, sizing, location, and capacity type decisions. The course will emphasize modeling approaches, key issues, and algorithms.

IEOR E4418y Logistics and transportation management

Lect: 3. 3 pts. Professor Kachani.

Prerequisite: IEOR E3608 or E4004, or the 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 FE

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, simulation 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 E4550x Entrepreneurial business creation for engineers

Lect: 3. 3 pts. Professor Robbins.

Prerequisites: ECON W1105 and ECON W2261. Introduces the basic concepts and methodologies that are used by the nonengineering part of the world in creating, funding, investing in, relating to, and operating entrepreneurial ventures. The first half of the course focuses on the underpinning principles and skills required in recognizing, analyzing, evaluating, and nurturing a business idea. The second half focuses on basic legal knowledge necessary in creating a business entity, defending your business assets, and promoting

effective interaction with other individuals and organizations.

IEOR E4600y Applied integer programming

Lect: 3. 3 pts. Professor Bienstock.

Prerequisites: IEOR E3608 and E4004, linear algebra (MATH V2010 or APMA E3101), and a working knowledge of computer programming. Applications of mathematical programming techniques, especially integer programming, with emphasis on software implementation. Typical applications: capacity expansion, network design, and scheduling.

IEOR E4601y Dynamic pricing and revenue management

Lect: 2.5. 3 pts. Professor Gallego.

Prerequisite: SIEO W4150 and IEOR E4004. Focus on capacity allocation, dynamic pricing and revenue management. Perishable and/or limited product and pricing implications. Applications to various industries, including service, airlines, hotel, resource rentals, etc.

IEOR E4602y Quantitative risk management

Lect: 2.5. 3 pts. Professor Blanchet.

Prerequisite: SIEO W4150 and IEOR E4106. Risk management models and tools; measure risk using statistical and stochastic methods, hedging, and diversification. Examples include insurance risk, financial risk, and operational risk. Topics covered include VaR, estimating rare events, extreme value analysis, time series estimation of extremal events, axioms of risk measures, hedging using financial options, credit risk modeling, and various insurance risk models.

OPERATIONS RESEARCH: FIRST AND SECOND YEARS

OPERATIONS RESEARCH: FIRST AND SECOND YEARS				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	→ Linear algebra (3) ¹
PHYSICS (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
CHEMISTRY (choose one course)	C1403 (3) or C1404 (3) or C1604 (3.5) or C3045 (3.5)			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	→ C1010 (3) → Z1003 (0)	→ C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES	ECON W1105 (4) and W1155 recitation (0) either semester		HUMA C1001, COCI C1101, or Global Core (3–4)	HUMA C1002, COCI C1102, or Global Core (3–4)
			HUMA W1121 or W1123 (3) either semester	
FIRST- AND SECOND-YEAR DEPT. REQUIREMENTS	Professional-level course (3) (see pages 12–13)		ENGI E2261 (3)	SIEO W3600 (4)
COMPUTER SCIENCE			COMS W1004 (Java) (3) or COMS W1007 (Java) (3) ² and COMS W3134 (3) or COMS W3137 (4) ²	
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.

IEOR E4620x Pricing models for financial engineering

Lect: 2.5. 3 pts. Professor Tatevossian.

Prerequisite: IEOR E4700. Models for pricing and hedging equity, fixed-income, credit-derivative securities, standard tools for hedging and risk management, models and theoretical foundations for pricing equity options (standard European, American equity options, Asian options), standard Black-Scholes model (with multi-asset extension), asset allocation, portfolio optimization, investments over long-time horizons, and pricing of fixed-income derivatives (Ho-Lee, Black-Derman-Toy, Heath-Jarrow-Morton interest-rate model). Note: Students may not take both IEOR E4630 and DRAN B8835.

IEOR E4630 Asset allocation

Lect: 2.5. 3 pts. Professor Iyengar.

Introduction to modern asset allocation techniques. The following topics are covered: bond portfolio selection, mean-variance portfolio selection, active portfolio selection, robust portfolio selection, beyond mean-variance: VaR, CVaR and approximation, and implementation details: parameter estimation, Bayesian approaches, transaction and trading costs.

IEOR E4700x and y Introduction to financial engineering

Lect: 3. 3 pts. Professors Yao and Gallego.

Prerequisite: IEOR E3106 or IEOR E4106, or the equivalent. Introduction to investment and financial instruments via portfolio theory and derivative securities, using basic operations research/engineering methodology. Portfolio theory, arbitrage;

Markowitz model, market equilibrium, and the capital asset pricing model. General models for asset price fluctuations in discrete and continuous time. Elementary introduction to Brownian motion and geometric Brownian motion. Option theory; Black-Scholes equation and call option formula. Computational methods such as Monte Carlo simulation.

IEOR E4701s Stochastic models for financial engineering

Lect: 3. 3 pts. Professor Cont.

Prerequisite: SIEO W4105 or the equivalent. Review of elements of probability theory, Poisson processes, exponential distribution, renewal theory. Wald's equation. Introduction to discrete-time Markov chains and applications to queueing theory, inventory models, branching processes.

OPERATIONS RESEARCH: THIRD AND FOURTH YEARS

OPERATIONS RESEARCH: THIRD AND FOURTH YEARS				
	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES¹	MATH E1210 (3) Ordinary diff. equations IEOR E3608 (4) Mathematical prog. 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
TECHNICAL ELECTIVES	Choose four electives (12 pts. total): Please consult the list on the departmental Web site: www.ieor.columbia.edu			
NONTECH ELECTIVES	Complete 27-point requirement. See page 11 or www.engineering.columbia.edu for details			

¹Taking required courses later than the prescribed semester is not permitted.

IEOR E4702s Statistical inference for financial engineering

Lect: 1.5. 1.5 pts. Professor Kou.

The course covers basic tools of statistical inference relevant to financial engineering. The statistical topics covered include point estimation, maximum likelihood estimators, confidence intervals, the delta method, hypothesis testing, and goodness of fit tests. The financial examples include selection bias in finance, estimation of drift and volatility in the geometric Brownian motion model, the leptokurtic feature, and difficulties in estimating the tail distributions of asset returns.

IEOR E4703x Monte Carlo simulation

Lect: 3. 3 pts. Professor Blanchet.

Prerequisite: IEOR E4701 or the equivalent. Multivariate random number generation, bootstrapping, Monte Carlo simulation, efficiency improvement techniques. Simulation output analysis, Markov-chain Monte Carlo. Applications to financial engineering. Introduction to financial engineering simulation software and exposure to modeling with real financial data. Note: Students who have taken IEOR E4404 may not register for this course.

IEOR E4705x Studies in operations research

Lect: 3. 3 pts. Professor Riccio.

Prerequisites: IEOR E3608 (or E4004) and E4106 (or E3106). Analysis and critique of current operations research studies. Blood bank inventory, fire departments, police departments, and housing operations research studies are considered.

IEOR E4706s Foundations in financial engineering

Lect: 3. 3 pts. Professors Kou and Tilman.

Prerequisites: SIEO W4150 and linear algebra (MATH V2010 or APMA E3101). Corequisites: IEOR E4701 and E4702 or their equivalents.

Bond mathematics. Introduction to forwards, futures, and other derivative securities. Discrete-time models of equity markets and the term structure. Pricing and dynamic hedging of derivative securities. Option pricing and Black-Scholes, introduction to real options and portfolio optimization.

IEOR E4707x Financial engineering: continuous-time asset pricing

Lect: 3. 3 pts. Professor Cont.

Prerequisite: IEOR E4701. 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 Seminar on classical and new papers in financial engineering

Lect: 3. 3 pts. Professor Derman.

Prerequisites: IEOR E4701 and 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 E4709y Data analysis for financial engineering

Lect: 3. 3 pts. The faculty.

Prerequisite: IEOR E4701. 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 E4710y Term structure models

Lect: 2. 3 pts. The faculty.

Prerequisites: IEOR E4706, E4707, and proficiency in programming. Interest rate models and numerical techniques for pricing and hedging interest rate contracts and fixed income securities.

IEOR E4718y Introduction to the implied volatility smile

Lect: 3. 3 pts. Professor Derman.

Prerequisite: IEOR E4706 or some knowledge of derivatives valuation models. During the past fifteen years the behavior of market options prices have shown systematic deviations from the classic Black-Scholes model. The course will examine the empirical behavior of implied volatilities, in particular the volatility smile that now characterizes most markets, and then discuss the mathematics and intuition behind new models that can account for the smile, and then examine their consequences for hedging and valuation.

IEOR E4720-E4729s and y Topics in quantitative finance

Lect: 2-2.5. 1.5-3 pts. The faculty.

Selected topics of interest in the area of quantitative finance. Offerings vary each year; possible topics include asset management, energy derivatives, experimental finance, foreign exchange and related derivative instruments, inflation derivatives, hedge fund management, modeling equity derivatives in Java, mortgage-backed securities, numerical solutions of partial differential equations, quantitative portfolio management, risk

OPERATIONS RESEARCH: ENGINEERING MANAGEMENT SYSTEMS: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	Linear algebra (3) ¹
PHYSICS (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	
CHEMISTRY (choose one course)	C1403 (3) or C1404 (3) or C1604 (3.5) or C3045 (3.5)			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	C1010 (3) Z1003 (0)	C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES	ECON W1105 (4) and W1155 recitation (0) either semester		HUMA C1001, COCI C1101, or Global Core (3–4)	HUMA C1002, COCI C1102, or Global Core (3–4)
			HUMA W1121 or W1123 (3) either semester	
FIRST- AND SECOND-YEAR DEPT. REQUIREMENTS	Professional-level course (3) (see pages 12–13)		ENGI E2261 (3)	SIEO W3600 (4)
COMPUTER SCIENCE			COMS W1004 (Java) (3) or COMS W1007 (Java) (3) ² and COMS W3134 (3) or COMS W3137 (4) ²	
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.

management, trading and technology in financial markets.

IEOR E4724x Topics in quantitative finance: hedge fund management

Lect: ?. 1.5–3 pts. Professor Metzger.

The course covers the critical managerial aspects and characteristics of hedge funds and the hedge fund industry, including legal regulations, strategies, risk management, performance evaluation, etc.

IEOR E4725y or s Topics in quantitative finance: numerical solutions of partial differential equations

Lect: ?. 1.5–3 pts. Professor Kani.

The course covers derivations and solutions of partial differential equations under a variety of

underlying stochastic price processes. Students will gain exposure to applications of partial differential equations to security pricing in different financial markets (i.e., equity derivatives, fixed income securities, and credit derivative markets).

IEOR E4726y Topics in quantitative finance: experimental finance

Lect: ?. 3 pts. Professors Stanton and Lipkin.

The course introduces concepts to propose trading schema, organize tests via options/stock databases, and carry out tests efficiently and accurately. It exposes students to the striking differences between static, thermodynamic/SDE model solutions and real (time-of-flight) pricing. They will become familiar with computational techniques for modeling and testing proposals for trading strategies.

IEOR E4731y Credit derivatives

Lect: 2.5. 3 pts. The faculty.

Prerequisites: IEOR E4701 and E4707.

Introduction to quantitative modeling of credit risk, with a focus on the pricing of credit derivatives. Focus on the pricing of single-name credit derivatives (credit default swaps) and collateralized debt obligations (CDOs). Detail topics include: the striking difference and credit risk, arbitrage pricing, default times, single-name credit derivatives, structured models for single-name credit risk, multi-name default barrier models and multi-name reduced form models.

IEOR E4900x, y, and s Master's research or project

1 to 3 pts. The faculty.

Prerequisite: Approval by a faculty member who

OPERATIONS RESEARCH: ENGINEERING MANAGEMENT SYSTEMS: THIRD AND FOURTH YEARS

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES¹	IEOR E3608 (4) Mathematical prog. MATH E1210 (3) Ordinary diff. equations IEOR E3106 (3) Stochastic models ECON W3211 (3) Microeconomics	IEOR E3402 (4) Production planning ECON W3213 (3) Macroeconomics COMS W4111 (3) Database systems	IEOR E4003 (3) Industrial econ. IEOR E4404 (4) Simulation	IEOR E4001 (3) Des. & mgmt. of prod. & service sys. IEOR E4550 Entrepren. bus. creation for engrs. or IEOR E4998 Managing technol. innov. & entrepreneurship
ELECTIVES	TECH	Technical and technology electives (12 pts. total) ²		
	MANAGEMENT	Management electives (9 pts. total): Please consult lists posted on IEOB Web site: www.ieor.columbia.edu		
	NONTECH	Complete 27-point requirement; see page 11 or www.engineering.columbia.edu for details		

¹Taking required courses later than the prescribed semester is not permitted.

²At least two technical electives must be chosen from IEOB; the complete list is available at www.ieor.columbia.edu.

agrees to supervise the work. Independent work involving experiments, computer programming, analytical investigation, or engineering design.

IEOR E4998x and y Managing technological innovation and entrepreneurship

Lect: 3. 3 pts. Professor McGourty.

This course will focus on the management and consequences of technology-based innovation. The course explores how new industries are created, how existing industries can be transformed by new technologies, the linkages between technological development and the creation of wealth and the management challenges of pursuing strategic innovation.

IEOR E4999x, y, and s Curricular practical training

1 to 2 pts. Professor Derman.

Prerequisite: Instructor's written approval. Only for IEOB graduate students who need relevant work experience as part of their program of study. Final reports required. This course may not be taken for pass/fail credit or audited.

IEOR E6400y Scheduling: deterministic models

Lect: 2. 3 pts. Professor Stein.

Prerequisite: IEOB 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. The faculty.

Prerequisite: IEOB E4004, SIEO W4150, or the instructor's permission. Vehicle routing in distribution systems. Routing problems in VLSI. Effects of randomness. Students registering for 3 points are required to do a term project.

MSIE W6408y Inventory theory

Lect: 2. 3 pts. The faculty.

Prerequisite: SIEO W4150 and dynamic programming. Construction and analysis of mathematical models used in the design and analysis of inventory systems. Deterministic and stochastic demands and lead times. Optimality of (s, S) policies. Multiproduct and multi-echelon systems. Computational methods.

SIEO W6501x Stochastic processes and applications, I

Lect: 2.5. 3 pts. The faculty.

Prerequisite: SIEO W4105 or the equivalent. Advanced treatment of discrete and continuous-time Markov chains; elements of renewal theory; martingales; Brownian motion, stochastic integrals, Ito's rule.

SIEO W6502y Stochastic processes and applications, II

Lect: 2.5. 3 pts. Not given in 2009–2010.

Prerequisites: STAT G6104 and SIEO W6501. Recommended corequisite: STAT G6105. With the instructor's permission, the second term may be taken without the first. Introduction to martingales in continuous time. Brownian motion: construction, basic properties, sample paths. Stochastic integration, Ito's rule, applications. Introduction to stochastic differential equations and diffusion processes. Applications to financial economics: option pricing, consumption/ investment problems.

IEOR E6601y Advanced topics in linear programming

Lect: 2. 3 pts. The faculty.

Prerequisite: IEOB 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: IEOB E6613 or the equivalent. Convex sets and functions, convex duality and

OPERATIONS RESEARCH: FINANCIAL ENGINEERING: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	Linear algebra (3) ¹ and ODE (3)
PHYSICS (three tracks, choose one)	C1401 (3) C1601 (3.5) C2801 (4.5)	C1402 (3) C1602 (3.5) C2802 (4.5)	Physics or chemistry lab: PHYS C1493 (3) or PHYS W3081 (2) or CHEM C1500 (3) or CHEM C2507 (3) or CHEM C3085 (4) or	
CHEMISTRY (choose one course)	C1403 (3.5) or C1404 (3.5) or C1604 (3.5) or C3045 (3.5)			
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	C1010 (3) Z1003 (0)	C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES	ECON W1105 (4) and W1155 recitation (0) either semester		HUMA C1001, COCI C1101, or Global Core (3–4)	HUMA C1002, COCI C1102, or Global Core (3–4)
			HUMA W1121 or W1123 (3) either semester	
FIRST- AND SECOND- YEAR DEPT. REQUIREMENTS	Professional-level course (3) (see pages 12–13)		ENGI E2261 (4) and SIEO W3658 (3) or SIEO W4105 (3) and STAT W3659 (3) or STAT W4107 (3)	
COMPUTER SCIENCE			COMS W1004 (Java) (3) or COMS W1007 (Java) (3) and COMS W3134 (3) or COMS W3137 (3) ²	
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹The linear algebra requirement may be filled by either MATH V2010 or APMA E3101.

²Computer programming should be taken consecutively with data structures.

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. Not given in 2009–2010.

Prerequisites: IEOR E6613 and E6614. Algorithms for matching problems. Introduction to matroids; polyhedral combinatorics. Complexity theory and NP completeness. Perfect graphs and the ellipsoid method.

IEOR E6606y Advanced topics in network flows

Lect: 3. 3 pts. The faculty.

Prerequisite: Knowledge of elementary graph algorithms and computational complexity, equivalent to IEOR E6605, or COMS W4203 and W4231. Analysis of algorithms and their complexity for a variety of network routing problems. Topics: overall minimum cuts, minimum cost network flows, flows with losses and gains, parametric flows, dynamic flows, multicommodity flows and applications.

IEOR E6608x Integer programming

Lect: 2. 3 pts. The faculty.

Prerequisite: IEOR E6613 or the equivalent. Theoretical and algorithmical aspects of integer programming (IP). Theoretical topics: structure

of the set of feasible solutions of an IP problem, integral polyhedra, totally unimodular matrices, totally dual integral systems, Lovasz’s lattice reduction method, and Lenstra’s IP algorithm. Algorithmical topics to center on branch and bound algorithms and the “facet” approach to cutting-plane algorithms.

IEOR E6609y Dynamic programming

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

Prerequisite: IEOR E4701 or E4106 or the equivalent. General discrete time deterministic, dynamic programming, discrete time-parameter finite branching, Markov decision chains, team decisions, certainty equivalence, continuous time-parameter Markov branching decision processes. Applications

OPERATIONS RESEARCH: FINANCIAL ENGINEERING: THIRD AND FOURTH YEARS

		SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES		IEOR E3608 (4) Mathematical prog.	IEOR E3402 (4) Production planning	IEOR E4307 (3) Forecasting	IEOR E4500 (3) Applications prog. for FE
		IEOR E3106 (3) Stochastic models	IEOR E4404 (4) Simulation	IEOR E4407 (3) Game theoretic models of operations	IEOR E4630 (3) Asset allocation
		IEOR E4003 (3) Industrial econ.	IEOR E4700 (3) Intro. to FE	IEOR E4620 (3) Pricing models for FE	ECON E3412 (3) Intro. to econometrics
		ECON W3213 (3) Macroeconomics	COMS W4111 (3) Database systems ECON W3211 (3) Microeconomics		
ELECTIVES	FE TECH	Please consult the list on the departmental Web site: www.ieor.columbia.edu			
	NONTECH	Complete 27-point requirement; see page 11 or www.engineering.columbia.edu for details			

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. Not given in 2009–2010.

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. Not given in 2008–2009.

Prerequisites: IEOR E4701 or E4106, and SIEO W4150. An overview of the techniques available to formulate the reliability structure of a problem, to model the various element probabilities, to estimate parameters of element probability distributions based on data, and to unite these steps to obtain the reliability function of a system.

IEOR E6703x Advanced financial engineering

Lect: 2. 3 pts. Professor Kou.

Prerequisites: IEOR E4106 or E4701, 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 structure 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: IEOR E4106 or E4701. Introduction to congestion and related stochastic models. Topics include birth and death models, measures of performance, Little's Law, conservation law, PASTA, work in system, service disciplines and priorities, regenerative processes, stability and stationary distributions, approximations and bounds. Examples from telecommunications, production, inventory, and computer science.

IEOR E6706y Queueing networks

Lect: 2. 3 pts. Professor Yao.

Prerequisite: IEOR E4106 or E4701. An introduction to the analysis of queueing networks. Applications to computer and communication systems. The course covers reversibility, local balance, open and closed network models, computational procedures, and other related topics.

IEOR E6707y Advanced topics in queueing theory

Lect: 2. 3 pts. Professor Whitt.

Prerequisite: IEOR E6704 or the instructor's permission. Queueing models with general arrival and service processes, Loynes'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. Not given in 2009–2010.

Prerequisites: IEOR E4004, E4404, and E4106. Modeling, analysis, control, and optimization of discrete event stochastic systems. Generalized semi-Markov process models; sample path analysis; stochastic optimization optimal control. Applications to manufacturing and communication problems.

IEOR E6710y Markovian decision processes

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

Prerequisite: IEOR E4106 or E4701. Dynamic systems observed periodically and partially controlled by decisions made at each time of observation. Methods of determining optimal decision policies. Applications to inventory, inspection, maintenance, and replacement theories.

IEOR E6711x Stochastic models, I

Lect: 3. 4.5 pts. Professor Whitt.

Prerequisite: SIEO W4105 or the equivalent. Advanced treatment of stochastic modeling in the context of queueing, reliability, manufacturing, insurance risk, financial engineering and other engineering applications. Review of elements of probability theory; exponential distribution; renewal theory; Wald's equation; Poisson processes. Introduction to both discrete and continuous-time Markov chains; introduction to Brownian motion.

IEOR E6712y Stochastic models, II

Lect: 3. 4.5 pts. Professor Yao.

Prerequisite: IEOR E6711 or the equivalent. Continuation of IEOR E6711, covering further topics in stochastic modeling in the context of queueing, reliability, manufacturing, insurance risk, financial engineering, and other engineering applications. Topics from among generalized semi-Markov processes; processes with a nondiscrete state space; point processes; stochastic comparisons; martingales; introduction to stochastic calculus.

IEOR E6801x Monte Carlo methods

Lect: 2. 3 pts. Professor Blanchet.

Prerequisites: IEOR E4106 or E4701, and SIEO 4150, plus a working knowledge of programming. No prior knowledge of simulation is required. Random variate generation, discrete event simulation, Monte Carlo simulation, simulation output analysis, variance reduction, improving simulation efficiency, simulation-based derivative-estimation/sensitivity-analysis, and quasi-Monte Carlo techniques. Application of these techniques to financial engineering and performance analysis/ optimization of computer networking, telecommunications, and production systems.

IEOR E8100 Advanced topics in IEOR

Lect: 1–3. 1 to 3 pts. Instructor to be announced.

Prerequisite: Faculty 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.

Program in the Department of Applied Physics and Applied Mathematics, sharing teaching and research with the faculty of the Henry Krumb School of Mines.

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 James S. Im
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IN CHARGE OF SOLID-STATE
 SCIENCE AND ENGINEERING
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 Professor of Physics
 Wen I. Wang
 Professor of Electrical
 Engineering
 Chee Wei Wong
 Associate Professor of
 Mechanical Engineering

Materials science and engineering (MSE) focuses on understanding, designing, and producing technology-enabling materials by analyzing the relationships among the synthesis and processing of materials, their properties, and their detailed structure. This includes a wide range of materials such as metals, polymers, ceramics, and semiconductors. Solid-state science and engineering focuses on understanding and modifying the properties of solids from the viewpoint of the fundamental physics of the atomic and electronic structure.

Undergraduate and graduate programs in materials science and engineering are coordinated through the Materials Science and Engineering Program in the Department of Applied Physics and Applied Mathematics. This program promotes the interdepartmental nature of the discipline and involves the Departments of Applied Physics and Applied Mathematics, Chemical Engineering and Applied Chemistry, Electrical Engineering, and Earth and Environmental Engineering (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, Billinge, Chan, Herman, Im, Marianetti, Neumark, Noyan, 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 tech-

niques to reveal details of structure, ranging from the atomic to the macroscopic scale—details essential to understanding properties such as mechanical strength, electrical conductivity, and technical magnetism. These studies also give insight into problems of the deterioration of materials in service, enabling designers to prolong the useful life of their products. Materials science and engineering also focus on new ways to synthesize and process materials, from bulk samples to ultrathin films to epitaxial heterostructures to nanocrystals. This involves techniques such as UHV sputtering; molecular beam epitaxy; plasma etching; laser ablation, chemistry, and recrystallization; and other nonequilibrium processes. The widespread use of new materials and the new uses of existing materials in electronics, communications, and computers have intensified the demand for a systematic approach to the problem of relating properties to structure and necessitates a multidisciplinary approach.

Solid-state science and engineering uses techniques such as transport

measurements, X-ray photoelectron spectroscopy, inelastic light scattering, luminescence, and nonlinear optics to understand electrical, optical, and magnetic properties on a quantum mechanical level. Such methods are used to investigate exciting new types of structures, such as two-dimensional electron gases in semiconductor heterostructures, superconductors, and semiconductor surfaces and nanocrystals.

Current Research Activities

Current research activities in the materials science and engineering program at Columbia focus on thin films and electronic materials that enable significant advances in information technologies. Specific topics under investigation include interfaces, stresses, and grain boundaries in thin films; lattice defects and electrical properties of semiconductors; laser processing and ultrarapid solidification of thin films; nucleation in condensed systems; optical and electric properties of wide-band semiconductors; synthesis of nanocrystals, carbon nanotubes, and nanotechnology-related materials; deposition, in-situ characterization, electronic testing, and ultrafast spectroscopy of magnetoelectronic ultrathin films and heterostructures. In addition, there is research in surface and colloid chemistry involving both inorganic and organic materials such as surfactants, polymers, and latexes, with emphasis on materials/environment interactions.

The research activities in solid-state science and engineering are described later in this section.

Laboratory Facilities

Facilities and research opportunities also exist within the interdepartmental Materials Research Science and Engineering Center (MRSEC), Nanoscale Science and Engineering Center (NSEC), and Energy Frontier Research Center (EFRC), which focus on complex films formed from nanoparticles, molecular electronics, and solar energy conversion, respectively. Modern clean room facilities with optical and e-beam lithography, thin film deposition, and surface analytical probes (STM, SPM, XPS) are available. More specialized equipment exists in individual research groups in solid state engi-

neering and materials science and engineering. The research facilities in solid-state science and engineering are listed in the sections for each host department. Facilities, and research opportunities, also exist within the interdepartmental Materials Research Science and Engineering Center, which focuses on complex films composed of nanoparticles.

UNDERGRADUATE PROGRAM IN MATERIALS SCIENCE AND ENGINEERING

This program provides the basis for developing, improving, and understanding materials and processes for electronic, structural, and other applications. It draws from physics, chemistry, and other disciplines to provide a coherent background for immediate application in engineering or for subsequent advanced study. The emphasis is on fundamentals relating atomic- to microscopic-scale phenomena to materials properties and processing, including design and control of industrially important materials processes. Core courses and electives combine rigor with flexibility and provide opportunities for focusing on such areas as electronic materials, polymers, ceramics, biomaterials, structural materials, and metals and mineral processing. There are also opportunities for combining materials science and engineering with interests in areas such as medicine, business, law, or government.

The unifying theme of understanding and interrelating materials synthesis, processing, structure, and properties forms the basis of our MSAE program and is evident in the undergraduate curriculum and in faculty research activities. These activities include work on polycrystalline silicon for flat panel displays; high-temperature superconductors for power transmission and sensors; semiconductors for laser and solar cell applications; magnetic heterostructures for information storage and novel computation architectures; electronic ceramics for batteries, gas sensors, and fuel cells; electrodeposition and corrosion of metals; and the analysis and design of high-temperature reactors. Through involvement with our research groups, students gain valuable hands-on experience and are often engaged in joint projects with

industrial and government laboratories.

The materials science and engineering undergraduate curriculum requires sixteen courses in the third and fourth years, of which four are restricted electives. This program allows students to specialize in a subdiscipline of MSAE if they so choose. Students must take twelve required courses and four electives. At least two electives must be in the Type A category, and at most two may be in the Type B category. The Type B electives are listed under different materials subdisciplines for guidance. Still, some courses listed under different categories may appeal to students interested in a given area. For example, *CHEE E4252: Introduction to surface and colloidal chemistry* should also be considered by students interested in biomaterials and environmental materials.

Type A electives are:

CHEE E4530: Corrosion of metals
MSAE E4207: Lattice vibrations and crystal defects
MSAE E4250: Ceramics and composites
ELEN E4944: Principles of device microfabrication

Type B electives are:

BIOMATERIALS

BMEN E4300: Solid biomechanics
BMEN E4301: Structure, mechanics, and adaptation of bone
BMEN E4501: Tissue engineering, I: biological tissue substitutes

ELECTRONIC MATERIALS

APPH E3100: Introduction to quantum mechanics
APPH E3300: Applied electromagnetism
APPH E4100: Quantum physics of matter
APPH E4110: Modern optics
ELEN E4301: Introduction to semiconductor devices
ELEN E4411: Fundamentals of photonics

ENVIRONMENTAL MATERIALS

EAAE E4001: Industrial ecology of Earth resources
EAAE E4160: Solid and hazardous waste management

MECHANICAL PROPERTIES OF MATERIALS

ENME E3114: Experimental mechanics of solids
ENME E4113: Advanced mechanics of solids
ENME E4114: Mechanics of fracture and fatigue
MECE E4608: Manufacturing processes

SOFT MATERIALS AND SURFACES

CHEE C3443: Organic chemistry (note that C3444 is not allowed)
CHEE E4252: Introduction to surface and colloid chemistry
APMA E4400: Introduction to biophysical modeling

OTHER

MSAE E3900: Undergraduate research in materials science

Alternative courses can be taken as electives with the approval of the undergraduate adviser. Of the 24 points of elective content in the third and fourth years, at least 12 points of restricted electives approved by the adviser must be taken. Of the remaining 12 points of electives allotted, a sufficient number must actually be taken so that no fewer than 64 points of courses are credited to the third and fourth years. Those remaining points of electives are intended primarily as an opportunity to complete the four-year, 27-point nontechnical requirement, but any type of course work can satisfy them.

GRADUATE PROGRAMS IN MATERIALS SCIENCE AND ENGINEERING

Master of Science Degree

Candidates for the Master of Science degree follow a program of study formulated in consultation with, and approved by, a faculty adviser. A minimum of 30 points of credit must be taken in graduate courses within a specific area of study of primary interest to the candidate. All degree requirements must be completed within five years. A candidate is required to maintain at least a 2.5 grade point average. Applicants for admission are required to take the Graduate Record Examinations. A research report (6 points of credit, *MSAE 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 qualifying examination, which is designed to test the ability of the candidate to apply course work in problem solving and creative thinking. The standard is first-year graduate level. There are two four-hour examinations over a two-day period.

Candidates in the program must take an oral examination within one year of taking the qualifying examination. Within two years of taking the qualifying exami-

nation, candidates must submit a written proposal and defend it orally before a Proposal Defense Committee consisting of three members of the faculty, including the adviser. Doctoral candidates must submit a thesis to be defended before a Dissertation Defense Committee consisting of five faculty members, including two professors from outside the doctoral program. Requirements for the Eng.Sc.D. (administered by the School of Engineering and Applied Science) and the Ph.D. (administered by the Graduate School of Arts and Sciences) are listed elsewhere in this bulletin.

Areas of Research

Materials science and engineering is concerned with synthesis, processing, structure, and properties of metals, ceramics, polymers, and other materials, with emphasis on understanding and exploiting relationships among structure, properties, and applications requirements. Our graduate research programs encompass projects in areas as diverse as polycrystalline silicon, electronic ceramics grain boundaries and interfaces, microstructure and stresses in microelectronics thin films, oxide thin films for novel sensors and fuel cells, wide-band-gap semiconductors, optical diagnostics of thin-film processing, ceramic nanocomposites, electro-deposition and corrosion processes, magnetic thin films for giant and colossal magnetoresistance, chemical synthesis of nanoscale materials, nanocrystals, carbon nanotubes, nanostructure analysis using X-ray and neutron diffraction techniques, and electronic structure calculation of materials using density functional and dynamical mean-field theories. 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 mechan-

MATERIALS SCIENCE AND ENGINEERING PROGRAM: FIRST AND SECOND YEARS

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS¹	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and ODE (3)
PHYSICS (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)
CHEMISTRY (three tracks, choose one)	C1403 (3.5) C1604 (3.5) C3045 (3.5)	C1404 (3) Lab C1500 (2) either semester C2507 (3) C3046 (3), Lab C2507 (3)	C3545 (3)	
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) Z0006 (0)	C1010 (3) Z1003 (0)	C1010 (3)	
REQUIRED NONTECHNICAL ELECTIVES			HUMA C1001, COCI C1101, or Global Core (3–4) HUMA W1121 (3) or W1123 (3)	HUMA C1002, COCI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
REQUIRED TECH ELECTIVES	(3) Student's choice, see list of first-and second-year technical electives (professional-level courses; see pages 12–13)			
COMPUTER SCIENCE	A computer language of the student's choice at the 1000 level or higher			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹Students with advanced standing may start the calculus sequence at a higher level.

ics 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); the structure of nanomaterials (Professor Billinge, Henry Krumb School of Mines/ Applied Physics and Applied Mathematics); electronic structure calculations of materials (Professor Marianetti, Henry Krumb School of Mines/ Applied Physics and Applied Mathematics); and optical nanostructures (Professor Wong, Henry Krumb School of Mines/ Mechanical Engineering).

MATERIALS SCIENCE AND ENGINEERING: THIRD AND FOURTH YEARS

MATERIALS SCIENCE AND ENGINEERING: THIRD AND FOURTH YEARS				
	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES	MSAE E3103 (3) Elements of mat. sci. MSAE E 3111 (3) Thermodynamics, kinetic theory, and statistical mechanics ENME E3113 (3) ¹ Mechanics of solids	MSAE E3104 (3) Laboratory in mat. sci. MSAE E3141 (3) Processing of metals and semiconductors MSAE E3142 (3) ³ Processing of ceramics and polymers	MSAE E3156 (3) Design project MSAE E4101 (3) Structural analysis of materials MSAE E4206 (3) Electronic and magnetic properties of solids	MSAE E3157 (3) Design project MSAE E4202 (3) Thermodynamics and reactions in solids MSAE E4215 (3) Mechanical behavior of materials
ELECTIVES	6 points ²	6 points ²	6 points ²	6 points ²
TOTAL POINTS	15	15	15	15

¹Students wishing to have advance preparation for ENME E3113 may take ENME-MECE E3105: Mechanics as an elective in Semester IV.

²At 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.

³Juniors substitute E4132 for E3142 when offered.

Program of Study

The applicant for the graduate specialty must be admitted to one of the participating programs: applied physics and applied mathematics, or electrical engineering. A strong undergraduate background in physics or chemistry and in mathematics is important.

The doctoral student must meet the formal requirements for the Eng.Sc.D. or Ph.D. degree set by the department in which he or she is registered. However, the bulk of the program for the specialty 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 Noyan.
 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 Marianetti.
 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 Billinge.
 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 semi-conductors with engineered microstructures for desired properties. Includes high-temperature, aqueous, and electrochemical processing; thermal and mechanical processing of metals and alloys; casting and solidification; diffusion, microstructural evolution, and phase transformations; modification and processing of surfaces and interfaces; deposition and removal of thin films. Processing of Si and other materials for elemental and compound semiconductor-based electronic, magnetic, and optical devices.

MSAE E3142y Processing of ceramics and polymers

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

Prerequisite: MSAE E3103 or the equivalent. Established and novel methods involved in the processing of polymers and ceramics. The fundamental aspects of the structure and properties of polymers and ceramic materials; strategy in the preparatory, synthesis, and processing methods for obtaining them. Topics include polymer synthesis, elastomers, thermoplastics, thermoset materials, design and molding processes. Ceramics: inorganic glasses and composites, materials production and principle inorganic chemistry.

MSAE E3156x-E3157y Design project

3 pts. Members of the faculty.

Prerequisite: Senior standing. May be repeated with the permission of the undergraduate adviser. E3156: A design problem in materials science or metallurgical engineering selected jointly by the student and a professor in the department. The project requires research by the student, directed reading, and regular conferences with the professor in charge. E3157: Completion of the research, directed reading, and conferences, culminating in a written report and an oral presentation to the department.

MSAE E3900x and y Undergraduate research in materials science

0 to 4 pts. Members of the faculty.

This course may be repeated for credit, but no more than 6 points may be counted toward the satisfaction of the B.S. degree requirements. Candidates for the B.S. degree may conduct an investigation in materials science or carry out a special project under the supervision of the staff. Credit for the course is contingent upon the submission of an acceptable thesis or final report.

MSAE E4090x Nanotechnology

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

Professor Herman.

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

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. Not given in 2009–2010.

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 Marianetti.

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 material-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 E4990x and y Special topics in materials science and engineering

Lect: 3. 3 pts. Instructors to be announced.

Prerequisite: The instructor's permission. This course may be repeated for credit. Topics and instructors change from year to year. For advanced undergraduate students and graduate students in engineering, physical sciences, and other fields.

MSAE E4999x and y and S4999 Curricular practical training

1 pt. Members of the faculty.

Prerequisites: Internship and adviser's approval (must be obtained in advance). Only for master's students in the Department of Applied Physics and Applied Mathematics who may need relevant work experience as part of their program of study. Final report required. This course may not be taken for pass/fail or audited.

MSAE E6020y Electronic ceramics

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

Not given in 2009–2010.

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. 3 pts. Professor Kim.

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 E6091y Magnetism and magnetic materials

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

Not given in 2009–2010.

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 2009–2010.

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 2009–2010.

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 2009–2010.

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 2009–2010.

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 2009–2010.

Prerequisite: MSAE E4202 or the instructor's permission. Laser-, electron-, and ion-beam modification of materials to achieve unique microstructures and metastable phases for electronic and structural applications. Fundamentals of energy deposition and heat flow during laser- and electron-beam irradiation. Atomic displacement processes in ion-irradiated materials. Beam-induced microstructural evolution, crystallization, surface alloying, rapid solidification, and metastable phase formation. Review of current industrial applications.

MSAE E6230y Kinetics of phase transformations

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

Not given in 2009–2010.

Prerequisite: MSAE E4202 or the instructor's permission. Principles of nonequilibrium thermodynamics: stochastic equations; nucleation, growth, and coarsening reactions in solids; spinodal decomposition; eutectic and eutectoid transformations.

MSAE E6251y Thin films and layers

Lect: 3. 3 pts. Professor Chan.

Vacuum basics, deposition methods, nucleation and growth, conditions for epitaxy, relation between microstructure and deposition conditions, stress, adhesion, interconnects, and electromigration.

MSAE E6273x and y, and s Materials science reports

0 to 6 pts. Members of the faculty.

Formal written reports and conferences with the appropriate member of the faculty on a subject of special interest to the student but not covered in the other course offerings.

MSAE E8235x and y Selected topics in materials science

Lect: 3. 3 pts. Instructors 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 2009–2010.

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. Members of the faculty.

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:

CHEE E4050: Principles of industrial electrochemistry

CHEN E4201: Engineering applications of electrochemistry

CHEE E4252: Introduction to surface and colloid chemistry

CHEE E4530: Corrosion of metals

CHEN E4620: Introduction to polymer science

CHEN E4630: Polymer laboratory

CIEN E4212: Structural assessment

CIEN E4332: Finite element analysis, I

CHEN E3110: Transport phenomena, I: theory and methodology of rate phenomena

EAAE E4011: Industrial ecology of manufacturing

EAAE E4160: Solid and hazardous waste management

EAAE E4900: Applied transport and chemical rate phenomena

EAAE E6228: Theory of flotation

ENME E3113: Mechanics of solids

ENME E6315: Theory of elasticity

MECHANICAL ENGINEERING

220 S. W. Mudd, MC 4703, 212-854-2965
www.columbia.edu/cu/mechanical



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Mechanical engineering is a diverse subject that derives its breadth from the need to design and manufacture everything from small individual parts/devices (e.g., micro-scale sensors, inkjet printer nozzles) to large systems (e.g., spacecraft and machine tools). The role of a mechanical engineer is to take a product from an idea to the marketplace. In order to accomplish this, a broad range of skills are needed. The particular skills in which the mechanical engineer acquires deeper knowledge are the ability to understand the forces and the thermal environment that a product, its parts, or its subsystems will encounter; design them for functionality, aesthetics, and the ability to withstand the forces and the thermal environment they will be subjected to; determine the best way to manufacture them and ensure they will operate without failure. Perhaps the one skill that is the mechanical engineer's exclusive domain is the ability to analyze and design objects and systems with motion.

Since these skills are required for virtually everything that is made, mechani-

cal engineering is perhaps the broadest and most diverse of engineering disciplines. Hence mechanical engineers play a central role in such industries as automotive (from the car chassis to its every subsystem—engine, transmission, sensors); aerospace (airplanes, aircraft engines, control systems for airplanes and spacecraft); biotechnology (implants, prosthetic devices, fluidic systems for pharmaceutical industries); computers and electronics (disk drives, printers, cooling systems, semiconductor tools); microelectromechanical systems, or MEMS (sensors, actuators, micro power generation); energy conversion (gas turbines, wind turbines, solar energy, fuel cells); environmental control (HVAC, air-conditioning, refrigeration, compressors); automation (robots, data/image acquisition, recognition, and control); manufacturing (machining, machine tools, prototyping, microfabrication).

To put it simply, mechanical engineering deals with anything that moves, including the human body, a very complex machine. Mechanical engineers learn about materials, solid and fluid mechanics, thermodynamics, heat

transfer, control, instrumentation, design, and manufacturing to realize/understand mechanical systems. Specialized mechanical engineering subjects include biomechanics, cartilage tissue engineering, energy conversion, laser-assisted materials processing, combustion, MEMS, microfluidic devices, fracture mechanics, nanomechanics, mechanisms, micro-power generation, tribology (friction and wear), and vibrations. The American Society of Mechanical Engineers (ASME) currently lists thirty-six technical divisions, from advanced energy systems and aerospace engineering to solid waste engineering and textile engineering.

The breadth of the mechanical engineering discipline allows students a variety of career options beyond some of the industries listed above. Regardless of the particular future path they envision for themselves after they graduate, their education would have provided them with the creative thinking that allows them to design an exciting product or system, the analytical tools to achieve their design goals, the ability to meet several sometimes conflicting con-

straints, and the teamwork needed to design, market, and produce a system. These skills also prove to be valuable in other endeavors and can launch a career in medicine, law, consulting, management, banking, finance, and so on.

For those interested in applied scientific and mathematical aspects of the discipline, graduate study in mechanical engineering can lead to a career of research and teaching.

Current Research Activities

Current research activities in the Department of Mechanical Engineering are in the areas of controls and robotics, energy and micropower generation, fluid mechanics, heat/mass transfer, mechanics of materials, manufacturing, material processing, MEMS, nanotechnology, and orthopedic biomechanics.

Biomechanics and Mechanics of Materials. Some of the current research in biomechanics is concerned with the application of continuum theories of mixtures to problems of electromechanical behavior of soft biological tissues, contact mechanics, lubrication of diarthrodial joints, and cartilage tissue engineering. (Ateshian)

In the area of the mechanics of materials, research is performed to better understand material constitutive behavior at the micro- and mesoscale. This work is experimental, theoretical, and computational in nature. The ultimate goal is to formulate constitutive relationships that are based on physical concepts rather than phenomenology, as in the case of plasticity power-law

hardening. In addition, the role that the constitutive relations play in the fracture and failure of materials is emphasized. (Kysar)

In the area of molecular mechanics in biology, mechanical effects on stem cell differentiation is studied to understand the underlying molecular mechanisms. The molecular motion in living cells is monitored to examine how the dynamics of molecules determine the specificity of stem cell differentiation. Mechanics of molecular motors is studied to correlate their functions with cell differentiation. (Liao)

Control, Design, and Manufacturing.

Control research emphasizes iterative learning control (ILC) and repetitive control (RC). ILC creates controllers that learn from previous experience performing a specific command, such as robots on an assembly line, aiming for high-precision mechanical motions. RC learns to cancel repetitive disturbances, such as precision motion through gearing, machining, satellite precision pointing, particle accelerators, etc. Time optimal control of robots is being studied for increased productivity on assembly lines through dynamic motion planning. Research is also being conducted on improved system identification, making mathematical models from input-output data. The results can be the starting point for designing controllers, but they are also studied as a means of assessing damage in civil engineering structures from earthquake data. (Longman)

Robotics and mechanism synthesis research focuses on the analysis of kine-

matic relationship, optimization, and design of linkages and spatial mechanisms, and the development of novel robotic mechanical architectures. These new robotic architectures include parallel robots, hybrid robots, snakelike robots, and flexible and flexure-based robots. The theoretical aspects of this research include applications of line geometry tools and screw theory for analysis and synthesis of robotic devices, applications of actuation redundancy and kinematic redundancy for stiffness control, and applications of algebraic geometry methods for robot synthesis. The applied aspects of this research include task-based design and construction of new devices/robots for robotic medical assistance in the surgical arena. (Simaan)

In the area of advanced manufacturing processes and systems, current research concentrates on laser materials processing. Investigations are being carried out in laser micromachining; laser forming of sheet metal; microscale laser shock-peening, material processing using improved laser-beam quality. Both numerical and experimental work is conducted using state-of-the-art equipment, instruments, and computing facilities. Close ties with industry have been established for collaborative efforts. (Yao)

Energy, Fluid Mechanics, and Heat/Mass Transfer.

In the area of energy, one effort addresses the design of flow/mass transport systems for the extraction of carbon dioxide from air. Another effort addresses the development of distributed sensors for use in microsites and performance evaluation

of energy and environmental systems. The design and testing of components and systems for micropower generation is part of the thermofluids effort as well as part of the MEMS effort. (Modi)

In the area of fluid mechanics, study of low-Reynolds-number chaotic flows is being conducted both experimentally and numerically, and the interactions with molecular diffusion and inertia are presently being investigated. Other areas of investigation include the fluid mechanics of inkjet printing, drop on demand, the suppression of satellite droplets, shock wave propagation, and remediation in high-frequency printing systems. (Attinger, Modi)

In the area of microscale transport phenomena, current research is focused on understanding the transport through interfaces, as well as the dynamics of interfaces. For instance, an oscillating microbubble creates a microflow pattern able to attract biological cells. High-speed visualization is used together with innovative laser measurement techniques to measure the fluid flow and temperature field with a very high resolution. (Attinger)

In the area of nanoscale thermal transport, our research efforts center on the enhancement of thermal radiation transport across interfaces separated by a nanoscale gap. The scaling behavior of nanoscale radiation transport is measured using a novel heat transfer measurement technique based on the deflection of a bi-material atomic force microscope cantilever. Numerical simulations are also performed to confirm these measurements. The measurements are also used to infer extremely small variations of van der Waals forces with temperature. This enhancement of radiative transfer will ultimately be used to improve the power density of thermophotovoltaic energy conversion devices. (Narayanaswamy)

Research in the area of tribology—the study of friction, lubrication, and wear—focuses on studying the wear damage and energy loss that is experienced in power generation components such as piston rings, fuel injection systems, geartrains, and bearings. Next-generation lubricants, additives, surface coatings, and surface finishes are being studied in order to determine their effects on friction and wear. Additionally, environmentally

friendly lubricants are also being identified and characterized. (Terrell)

MEMS and Nanotechnology. In these areas, research activities focus on power generation systems, nanostructures for photonics, fuel cells and photovoltaics, and microfabricated adaptive cooling skin and sensors for flow, shear, and wind speed. Basic research in fluid dynamics and heat/mass transfer phenomena at small scales also support these activities. (Attinger, Hone, Lin, Modi, Narayanaswamy, Wong)

We study the dynamics of microcantilevers and atomic force microscope cantilevers to use them as microscale thermal sensors based on the resonance frequency shifts of vibration modes of the cantilever. Bi-material microcantilever-based sensors are used to determine the thermophysical properties of thin films. (Narayanaswamy)

Research in the area of nanotechnology focuses on nanomaterials such as nanotubes and nanowires and their applications, especially in nanoelectromechanical systems (NEMS). A laboratory is available for the synthesis of carbon nanotubes and semiconductor nanowires using chemical vapor deposition (CVD) techniques and to build devices using electron-beam lithography and various etching techniques. This effort will seek to optimize the fabrication, readout, and sensitivity of these devices for numerous applications, such as sensitive detection of mass, charge, and magnetic resonance. (Hone, Wong, Modi)

In the area of nanoscale imaging in biology, a super-resolution microscopy (nanoscopy) system is built to break the diffraction limit of light. The super-resolution microscopy system is to be used to observe molecular dynamics in living cells. A high-speed scanning system is designed and implemented to track molecular dynamics in a video rate. Control of sample motion in nanometer resolution is achieved by integrating single photon detection and nano-positioning systems. (Liao)

Research in the area of optical nanotechnology focuses on devices smaller than the wavelength of light, for example, in photonic crystal nanomaterials and NEMS devices. A strong research

group with facilities in optical (including ultrafast) characterization, device nanofabrication, and full numerical intensive simulations is available. Current efforts include silicon nanophotonics, quantum dot interactions, negative refraction, dramatically enhanced nonlinearities, and integrated optics. This effort seeks to advance our understanding of nanoscale optical physics, enabled now by our ability to manufacture, design, and engineer precise subwavelength nanostructures, with derived applications in high-sensitivity sensors, high-bandwidth data communications, and biomolecular sciences. Major ongoing collaborations across national laboratories, industrial research centers, and multiuniversities support this research. (Wong)

In the area of microscale power generation, efforts are dedicated to build a micromotor using acoustic energy amplified by a microbubble. (Attinger)

Research in the area of microtribology—the study of friction, lubrication, and wear at the microscale—analyzes the surface contact and adhesive forces between translating and rotating surfaces in MEMS devices. Additionally, the tribological behavior between sliding micro- and nano-textured surfaces is also of interest, due to the prospects of enhanced lubrication and reduced friction. (Terrell)

Research in BioMEMS aims to design and create MEMS and micro/nanofluidic systems to control the motion and measure the dynamic behavior of biomolecules in solution. Current efforts involve modeling and understanding the physics of micro/nanofluidic devices and systems, exploiting polymer structures to enable micro/nanofluidic manipulation, and integrating MEMS sensors with microfluidics for measuring physical properties of biomolecules. (Lin)

Biological Engineering and Biotechnology. Active areas of research in the musculoskeletal biomechanics laboratory include theoretical and experimental analysis of articular cartilage mechanics; theoretical and experimental analysis of cartilage lubrication, cartilage tissue engineering, and bioreactor design; growth and remodeling of biological tis-

sues; cell mechanics; and mixture theory for biological tissues with experiments and computational analysis (Ateshian).

The Hone group is involved in a number of projects that employ the tools of micro- and nano-fabrication toward the study of biological systems. With collaborators in biology and applied physics, the group has developed techniques to fabricate metal patterns on the molecular scale (below 10 nanometers) and attach biomolecules to create biofunctionalized nanoarrays. The group is currently using these arrays to study molecular recognition, cell spreading, and protein crystallization. Professor Hone is a co-PI of the NIH-funded Nanotechnology Center for Mechanics in Regenerative Medicine, which seeks to understand and modify at the nanoscale force- and geometry-sensing pathways in health and disease. The Hone group fabricates many of the tools used by the center to measure and apply force on a cellular level. (Hone)

In the area of molecular bioengineering, proteins are engineered to understand their mechanical effects on stem cell differentiation. Molecular motors are designed and engineered computationally and experimentally to identify key structural elements of motor functions. Fluorescent labels are added to the molecules of interest to follow their dynamics in living cells and to correlate their mechanical characteristics with the process of stem cell differentiation. (Liao)

Microelectromechanical systems (MEMS) are being exploited to enable and facilitate the characterization and manipulation of biomolecules. MEMS technology allows biomolecules to be studied in well-controlled micro/nanoenvironments of miniaturized, integrated devices, and may enable novel biomedical investigations not attainable by conventional techniques. The research interests center on the development of MEMS devices and systems for label-free manipulation and interrogation of biomolecules. Current research efforts primarily involve microfluidic devices that exploit specific and reversible, stimulus-dependent binding between biomolecules and receptor molecules to enable selective purification, concentration, and label-free detection of nucleic acid, protein, and small molecule analytes; miniatur-

ized instruments for label-free characterization of thermodynamic and other physical properties of biomolecules; and subcutaneously implantable MEMS affinity biosensors for continuous monitoring of glucose and other metabolites (Lin).

The advanced robotics and mechanism application lab (ARMA) is focused on surgical intervention using novel robotic architectures. Examples of these architectures include flexible snakelike robots, parallel robots, and cooperative robotic systems. The current research activity is focused on providing safer and deeper interaction with the anatomy using minimally invasive approaches, surgery through natural orifices, surgical task planning based on dexterity and performance measures, and manipulation of flexible organs. The ongoing funded research projects include NIH-funded grants on designing next-generation robotic slaves for incisionless surgical intervention (surgery through natural opening); minimally invasive surgery for the throat and upper airways; image-guided insertable robotic platforms for less invasive surgery (surgery that is carried out using a single incision in the abdomen); and robotic assistance for cochlear implant surgery (NSF funded, Simaan).

Mass radiological triage is critical after a large-scale radiological event because of the need to identify those individuals who will benefit from medical intervention as soon as possible. The goal of the ongoing NIH-funded research project is to design a prototype of a fully automated, ultra high throughput biosimetry. This prototype is supposed to accommodate multiple assay preparation protocols that allow the determination of the levels of radiation exposure that a patient received. The input to this fully autonomous system is a large number of capillaries filled with blood of patients collected using finger sticks. These capillaries are processed by the system to distill the micronucleus assay in lymphocytes, with all the assays being carried out in situ in multi-well plates. The research effort on this project involves the automation system design and integration including hierarchical control algorithms, design and control of custom built robotic devices, and auto-

mated image acquisition and processing for sample preparation and analysis (Simaan, Yao).

A technology that couples the power of multidimensional microscopy (three spatial dimensions, time, and multiple wavelengths) with that of DNA array technology is investigated in an NIH-funded project. Specifically, a system is developed in which individual cells selected on the basis of optically detectable multiple features at critical time points in dynamic processes can be rapidly and robotically micromanipulated into reaction chambers to permit amplified DNA synthesis and subsequent array analysis. Customized image processing and pattern recognition techniques are developed, including Fisher's linear discriminant preprocessing with neural net, a support vector machine with improved training, multiclass cell detection with error correcting output coding, and kernel principal component analysis (Yao).

Facilities for Teaching and Research

The undergraduate laboratories, occupying an area of approximately 6,000 square feet of floor space, are the site of experiments ranging in complexity from basic instrumentation and fundamental exercises to advanced experiments in such diverse areas as automatic controls, heat transfer, fluid mechanics, stress analysis, vibrations, microcomputer-based data acquisition, and control of mechanical systems.

Equipment includes microcomputers and microprocessors, analog-to-digital and digital-to-analog converters, lasers and optics for holography and interferometry, a laser-Doppler velocimetry system, a Schlieren system, dynamic strain indicators, a servohydraulic material testing machine, a photoelastic testing machine, an internal combustion engine, a dynamometer, subsonic and supersonic wind tunnels, a cryogenic apparatus, computer numerically controlled vertical machine centers (VMC), a coordinate measurement machine (CMM), and a rapid prototyping system. A CNC wire electrical discharge machine (EDM) is also available for the use of specialized projects for students with prior arrangement. The undergraduate laboratory also houses experimental setups for the

MECHANICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS STANDARD TRACK

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3)
PHYSICS (three tracks, choose one)	C1401 (3) ————— C1601 (3.5) ————— C2801 (4.5) —————	C1402 (3) ————— C1602 (3.5) ————— C2802 (4.5) —————	—————> C1403 (3) ³ —————> C2601 (3.5) ³	
CHEMISTRY	one semester lecture (3–4) C1403 or C1404 or C3045 or C1604	Lab C1500 (3) ¹		
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) ————— Z0006 (0) —————	C1010 (3) Z1003 (0) —————	C1010 (3)	
REQUIRED NONTECHNICAL COURSES			HUMA C1001, COCI C1101, or Global Core (3–4) HUMA W1121 or W1123 (3)	HUMA C1002, COCI C1102, or Global Core (3–4) ECON W1105 (4) and W1155 recitation (0)
REQUIRED TECHNICAL COURSES	(3) Student's choice, see list of first- and second-year technical electives (professional-level courses; see pages 12–13) ²		ENME-MECE E3105 (4) either semester	
COMPUTER SCIENCE	Computer language: W1003 (3) or W1004 (3) any semester			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹May substitute Physics Lab C1493 (3), C1494 (3), or W3081 (2).

²ELEN E1201 (see semester VI) satisfies this requirement. However, MECE E1001 is strongly encouraged.

³May substitute BIOL W2001 or higher.

understanding and performance evaluation of a complete small steam power generation system, a heat exchanger, and a compressor. Part of the undergraduate laboratory is a staffed machine shop with machining tools such as standard vertical milling machines, engine and bench lathes, programmable surface grinder, bandsaw, drill press, tool grinders, and a power hacksaw. The shop also has a tig welder.

A mechatronics laboratory affords the opportunity for hands-on experience with microcomputer-embedded control of electromechanical systems. Facilities

for the construction and testing of analog and digital electronic circuits aid the students in learning the basic components of the microcomputer architecture. The laboratory is divided into work centers for two-person student laboratory teams. Each work center is equipped with several power supplies (for low-power electronics and higher power control), a function generator, a multimeter, a proto-board for building circuits, a microcomputer circuit board (which includes the microcomputer and peripheral components), a microcomputer programmer, and a personal computer that contains a

data acquisition board. The data acquisition system serves as an oscilloscope, additional function generator, and spectrum analyzer for the student team. The computer also contains a complete microcomputer software development system, including editor, assembler, simulator, debugger, and C compiler. The laboratory is also equipped with a portable oscilloscope, an EPROM eraser (to erase microcomputer programs from the erasable chips), a logic probe, and an analog filter bank that the student teams share, as well as a stock of analog and digital electronic components.

MECHANICAL ENGINEERING: THIRD AND FOURTH YEARS STANDARD TRACK

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES	MECE E3018 (3) Lab I	MECE E3028 (3) Lab II	MECE E3038 (3) 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) ¹ Mechanics	MECE E4608 (3) Manufacturing proc.		
	ENME E3113 (3) Mechanics of solids	ELEN E1201 (3.5) Intro. elec. eng.		
TECHNICAL ELECTIVES			6 points	6 points
NONTECH ELECTIVES	3 points			6 points
TOTAL POINTS²	15	15.5	15	16

¹Strongly recommended to be taken in Semester III or IV.

²Students must complete 128 points to graduate.

The department maintains a modern computer-aided design laboratory equipped with fifteen Silicon Graphics workstations and software tools for design, CAD, FEM, and CFD.

The research facilities are located within individual or group research laboratories in the department, and these facilities are being continually upgraded. To view the current research capabilities please visit the various laboratories within the research section of the department Web site (www.me.columbia.edu/pages/research/index.html). The students and staff of the department can, by prior arrangement, use much of the equipment in these research facilities. Through their participation in the NSF-MRSEC center, the faculty also have access to shared instrumentation and the clean room located in the Shapiro Center for Engineering and Physical Science Research. Columbia University's extensive library system has superb scientific and technical collections

(www.columbia.edu/cu/lweb).

E-mail and computing services are maintained by Columbia University Information Technology (CUIT) (www.columbia.edu/cuit).

UNDERGRADUATE PROGRAM

The objectives of the undergraduate program in mechanical engineering are as follows:

The Mechanical Engineering Department at Columbia University is dedicated to graduating mechanical engineers who:

1. practice mechanical engineering in a broad range of industries;
2. pursue advanced education, research and development, and other creative and innovative efforts in science, engineering, and technology, as well as other professional careers;
3. conduct themselves in a responsible, professional, and ethical manner;
4. participate as leaders in their fields of expertise and in activities that support service and economic development

nationally and throughout the world.

Highly qualified students are permitted to pursue an honors course consisting of independent study under the guidance of a member of the faculty.

Upon graduation the student may wish to enter employment in industry or government, or continue with graduate study. Alternatively, training in mechanical engineering may be viewed as a basis for a career in business, patent law, medicine, or management. Thus, the department's undergraduate program provides a sound foundation for a variety of professional endeavors.

The program in mechanical engineering leading to the B.S. degree is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

Of the 21 points of elective content in the third and fourth years, at least 12 points of technical courses, including at least 6 points from the Department of Mechanical Engineering, must be taken.

MECHANICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS EARLY DECISION TRACK

	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
MATHEMATICS	MATH V1101 (3)	MATH V1102 (3)	MATH V1201 (3)	MATH V1202 (3) and APMA E2101 (3)
PHYSICS (three tracks, choose one)	C1401 (3) ————— C1601 (3.5) ————— C2801 (4.5) —————	C1402 (3) ————— C1602 (3.5) ————— C2802 (4.5) —————	—————> C1403 (3) ³ —————> C2601 (3.5) ³	
CHEMISTRY	one semester lecture (3–4) C1403 or C1404 or C3045 or C1604	Lab C1500 (3) ²		
ENGLISH COMPOSITION (three tracks, choose one)	C1010 (3) Z1003 (0) ————— Z0006 (0) —————	—————> C1010 (3) —————> Z1003 (0)	—————> C1010 (3)	
REQUIRED NONTECHNICAL COURSES			HUMA C1001, COCI C1101, or Global Core (3–4)	HUMA C1002, COCI C1102, or Global Core (3–4)
REQUIRED TECHNICAL COURSES	(3) Student's choice, see list of first- and second- year technical electives (professional-level courses; see page 12) ¹	ENME E3105 (4) Mechanics	ENME E3113 (3) Mechanics of solids	ELEN E1201 (3.5) Intro. elec. eng. MECE E3408 (3) Graphics & design
COMPUTER SCIENCE	Computer language: W1003 (3) or W1004 (3) any semester			
PHYSICAL EDUCATION	C1001 (1)	C1002 (1)		
GATEWAY LAB	E1102 (4) either semester			

¹ELEN E1201 (see semester IV) satisfies this requirement. However, MECE E1001 is strongly encouraged.

²May substitute Physics Lab C1493 (3), C1494 (3), or W3081 (2).

³May substitute BIOL W2001 or higher.

Those remaining points of electives are intended primarily as an opportunity to complete the four-year, 27-point non-technical requirement. Consistent with professional accreditation standards, courses in engineering science and courses in design must have a combined credit of 48 points. Students should see their advisers for details.

Fundamentals of Engineering (FE) Exam

The FE exam is a state licensing exam and the first step toward becoming a Professional Engineer (P.E.). P.E. licensure is important for engineers to obtain—it

shows a demonstrated commitment to professionalism and an established record of abilities that will help a job candidate stand out in the field. Ideally, the FE exam should be taken in the senior year while the technical material learned while pursuing the undergraduate degree is still fresh in the student's mind. In addition to the FE exam, achieving P.E. licensure requires some years of experience and a second examination, which tests knowledge gained in engineering practice. For more information, please see www.columbia.edu/cu/mechanical/misc-pages/FE_Exam.html.

The Mechanical Engineering Depart-

ment strongly encourages all seniors to take this exam and offers a review course covering material relevant to the exam, including a practice exam to simulate the testing experience. The FE exam is given in the fall and spring of each year. The review course is offered in the spring semester, concluding before the spring exam.

GRADUATE PROGRAMS

Master of Science Degree Program

The program leading to the Master of Science degree in mechanical engineering requires completion of a minimum

MECHANICAL ENGINEERING: THIRD AND FOURTH YEARS EARLY DECISION TRACK

	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES	MECE E3018 (3) Lab I MECE E3100 (3) Fluids I MECE E 3301 (3) Thermodynamics	MECE E3028 (3) Lab II MECE E3311 (3) Heat transfer MECE E4608 (3) Manufacturing proc.	MECE E3038 (3) Lab III MECE E3409 (3) CAD MECE E3601 (3) Classical control sys.	MECE E3410 (4) Engineering design
REQUIRED NONTECHNICAL COURSES	HUMA W1121 or W1123 (3)	ECON W1105 (4) and W1155 recitation (0)		
TECHNICAL ELECTIVES		3 points	3 points	6 points
NONTECH ELECTIVES	3 points		3 points	6 points
TOTAL POINTS¹	15	16	15	16

¹Students must complete a minimum of 128 points to graduate.

of 30 points of approved course work consisting of no fewer than ten courses. A thesis based on either experimental, computational, or analytical research is optional and may be counted in lieu of up to 6 points of course work. In general, attainment of the degree requires one academic year of full-time study, although it may also be undertaken on a part-time basis over a correspondingly longer period. A minimum grade point average of 2.5 is required for graduation.

The M.S. degree in mechanical engineering requires a student to take a sequence of courses that shows a “clearly discernible specialty or concentration.” In consultation with his/her adviser an M.S. student can develop a concentration specifically tailored to his/her interests and objectives, and we refer to this as the *standard track*. Alternatively, M.S. students can pick from a set of predefined concentrations, or *special tracks*.

Typical choices of concentration in the standard track 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.

Rather than apply for the standard track, students can apply for a *special track* in either energy systems or in micro/nanoscale engineering. The requirements for a special track are identical to those of the standard track, with one exception: a special track student must take at least 15 of his/her points from a list determined by a special track adviser in consultation with a

special track advisory committee. The name of the special track will be listed on a student’s transcript. The currently available special tracks are listed below.

[M.S. in Mechanical Engineering with Concentration in Energy Systems](#)

Advisers: Profs. Daniel Attinger and Vijay Modi

The concentration in energy systems provides the M.S. candidate with a global understanding of current energy challenges. Advanced thermofluidic knowledge is provided to design and optimize energy systems, with a strong emphasis on renewable energies. Courses related to energy and environmental policy, two strong areas of Columbia as a global university, can be integrated into the course sequence. This concentration is a suitable preparation for careers in energy production and energy consultation.

Requirements: While satisfying the general mechanical engineering requirements, take at least five courses from:

- MECE E4211:** Energy: sources and conversion
- MECE E4302:** Advanced thermodynamics
- MECE E4312:** Solar thermal engineering
- MECE E4314:** Energy dynamics of green buildings

- MECE E6100:** Advanced mechanics of fluids
MECE E6104: Case studies in computational fluid dynamics
MECE E6313: Advanced heat transfer
APPH E4130: Physics of solar energy
EAAE E6126: Carbon sequestration
EAAE E6208: Combustion chemistry or processes
INTA W4200: Alternative energy resources
ARCH A4684: Sustainable design
SIPA U4727: Environmental politics and policy management
SIPA U6060: International energy systems and business structures

M.S. in Mechanical Engineering with Concentration in Micro/Nanoscale Engineering

Advisers: Profs. James Hone and Jeff Kysar

The concentration in micro/nanoscale engineering provides the M.S. candidate with an understanding of engineering challenges and opportunities in micro- and nanoscale systems. The curriculum addresses fundamental issues of mechanics, fluid mechanics, optics, heat transfer, and manufacturing at small-size scales. Application areas include MEMS, bio-MEMS, microfluidics, thermal systems, and carbon nanostructures.

Requirements: While satisfying the general mechanical engineering requirements, take at least five courses from:

- MECE E4212:** Microelectromechanical systems
MECE E4213: BioMEMS
MECE E6105: Transport phenomena in the presence of interfaces
MECE E6700: Carbon nanotubes
MECE E6710: Nanofabrication laboratory
MECE E6720: Nano/microscale thermal transport processes
MECE E8990: Small scale mechanical behavior
ELEN E4503: Sensors, actuators, and electro-mechanical systems
ELEN E6945: Device nanofabrication
BMEN E4590: BioMEMS: cellular and molecular applications
MSAE E4090: Nanotechnology

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 requirement until the dissertation is submitted for approval.

All doctoral students are required to successfully complete four semesters of the mechanical engineering seminar *MECE E9500*.

COURSES IN MECHANICAL ENGINEERING

MECE E1001x Mechanical engineering: micromachines to jumbo jets

Lect: 3 3 pts. Professor Ateshian.

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

MECE E3018x Mechanical engineering laboratory, I

Lect: 1. Lab: 5. 3 pts. Professor Kysar.

Introduction to engineering instrumentation and measurement of pressure, fluid flow, temperature, stress, viscosity, etc., based upon digital data acquisition and processing. Experimental examination of basic mechanics, such as beams and simple structures. Probability theory: distribution, tests of significance, correlation, ANOVA, linear regression, and design of experiments. A lab fee of \$50 is collected.

MECE E3028y Mechanical engineering laboratory, II

Lect: 1. Lab: 5. 3 pts. Professor Wong.

Experiments in engineering and physical phenomena: aerofoil lift and drag in wind tunnels, laser doppler anemometry in immersed fluidic channels, supersonic flow and shock waves, Rankine thermodynamical cycle for power generation, and structural truss mechanics and analysis. A lab fee of \$50 is collected.

MECE E3038y Mechanical engineering laboratory, III

Lect: 1. Lab: 5. 3 pts. Professor Stolfi.

Mechatronic control of mechanical and electro-mechanical systems. Control of various thermodynamic cycles, including an internal combustion engine (Otto cycle). Reverse engineering of an electro-mechanical product. A lab fee of \$50 is collected.

MECE E3100x Introduction to mechanics of fluids

Lect: 3. 3 pts. Professor Attinger.

Prerequisite: ENME E3105. Basic continuum concepts. Liquids and gases in static equilibrium. Continuity equation. Two-dimensional 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 Basalo.

Classical thermodynamics. Basic properties and concepts, thermodynamic properties of pure substances, equation of state, work, heat, the first and second laws for flow and nonflow processes, energy equations, entropy, and irreversibility. Introduction to power and refrigeration cycles.

MECE E3311y Heat transfer

Lect: 3. 3 pts. Professor Narayanaswamy.

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 Lin.

Prerequisites: ENME E3105 and MECE E3408. Introduction to mechanisms and machines, analytical and graphical synthesis of mechanism, displacement analysis, velocity analysis, acceleration analysis of linkages, dynamics of mechanism, cam design, gear and gear trains, and computer-aided mechanism design.

MECE E3408y Computer graphics and design

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

Introduction to drafting, engineering graphics, computer graphics, solid modeling, and mechanical engineering design. Interactive computer graphics and numerical methods applied to the solution of mechanical engineering design problems. A laboratory fee of \$175 is collected.

MECE E3409x Machine design

Lect: 3. 3 pts. Professor Simaan.

Prerequisite: MECE E3408. Computer-aided

analysis of general loading states and deformation of machine components using singularity functions and energy methods. Theoretical introduction to static failure theories, fracture mechanics, and fatigue failure theories. Introduction to conceptual design and design optimization problems. Design of machine components such as springs, shafts, fasteners, lead screws, rivets, welds. Modeling, analysis, and testing of machine assemblies for prescribed design problems. Problems will be drawn from statics, kinematics, dynamics, solid modeling, stress analysis, and design optimization.

MECE E3410y Engineering design

Lect: 4. 4 pts. Professor Stolfi.

Prerequisite: Senior standing. Elements of the design process: concept formulation, systems synthesis, design analysis optimization. Selection and execution of a project involving the design of an actual engineering device or system. A laboratory fee of \$125 is collected.

MECE E3411y Fundamentals of engineering

Lect: 3. 1 pt. Professor Stolfi.

Prerequisite: Senior standing. Review of core courses in mechanical engineering, including mechanics, strength of materials, fluid mechanics, thermodynamics, heat transfer, materials and processing, control, and mechanical design and analysis. Review of additional topics, including engineering economics and ethics in engineering. The course culminates with a comprehensive examination, similar to the Fundamentals of Engineering examination.

EEME E3601x Classical control systems

Lect: 3. 3 pts. Professor Longman.

Prerequisite: MATH E1210. Analysis and design of feedback control systems. Transfer functions; block diagrams; proportional, rate, and integral controllers; hardware, implementation. Routh stability criterion, root locus, Bode and Nyquist plots, compensation techniques.

MECE E3900x-E3901y Honors tutorial in mechanical engineering

3 pts. Professors Ateshian, Attinger, Hone, Kysar, Liao, Lin, Longman, Modi, Narayanaswamy, Simaan, Stolfi, Terrell, 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, Attinger, Hone,

Kysar, Liao, Lin, Longman, Modi, Narayanaswamy, Simaan, Stolfi, Terrell, Wong, and Yao. Hours to be arranged by faculty supervising the work.

Prerequisites: Approval by faculty member who agrees to supervise the work. Normally not to be taken in a student's final semester. Independent project involving theoretical, computational, experimental or engineering design work. May be repeated, but no more than 3 points may be counted toward degree requirements. Projects requiring machine-shop use must be approved by the laboratory supervisor.

MECE E4058x and y Mechatronics and embedded microcomputer control

Lect: 3. 3 pts. Professor Stolfi.

Prerequisite: ELEN E1201. Recommended: ELEN E3000. Enrollment limited to 12 students. Mechatronics is the application of electronics and microcomputers to control mechanical systems. Systems explored include on/off systems, solenoids, stepper motors, dc motors, thermal systems, magnetic levitation. Use of analog and digital electronics and various sensors for control. Programming microcomputers in Assembly and C. Lab required; a lab fee of \$75 is collected.

MECE E4100y Mechanics of fluids

Lect: 3. 3 pts. 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 E4213y Biomicroelectromechanical systems (BioMEMS): design, fabrication, and analysis

Lect: 3. 3 pts. Professor Lin.

Prerequisites: MECE E3100 and MECE E3311, or a course in transport phenomena, or the instructor's permission. Silicon and polymer

micro/nanofabrication techniques; hydrodynamic microfluidic control; electrokinetic microfluidic control; microfluidic separation and detection; sample preparation; micro bioreactors and temperature control; implantable MEMS including sensors, actuators, and drug delivery devices.

MECE E4302y Advanced thermodynamics

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

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. Professor Akbari.

This course will introduce you to the basics of theory, design, selection, and applications of turbomachinery. Turbomachines are widely used in many engineering applications, such as energy conversion, power plants, air-conditioning, pumping, refrigeration, and vehicle engines, as there are pumps, blowers, compressors, gas turbines, jet engines, wind turbines, etc. Applications are drawn from energy conversion technologies, HVAC, and propulsion. The course will provide you with a basic understanding of the different kinds of turbomachines.

IEME E4310x The manufacturing enterprise

Lect: 3. 3pts. Professor Weinig.

The strategies and technologies of global manufacturing and service enterprises. Connections between the needs of a global enterprise, the technology and methodology needed for manufacturing and product development, and strategic planning as currently practiced in industry.

MECE E4312y Solar thermal engineering

Lect: 3. 3 pts. Professor Attinger.

Prerequisite: MECE E3311. Fundamentals of solar energy transport: radiation heat transfer, convection, conduction, and phase change processes. Heat exchangers and solar collectors: basic methods of thermal design, flow arrangements, effects of variable conditions, rating procedures. Solar energy concentration. Piping systems: series and parallel arrangements, fluid movers. Thermal response and management of photovoltaic energy conversion. Solar energy storage. Solar cooling, solar thermal power, and cogeneration. Applications to the design of solar thermal engineering systems.

MECE E4314y Energy dynamics of green buildings

Lect: 3. 3 pts. Professors Naraghi and McGough.

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.

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 Terrell.

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 E4430y Automotive dynamics

Lect: 3. 3 pts. Professor Jazar.

Prerequisites: ENME 3105 or the equivalent; recommended: ENME 3106 or the equivalent. Automobile dynamic behavior is divided into three subjects: vehicle subsystems, ride, and handling. Vehicle subsystems include tire, steering, mechanisms, suspensions, gearbox, engine, clutch, etc. Regarding ride, vibrations and ride comfort are analyzed, and suspension optimization of a quarter car model is treated. Regarding handling, vehicle dynamic behavior on the road is analyzed, with emphasis on numerical simulations using planar as well as roll models.

MECE E4431 Space vehicle dynamics and control

Lect: 3. 3 pts. Not given in 2009–2010.

Prerequisite: ENME-MECE E3105; ENME E4202 recommended. Space vehicle dynamics and control, rocket equations, satellite orbits, initial trajectory designs from earth to other planets, satellite attitude dynamics, gravity gradient stabilization of satellites, spin-stabilized satellites, dual-spin satellites, satellite attitude control, modeling, dynamics, and control of large flexible spacecraft.

MECE E4501y Geometrical modeling

Lect: 3. 3 pts. Professor Srinivasan.

Prerequisite: COMS W1005. Relationship between 3-D geometry and CAD/CAM; representations of solids; geometry as the basis of analysis, design, and manufacturing; constructive solid geometry and the CSG tree; octree representation and applications; surface representations and intersections; boundary representation and boundary evaluation; applied computational geometry; analysis of geometrical algorithms and associated data structures; applications of geometrical modeling in vision and robotics.

MECE E4502x Computational geometry for CAD/CAM

Lect: 3. 3 pts. Professor Srinivasan.

Prerequisite: FORTRAN or PASCAL. Analysis of geometric problems and the design of efficient methodologies to obtain solutions to these problems. Algorithms to be studied include geometric searching, convex hulls, triangulations, Voronoi diagrams, intersections, hidden surfaces. Emphasis will be on practical aspects of these algorithms, and on applications of the solutions in computer-aided product design and manufacturing.

EEME E4601y Digital control systems

Lect: 3. 3 pts. Professor Longman.

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-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.

MECE E4602y Introduction to robotics

Lect: 3. 3 pts. Professor Jazar.

Overview of robot applications and capabilities. Linear algebra, kinematics, statics, and dynamics of robot manipulators. Survey of sensor technology: force, proximity, vision, compliant manipulators. Motion planning and artificial intelligence; manipulator programming requirements and languages.

MECE E4604x Product design for manufacturability

Lect: 3. 3 pts. Professor Walker.

Prerequisites: Manufacturing process, computer graphics, engineering design, mechanical design. General review of product development process; market analysis and product system design; principles of design for manufacturing; strategy for material selection and manufacturing process choice; component design for machining; casting; molding; sheet metal working and inspection; general assembly processes; product design for manual assembly; design for robotic and automatic assembly; case studies of product design and improvement.

MECE E4608y Manufacturing processes

Lect: 3. 3 pts. Professor Yao.

Prerequisite: ENME E3113 or the equivalent. Processes and materials of manufacture: metal cutting, forming, stamping, forging, welding, powder metallurgy; classification and fabricating characteristics of metals and composites; plastics, adhesives.

MECE E4609y Computer-aided manufacturing

Lect: 3. 3 pts. Professor Walker.

Prerequisites: An introductory course on manufacturing processes, and knowledge of computer aided design and mechanical design or the

instructor's permission. Computer-aided design, free-form surface modeling, tooling and fixturing, computer numeric control, 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 2009–2010.

Advanced analysis and modeling of the musculoskeletal system. Topics include advanced concepts of 3-D segmental kinematics, musculoskeletal dynamics, experimental measurements of joints kinematics and anatomy, modeling of muscles and locomotion, multibody joint modeling, introduction to musculoskeletal surgical simulations.

MEBM 4703y Molecular mechanics in biology

Lect: 3. 3 pts. Professor Liao.

Prerequisite: ENME E3105, APMA E2101, or the instructor's permission. Mechanical understanding of biological structures including proteins, DNA and RNA in cells and tissues. Force response of proteins and DNA, mechanics of membranes, biophysics of molecular motors, mechanics of protein-protein interactions. Introduction to modeling and simulation techniques, and modern biophysical techniques such as single molecule FRET, optical traps, AFM, and super-resolution imaging, for understanding molecular mechanics and dynamics.

MECE E4990x or y Special topics in mechanical engineering

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

Prerequisite: The instructor's permission. Topics and instructors change from year to year. For advanced undergraduate students and graduate students in engineering, physical sciences, and other fields.

MECE E4999x and y (sect. 001) Curricular practical training

1 pt. Professor Yao.

Prerequisite: Instructor's written approval. Only for ME graduate students who need relevant intern or fieldwork experience as part of their program of study as determined by the instructor. Written application must be made prior to registration outlining proposed study program. Final

reports required. This course may not be taken for pass/fail credit or audited. International students must also consult with the International Students and Scholars Office.

MECE E6100x Advanced mechanics of fluids

Lect: 3. 3 pts. Professor Panides.

Prerequisites: MATH E1210 and MECE E3100. Eulerian and Lagrangian descriptions of motion. Stress and strain rate tensors, vorticity, integral and differential equations of mass, momentum, and energy conservation. Potential flow.

MECE E6102y Computational heat transfer and fluid flow

Lect: 3. 3 pts. Not given in 2009–2010.

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 Panides.

Prerequisites: APMA E4200 and MECE E6100. Corequisites: APMA E4300 and MECE E4400. Hands-on case studies in computational fluid dynamics, including steady and transient flows, heat and mass transfer, turbulence, compressible flow, and multiphase flow. Identifying assumptions, computational domain selection, model creation and setup, boundary conditions, choice of convergence criteria, visualization and interpretation of computed results. Taught in the Mechanical Engineering Computer Laboratory with computational fluid dynamics software.

MECE E6105y Transport phenomena in the presence of interfaces

Lect: 3. 3 pts. Not given in 2009–2010.

Prerequisites: MECE E3301 and MECE E3311; MECE E4100 or the equivalent, or the instructor's permission; CHEE E4252 or the equivalent, or the instructor's permission. Surface energy and capillary phenomena. Wetting and spreading of liquids, wetting line pinning and hysteresis, dynamics of wetting. Surfactants. Bubbles: nucleation, stability, dynamics, microstreaming. Jets and drops: generation, dynamics, stability, and impact with surfaces. Measurement of transport phenomena involving interfaces. Interfacial transport phenomena involving thermal, chemical, or electrical gradients. Applications in microfluidic systems.

MECE E6200y Turbulence

Lect: 3. 3 pts. Not given in 2009–2010.

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 2009–2010.

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 Lai.

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.

MECE E6424x Vibrations in machines, I

Lect: 3. 3 pts. Professor Stolfi.

Prerequisite: MECE E3401. Review of vibration analysis of systems and mechanisms with one degree of freedom. Natural frequencies. Forced vibrations. Effects of dry and viscous friction. Energy methods of Rayleigh and Ritz. Suppression and elimination of vibration. Vibration isolation. Measuring instruments. Critical speeds in machinery. Synchronous whirl. Half-frequency whirl. Influence of bearing characteristics on critical speeds. Effect of gyroscopic moments. Systems with multiple degrees of freedom. Dynamic vibration absorbers. Self-tuning absorbers of pendulum and roller types. Lagrangian equations of motion

as applied to vibrating systems. General equations for transverse critical speeds of shafts. Surfing of helical springs.

EEME E6601x Introduction to control theory

Lect: 3. 3 pts. Professor Longman.

Prerequisite: MATH E1210. A graduate-level introduction to classical and modern feedback control that does not presume an undergraduate background in control. Scalar and matrix differential equation models and solutions in terms of state transition matrices. Transfer functions and transfer function matrices, block diagram manipulations, closed loop response. Proportional, rate, and integral controllers, and compensators. Design by root locus and frequency response. Controllability and observability. Luenberger observers, pole placement, and linear-quadratic cost controllers.

EEME E6602y Modern control theory

Lect: 3. 3 pts. Not given in 2009–2010.

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_∞ , 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 2009–2010.

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.

MECE E6614y Advanced topics in robotics and mechanism synthesis

Lect: 3. 3 pts. Professor Simaan.

Prerequisite: APMA E2101, APMA E3101, MECE E4602 (or COMS W4733). Recommended: MECE E3401 or the instructor's permission. Kinematic modeling methods for serial, parallel, redundant, wire-actuated robots and multifingered hands with discussion of open research problems. Introduction to screw theory and line geometry tools for kinematics. Applications of homotopy continuation methods and symbolic-numerical methods for direct kinematics of parallel robots and synthesis of mechanisms. Course uses textbook materials as well as a collection of recent research papers.

EEME E6620x or y Applied signal recognition and classification

Lect: 3. 3 pts. Not given in 2009–2010.

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. Not given in 2009–2010.

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 nanoelectronic devices. Applications of nanotubes.

MEEE E6710x or y Nanofabrication laboratory

Lecture: 1. Lab: 5. 3 pts. Professor Hone.

Prerequisite: ELEN E6945 or the instructor's permission. Laboratory in techniques for fabrication at the nanometer scale. Electron-beam lithography. Plasma etching and 3D nanofabrication. Thin film deposition. Self-assembly and 'bottom-up' nanofabrication. Fabrication of and testing of complete nanodevices. A lab fee of \$300 is required.

MECE E6720x Nano/microscale thermal transport processes

Lect: 3. 3 pts. Professor Liao.

Nano and microscale origins of thermal transport phenomena by molecules, electrons, phonons, and photons. Quantum mechanics and statistical physics. Density of states. Kinetic theory of gases. Boltzmann transport equation (BTE), classical and quantum size effects. Landauer formalism for transport via nanostructures. Macroscopic constitutive equations from BTE. Application to electronics cooling, thermoelectric and thermophotovoltaic devices, and energy conversion.

MECE E8020x-E8021y Master's thesis

1 to 3 pts. Professors Ateshian, Attinger, Hone, Kysar, Liao, Lin, Longman, Modi, Narayanaswamy, Simaan, Stolli, Terrell, 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 2009–2010.

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: 3. 3 pts. Not given in 2009–2010.

Prerequisites: EEME E6601 and E4601, or the instructor's permission. This course may be taken more than once, since the content changes from year to year, electing different topics from control theory such as learning and repetitive control, adaptive control, system identification, Kalman filtering, etc.

MECE E8990x and y Special topics in mechanical engineering

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

Prerequisites: Instructor's permission. This course may be taken for credit more than once. The instructor from the Mechanical Engineering Department and the topics covered in the course will vary from year to year. This course is intended for students with graduate standing in mechanical engineering and other engineering and applied sciences.

MECE E9000x and E9001y, and s Graduate research and study

1 to 3 pts. Professors Ateshian, Attinger, Hone, Kysar, Liao, Lin, Longman, Modi, Narayanaswamy, Simaan, Stolli, Terrell, 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, Attinger, Hone, Kysar, Liao, Lin, Longman, Modi, Narayanaswamy, Simaan, Stolli, Terrell, 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, Attinger, Hone, Kysar, Liao, Lin, Longman, Modi, Narayanaswamy, Simaan, Stolli, Terrell, 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 are designed to allow engineering and applied science students to study, to a limited extent, a discipline other than their major. Besides engineering minors offered by SEAS departments, new liberal arts minors are available.

A minor requires at least 15 points of credit, and no more than one course can be taken outside of Columbia or met through AP or IB credit. This includes courses taken through study abroad. In SEAS departments with more than one major program, a minor in the second program may be permitted, if approved by the department.

No substitutions or changes of any kind from the approved minors are permitted (see lists below). No appeal for changes will be granted. Please note that the same courses may not be used to satisfy the requirements of more than one minor. No courses taken for pass/fail may be counted for a minor. Minimum GPA for the minor is 2.0. Departments outside SEAS have no responsibility for nonengineering minors offered by SEAS.

For a student to receive credit for a course taken while studying abroad, the department offering the minor must approve the course in writing, ahead of the student's study abroad.

Students must expect a course load that is heavier than usual. In addition, unforeseen course scheduling changes, problems, and conflicts may occur. The School cannot guarantee a satisfactory completion of the minor.

MINOR IN AMERICAN STUDIES

Minimum: 18 points.

1. **AMST W101:** Introduction to American studies 3.0 points
- 2-6. **Five additional courses in American Studies with no distribution or seminar requirements. Students are encouraged to take seminars.**

MINOR IN APPLIED MATHEMATICS

Prospective students should consult the first- and second-year requirements for applied mathematics majors to ensure that prerequisites for the applied mathematics minor are satisfied in the first two years.

Course work counting toward the applied mathematics minor may not include advanced placement credits. Any substitutions for the courses listed below require the approval of the applied mathematics program adviser.

1. **APMA E3101:**
Linear algebra 3.0 points
or
MATH V2010: Linear algebra 3.0 points
2. **APMA E3102:**
Partial differential equations 3.0 points
or
MATH V3028:
Partial differential equations 3.0 points
- 3-5. **Any three of the following courses:**
 - APMA E4300:**
Introduction to numerical methods 3.0 points
 - APMA E4204:** Functions of a complex variable 3.0 points
 - APMA E4101:** Introduction to dynamical systems 3.0 points
 - MATH V2500:**
Analysis and optimization 3.0 points

- SIEO W4105:** Probability 3.0 points
- STAT W4107:**
Statistical inference 3.0 points

or any other course designated *APMA*, *MATH*, *STAT*, *IEOR*, or *COMS* that is approved by the applied mathematics program adviser.

MINOR IN APPLIED PHYSICS

Prospective students should consult the first- and second-year requirements for applied physics majors to ensure that prerequisites for the applied physics minor are satisfied in the first two years.

Course work counting toward the applied physics minor may not include advanced placement credits.

1. **APPH E4901:** Seminar: problems in applied physics 1.0 points
2. **PHYS W3003:** Mechanics 3.0 points
3. **APPH E3100:** Introduction to quantum mechanics 3.0 points
4. **APPH E3300:**
Applied electromagnetism 3.0 points
5. **MSAE E3111:** Thermodynamics, kinetic theory, and statistical mechanics 3.0 points
6. **Two of the following courses:**
 - APPH E4010:**
Introduction to nuclear science 3.0 points
 - APPH E4100:**
Quantum physics of matter 3.0 points
 - APPH E4110:** Modern optics 3.0 points
 - APPH E4112:**
Laser physics 3.0 points
 - APPH E4300:**
Applied electrodynamics 3.0 points
 - APPH E4301:**
Introduction to plasma physics 3.0 points

MINOR IN ARCHITECTURE

1. Studio course (choose one from the following):

ARCH V1020: Introduction to architectural design and visual culture	3.0 points
ARCH V3101: Arch representation: abstraction	4.0 points
ARCH V3103: Arch representation: perception	4.0 points

2–4. History/theory courses (see Note below)

5. Elective course (must be either an approved second design studio or an additional history/theory course)

Note: A list of the approved history/theory courses is available at the departmental office each semester.

MINOR IN ART HISTORY

1–7. Seven courses in art history, covering four of the following areas: (a) ancient Mediterranean, (b) medieval Europe, (c) Renaissance and baroque, (d) 18th, 19th, and 20th century, and (e) non-Western.

MINOR IN BIOMEDICAL ENGINEERING

The Biomedical Engineering program offers a minor in one of three tracks: (I) cellular engineering, (II) biomechanics, and (III) biomedical imaging. Students who wish to get a minor in biomedical engineering should take the core BME requirements, as well as select courses from one of the three tracks, described below. Participation in the minor is subject to the approval of the major program adviser.

Core BME Requirements

1. BIOL C2005: Introductory biology, I	4.0 points
2. BMEN E4001: Quantitative physiology, I or BMEN E4002: Quantitative physiology, II	3.0 points

I. CELL AND TISSUE ENGINEERING TRACK

3. CHEN E3010: Chemical engineering thermodynamics or BMEN E4210: Thermodynamics of biological systems	4.0 points
4. BMEN E4501: Tissue engineering, I	3.0 points
5. BMEN E4502: Tissue engineering, II	3.0 points

6. One from the following courses:

BMEN E3320: Fluid biomechanics	3.0 points
BMEN E4570: Science and engineering of body fluids	3.0 points
ECBM E3060: Introduction to genomic information	3.0 points
CHEN E3110: Transport phenomena, I	4.0 points
CHEN E4700: Principles of genomic technologies	3.0 points
MSAE E3103: Elements of materials science	3.0 points

II. BIOMECHANICS TRACK

3. BMEN E4300: Solid biomechanics	3.0 points
4. BMEN E3320: Fluid biomechanics	3.0 points
5–6. Two from the following course groups:	
ENME E3113: Mechanics of solids	3.0 points
ENME E3161: Fluid mechanics or	4.0 points

MECE E3100: Introduction to mechanics of fluids	3.0 points
MECE E3301: Thermodynamics or MSAE E3111: Thermodynamics, kinetic theory, and statistical mechanics	3.0 points

III. BIOMEDICAL IMAGING TRACK

3. BMEN E4894: Biomedical imaging	3.0 points
4–5. Two from the following courses:	
BMEN E4430: Principles of magnetic resonance imaging	3.0 points
BMEN E4400: Wavelet applications in biomedical image and signal processing	3.0 points
BMEN E4898: Photonics	3.0 points
BMEN E4410: Ultrasound in diagnostic imaging	3.0 points
BMEN E4420: Biomedical signal processing and signal modeling	3.0 points

6. One from the following courses:

ELEN E3801: Signals and systems	3.0 points
ELEN E4810: Digital signal processing	3.0 points
ELEN E4830: Digital image processing	3.0 points

MINOR IN CHEMICAL ENGINEERING

Of the six courses required, at least three must have the *CHEN*, *CHEE*, or *CHAP* designator:

1. CHEN E3100: Material and energy balances	4.0 points
2. CHEN E3010: Principles of chemical engineering thermodynamics or	4.0 points

MSAE E3111: Thermodynamics, kinetic theory, and statistical mechanics	3.0 points
or	
MECE E3301: Thermodynamics	3.0 points
3. CHEN E3110: Transport phenomena, I or one of the following:	4.0 points
EAAE E4900: Applied transport and chemical rate phenomena	3.0 points
MECE E3100: Introduction to mechanics of fluids	3.0 points
ENME E3161: Fluid mechanics	4.0 points
4. CHEN E4230: Reaction kinetics and reactor design	3.0 points
5–6. Two courses from the following:	
Any 3000-level or higher BMCH, CHEN, CHAP, or CHEE course	
APMA E3101: Applied mathematics, I	3.0 points
APMA E3102: Applied mathematics, II	3.0 points
BMEN E3320: Fluid biomechanics	3.0 points
BMEN E4001: Quantitative physiology, I	3.0 points
BMEN E4002: Quantitative physiology, II	3.0 points
ELEN E3201: Circuit analysis	3.5 points
ELEN E3301: Electronic circuits	3.0 points
SIEO W3600: Introduction to probability and statistics	4.0 points
IEOR W4105: Probability	3.0 points
IEOR W4106: Stochastic models	3.0 points
MSAE E3103: Elements of materials science	3.0 points
MSAE E3142: Processing of ceramics and polymers	3.0 points

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 three)	
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
ENME 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
CIEE E4163: Environmental engineering: wastewater	3.0 points
CIEN E3129: Project management for construction	3.0 points
CIEN E4131: Principles of construction techniques	3.0 points

Note: At least three of the courses must be courses that are not required in the student's major.

MINOR IN COMPUTER SCIENCE

Students who pass the Computer Science Advanced Placement Exam, either A or AB, with a 4 or 5 will receive 3 points and exemption from *COMS W1004*. An additional elective is to be recommended but not required. Participation in the minor is subject to the approval of the major program adviser. For further information, please see the QuickGuide at www.cs.columbia.edu/education/undergrad/seasguide.

1. COMS W1004: Introduction to computer science and programming in Java	3.0 points
2. COMS W1007: Object-oriented programming and design	3.0 points
or	
COMS W1009: Introduction to computer science (honors)	3.0 points
3. COMS W3133: Data structures in C	3.0 points
or	
COMS W3134: Data structures in Java	3.0 points
or	
COMS W3137: Data structures and algorithms	4.0 points
or	
COMS W3139: Data structures and algorithms (honors)	4.0 points
4. COMS W3157: Advanced programming	4.0 points

5. COMS W3203: Discrete mathematics	3.0 points
6. COMS W3261: Computer science theory	3.0 points
7. CSEE W3827: Fundamentals of computer systems	3.0 points
or	
a 4000-level COMS technical elective	

MINOR IN DANCE

The SEAS dance minor consists of five 3-point courses. Please note that no performance/choreography courses below count toward the nontech requirement for SEAS students.

1–2. Two from the following history/criticism courses:

DNCE BC 2565: World dance history	
DNCE BC 2566: Western theatrical dance from the Renaissance to the 1960's	
DNCE BC 2570: Dance in New York City	
DNCE BC 3000: From the page to the dance stage	
DNCE BC 3570: Latin American and Caribbean dance: identities in motion	
DNCE BC 3574: Seminar on contemporary choreographers and their works	
DNCE BC 3576: Dance criticism	
DNCE BC 3577: Performing the political	
DNCE BC 3578: Traditions of African-American dance	

3–4. Two from the following performance/choreography courses:

DNCE BC 2555: Ensemble repertory: modern	
DNCE BC 3571: Solo repertory	
DNCE BC 2563: Dance composition: form	
DNCE BC 2564: Dance composition: content	
DNCE BC 3565: Group forms: advanced dance composition	
DNCE BC 2567: Music for dance	
DNCE BC 2557: Evolution of classic Spanish dance	
DNCE BC 2580: Tap as an American art form	
DNCE BC 3590: Rehearsal and performance in dance	

5. One elective.

MINOR IN EARTH AND ENVIRONMENTAL ENGINEERING

1–3. Three courses from the following:

EAAE E3101: Earth resource production systems	3.0 points
EAAE E3103: Energy, minerals and materials systems	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
EAAE E4560: Particle technology	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
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
CIEE E4257: Groundwater contaminant transport and remediation	3.0 points
CIEE E4163: Environmental engineering: wastewater	3.0 points
CHEN E4410: Environmental control technology	3.0 points
CHEN E3010: Principles of chemical engineering thermodynamics	3.0 points
CHEN E3110: Transport phenomena, I	4.0 points
SIEO W3600: Introduction to probability and statistics	4.0 points

MINOR IN EAST ASIAN STUDIES

1–5. Any two of the survey courses on Chinese, Japanese, Korean, or Tibetan civilization (ASCE V2359, V2361, V2363, V2365), plus three elective courses dealing with East Asia. The elective courses may be taken in departments outside of East Asian Languages and Cultures. The minor does not include a language requirement. However, one semester of an East Asian language class may be used to fulfill one of the three electives, as long as at least two semesters of that language have been taken. Placement exams may not be used in place of these courses.

MINOR IN ECONOMICS

- 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 W4280:** Corporate finance
- ECON V3025:** Financial economics
- ECON V3265:** Economics of money and banking
- ECON W4020:** Economics of uncertainty and information
- ECON W4080:** Globalization, incomes and inequality
- ECON W4211:** Advanced microeconomics
- ECON W4213:** Advanced macroeconomics
- ECON W4228:** Urban economics
- ECON G4235:** Historical foundations of modern economics
- ECON W4251:** Industrial organization
- ECON G4301:** Economic growth and development
- ECON W4321:** Economic development
- ECON W4329:** Economics of sustainable development
- ECON W4345:** World economic problems
- ECON W4370:** Political economy
- ECON W4400:** Labor economics
- ECON W4412:** Advanced econometrics
- ECON W4415:** Game theory
- ECON W4438:** Economics of race in the United States

- ECON W4457:** Industrial organization of art, entertainment and communications
- ECON W4465:** Public economics
- ECON W4480:** Gender and applied 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 W2257*, which may be taken after completion of *ECON W1105*. Some of the elective courses listed above have additional prerequisites. Courses may be taken only after the completion of all prerequisites. Please see the Columbia College bulletin for course descriptions and complete lists of prerequisites.

7. One from the following statistics courses (or sequence of courses):

- STAT W1211:** Introduction to statistics
- SIEO W3600:** Introduction to probability and statistics
- IEOR W3658:** Probability and
- STAT W3659 or W4107:** Statistical inference
- SIEO W4150:** Introduction to probability and statistics

Notes:

- The statistics course must be finished before taking *ECON W3412*, and it is recommended that students take *ECON W3412* in the semester following the statistics course.
- Generally speaking, course work done as part of the economics minor counts toward fulfilling the School's nontechnical requirements. However, *ECON W3412: Introduction to econometrics*, which may be used as a course in the minor program, may not be applied toward satisfaction of the nontechnical course requirements; refer to the non-technical section on pages 11–12 of this bulletin for further details.
- Students with AP credit for economics and an exemption for *ECON W1105* may use the credit toward the minor.
- Transfer or study abroad credits may not be applied to fulfill the requirements of the economics minor.

MINOR IN ELECTRICAL ENGINEERING

1. **ELEN E1201:** Introduction to electrical engineering 3.5 points
(May be replaced by a similar course or roughly equivalent experience)
2. **ELEN E3201:** Circuit analysis 3.5 points
3. **CSEE W3827:** Fundamentals of computer systems 3.0 points
4. **ELEN E3081 and ELEN E3082:** Electrical engineering labs 2.0 points
5. **ELEN E3801:** Signals and systems 3.5 points
6. **ELEN E3106:** Solid-state devices and materials 3.5 points
or
ELEN E3401: Electromagnetics 4.0 points

Note: Not available to computer engineering majors.

MINOR IN ENGINEERING MECHANICS

1. **ENME E3105:** Mechanics 4.0 points
2. **ENME E3113:** Mechanics of solids 3.0 points
3. **ENME E3161:** Fluid mechanics 4.0 points
or
MECE E3100: Mechanics of fluids 3.0 points
- 4-6. **Electives (any two):**
 - ENME E3106:** Dynamics and vibrations 3.0 points
 - ENME E3114:** Experimental mechanics of materials 4.0 points
or
MECE E3414: Advanced strength of materials 3.0 points
 - CIEN E3121:** Structural analysis 3.0 points
 - ENME E4202:** Advanced mechanics 3.0 points
 - ENME E4113:** Advanced mechanics of solids 3.0 points
 - ENME E4114:** Mechanics of fracture and fatigue 3.0 points
 - ENME E4214:** Theory of plates and shells 3.0 points
 - ENME E4215:** Theory of vibrations 3.0 points
 - MECE E3301:** Thermodynamics 3.0 points

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

Required: 15 points beyond second-year French.

- 1-2. **FREN W3420:** Introduction to French and francophone studies, I 3.0 points
and
FREN W3421: Introduction to French and francophone studies, II 3.0 points
- 3-5. **Three additional courses in French beyond satisfaction of the language requirement, including one course in French cultural studies and one in francophone literature.**

MINOR IN GERMAN

Required: 15 points beyond second-year German.

1. **GERM V3001 or V3002:** Advanced German, I or II 3.0 points
2. **GERM W3333:** Introduction to German literature 3.0 points
- 3-4. **Any two of the period survey courses in German literature and culture, GERM W3442, W3443, W3444, W3445; at least one of these must focus on pre-20th-century culture.**
5. **One course taken from any 3000/4000 level German or CompLit-German courses taught in German or English.**

MINOR IN GREEK OR LATIN

- 1-4. **A minimum of 13 points in the chosen language at the 1200-level or higher.**
5. **3 points in ancient history of the appropriate civilization.**

MINOR IN HISPANIC STUDIES

1. **SPAN W3300:** Advanced language through content 3.0 points
2. **SPAN W3330:** Introduction to the study of Hispanic cultures 3.0 points
3. **SPAN W3349:** Hispanic cultures, I: Islamic Spain through the colonial period 3.0 points
4. **SPAN W3350:** Hispanic cultures, II: Enlightenment to the present 3.0 points
5. **One additional 3000- or 4000-level elective course in the Department of Spanish and Portuguese**

Note: Please see the director of undergraduate studies in the Department of Spanish and Portuguese for more information.

MINOR IN HISTORY

- 1-5. **Minimum 15 points in the History Department with no distribution or seminar requirements. Transfer or study-abroad credits may not be applied.**

MINOR IN INDUSTRIAL ENGINEERING

1. **SIEO W3600:** Introduction to probability and statistics 4.0 points
2. **IEOR E3608:** Introduction to mathematical programming 4.0 points
3. **IEOR E3402:** Production-inventory planning and control 3.0 points
4. **IEOR E4003:** Industrial economics 3.0 points
- 5-6. **Electives: Two IEOR courses of interest and approved by a faculty adviser.**

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

1. MSAE E3103:

Elements of materials science 3.0 points

2–3. Two from the following courses:

MSAE E3111:

Thermodynamics, kinetic theory, and statistical mechanics 3.0 points

MSAE E3141: Processing of metals and semiconductors 3.0 points

MSAE E3142: Processing of ceramics and polymers 3.0 points

MSAE E4090: Nanotechnology 3.0 points

MSAE E4101: Structural analysis of materials 3.0 points

MSAE E4206: Electronic and magnetic properties of solids 3.0 points

MSAE E4215: Mechanical behavior of materials 3.0 points

MSAE E4250: Ceramics and composites 3.0 points

4–6. Three from the following courses

(other materials-related courses may be acceptable):

APPH E4100:

Quantum physics of matter 3.0 points

CHEE E4050:

Industrial and environmental electrochemistry 3.0 points

CHEE E4252: Introduction to surface and colloid chemistry 3.0 points

CHEE E4530:

Corrosion of metals 3.0 points

CHEE E4620: Introduction to polymer science 3.0 points

CHEE E4630: Polymer laboratory 3.0 points

CHEM C3443-C3444: Organic chemistry 3.5 points

ELEN E4411: Fundamentals of photonics 3.0 points

ELEN E4301: Introduction to semiconductor devices 3.0 points

ELEN E4944: Principles of device microfabrication 3.0 points

ENME E4113: Advanced mechanics of solids 3.0 points

ENME E4114: Mechanics of fracture and fatigue 3.0 points

MECE E4608: Manufacturing processes 3.0 points

MECE E4701: Introductory biomechanics 3.0 points

MINOR IN MECHANICAL ENGINEERING

1–4. Any four courses from the following (equivalent substitution courses require the approval of the mechanical engineering program adviser):

MECE E3100: Introduction to mechanics of fluids 3.0 points

or one of the following:

ENME E3161:

Fluid mechanics 4.0 points

CHEN E3110: Transport phenomena, I 4.0 points

EAAE E4900: Applied transport and chemical rate phenomena 3.0 points

ENME E3105: Mechanics 4.0 points

MECE E3301: Thermodynamics 3.0 points

or one from the following:

CHEN E3010: Principles of chemical engineering thermodynamics 4.0 points

MSAE E3111: Thermodynamics, kinetic theory, and statistical mechanics 3.0 points

ENME E3113: Mechanics of solids 3.0 points

MECE E3408: Computer graphics and design 3.0 points

MECE E3311: Heat transfer 3.0 points

MECE E4608: Manufacturing processes 3.0 points

MECE E3409: Computer-aided design 3.0 points

EEME E3601: Classical control systems 3.0 points

5–6. Electives: Two additional mechanical engineering courses from either the above list or the following (not all courses in this list are given every year):

MECE E3401: Mechanics of machines 3.0 points

MECE E4058: Mechatronics and embedded microcomputer control 3.0 points

MECE E4100: Mechanics of fluids 3.0 points

MECE E4211: Energy: sources and conversion 3.0 points

MECE E4212: Microelectromechanical systems 3.0 points

MECE E4302: Advanced thermodynamics 3.0 points

MECE E4404: Lubrication theory and design 3.0 points

MECE E4501: Geometrical modeling 3.0 points

MECE E4502: Computational geometry for CAD/CAM 3.0 points

EEME E4601: Digital control systems 3.0 points

MECE E4602: Introduction to robotics 3.0 points

MECE E4604: Product design for manufacturability 3.0 points

MECE E4609: Computer-aided manufacturing 3.0 points

MECE E4610: Advanced manufacturing processes 3.0 points

MINOR IN MIDDLE EAST AND ASIAN LANGUAGES AND CULTURES

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.

MINOR IN MUSIC

1. MUSI V2318-V2319: Diatonic harmony and counterpoint 6.0 points

2. MUSI V1312-V1313: Introductory ear training 1.0 points

3. MUSI V2314: Ear training, I 1.0 points

4. One course from the following:
 MUSI V3128: History of Western music I: Middle Ages to baroque 3.0 points
 MUSI V3129: History of Western music II: classical to 20th century 3.0 points

5–6. Any two electives at the 3000 or 4000 level. See also the SEAS-approved non-technical electives in music (page 15).

Notes:

- Students must successfully place out of MUSI V1002: *Fundamentals of Western music* (3.0 points).
- Requirement 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

1. IEOR E3106: Stochastic models 3.0 points

2. SIEO W3600: Introduction to probability and statistics 4.0 points

3. IEOR E3608: Introduction to mathematical programming 4.0 points

4. IEOR E4404: Simulation 3.0 points

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.

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.

Note: Please be aware that some philosophy courses may not count as nontechnical electives. Please refer to the listing on page xx.

MINOR IN POLITICAL SCIENCE

1–2. Two from the following courses:

W1201: Introduction to American government and politics	3.0 points
W1501: Comparative politics: an introduction	3.0 points
W1601: Introduction to international politics	3.0 points

3–5. Any three courses in the Political Science Department with no distribution requirement; total 9 points.

MINOR IN PSYCHOLOGY

Five courses required, including *PSYC W1001* and courses in at least two of the three groups listed below (for example, you could select two courses from Group I and two from Group III along with the required *W1001*); total 15 points (minimum).

1. **PSYC W1001:** The science of psychology

2–5. Any four courses from, at a minimum, two of the three groups below:

I. PERCEPTION AND COGNITION

Courses numbered in the 2200s, 3200s, or 4200s. Also **PSYC W1420, W1480, or W1490.**

II. PSYCHOBIOLOGY AND NEUROSCIENCE PSYC W1010:

Mind, brain, and behavior 3.0 points
Courses numbered in the 2400s, 3400s, or 4400s. Also **PSYC W1440.**

III. SOCIAL, PERSONALITY, AND ABNORMAL: Courses numbered in the 2600s, 3600s, or 4600s. Also **PSYC W1450 or W1455.**

MINOR IN RELIGION

1–5. Five courses (total 15 points), one of which must be at the 2000 level.

MINOR IN SOCIOLOGY

- | | |
|--|------------|
| 1. SOCI W1000: The social world | 3.0 points |
| 2. SOCI W2200: Evaluation of evidence | 3.0 points |
| 3. SOCI W3000: Social theory | 3.0 points |
- 4–5. Any two 2000-, 3000-, or 4000-level courses offered by the Department of Sociology; total 6 points.

Note: The year's array of elective courses can be found online in the Columbia College or General Studies bulletin.

MINOR IN STATISTICS

- | | |
|---|------------|
| 1. STAT W1211:
Introduction to statistics | 3.0 points |
| 2. STAT W2110:
Introduction to applied statistics | 3.0 points |
| 3. STAT W3105: Probability | 3.0 points |
| 4. STAT W3107: Statistical inference | 3.0 points |
| 5. STAT W4315: Linear regression | 3.0 points |
6. One Statistics Department 4000-level course, excluding **STAT W4105, W4107, W4150, and W4109.**

Notes:

- Students may substitute *STAT W1111* or *W4150* for *W1211*.
- Well-prepared students may substitute additional 4000-level statistics courses (to be taken after *STAT W4315*) for *W1211* and/or *W2110*.
- Students whose schedules do not permit taking *STAT W3105* or *W3107* may substitute *W4105* for *W3105*, *W4107* for *W3107*, or *W4109* for both *W3105* and *W3107*. Students may also substitute equivalent courses from the IEOR Department with approval of the Statistics Department director of undergraduate studies.

MINOR IN TECHNOLOGICAL ENTREPRENEURSHIP

Minimum: 15 points

1–3. Required courses:

ENGI E2261: Introduction to accounting and finance	3.0 points
BUSI W3021: Marketing and marketing management	3.0 points
IEOR E4998: Managing technological innovation and entrepreneurship	3.0 points

4–5. Electives (either two courses from list A or one course from list A and one from list B):

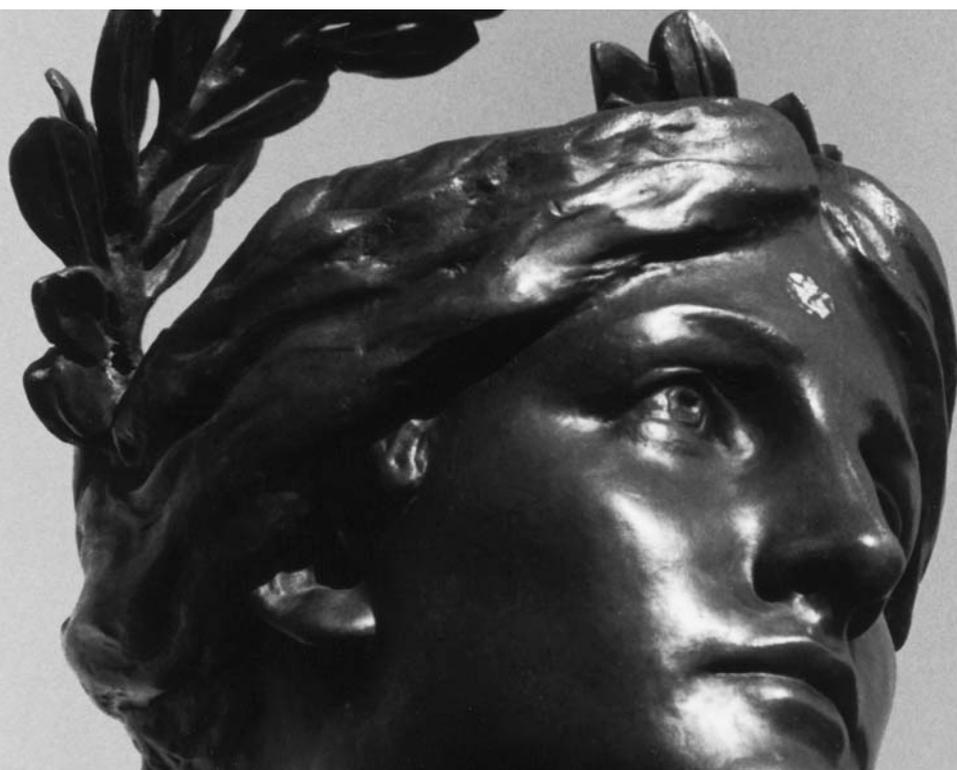
A. Engineering electives (at least one)

CHEN E4020: Protection of industrial and business property	3.0 points
CIEN E4136: Entrepreneurship in civil engineering and construction	3.0 points
COMS W4444: Programming and problem solving	3.0 points
BMEN E3998: Projects in biomedical engineering	3.0 points
IEOR E4550: Entrepreneurial business creation for engineers	3.0 points
ISME E4310: The manufacturing enterprise	3.0 points
Either SCNC W3010: Science, technology, and society or URBS V3310: Science and technology in urban environments (but not both)	3.0 points

B: Other electives (no more than one)

ECON W4280: Corporate finance	3.0 points
IEOR W4308: Industrial budgeting and finance control	3.0 points

Interdisciplinary Courses and Courses in Other Divisions of the University



Of the following courses, some may be requirements for degree programs, and others may be taken as electives. See your departmental program of study or consult with an adviser for more information.

ENGI E1102x and y Design fundamentals using advanced computer technologies

Lect: 4. 4 pts. Professor McGourty.

Core requirement for all entering SEAS students. Students learn the basics of engineering design from problem definition to detailed conceptual design. Computer technologies such as advanced three-dimensional graphical and computational applications are applied in the service of authentic community-based design projects, using the state-of-the-art design facility, the Botwinick Multimedia Learning Laboratory. Aligned with the technical components of the design, students develop collaboration, communication, problem solving, and project management skills, as well as a life-long orientation of social responsibility and community service. Lab fee: \$300.

ENGI E2261x Introduction to accounting and finance

Lect: 3. 3 pts. Professor Webster.

Prerequisite: ECON W1105. The concepts and methods underlying the financial statements of business corporations. Attention to problems of asset valuation, income determination, cash flows, and cost and profit behavior in response to changes in the level of business activity. Analysis of selected corporate financial statements, capital structure, and leverage. Strategies and analytical methods for the evaluation of capital projects.

SCNC W3010x and y Science, technology and society

Lect: 3. 3 pts. Professor McGourty.

Prerequisite: Students must have declared their concentration/major. By investigating the scientific and technical evolution and subsequent diffusion

of contemporary technological innovations, students learn how science and technology fit into the bigger picture; i.e. how technologies technically develop from concept to diffusion into society, how they work, and how they are bi-directionally related to social forces, cultural values, economic trends, environmental factors, and political influences. An essential part of the course work is participation in a community-based learning project, working with local nonprofit organizations.

EEHS E3900y History of telecommunications: from the telegraph to the Internet

Lect: 3. 3 pts. Professors Schwartz and Nebeker.

Historical development of telecommunications from the telegraphy of the mid-1800s to the Internet at present. Included are the technologies of telephony, radio, and computer communications. The coverage includes both the technologies themselves and the historical events that shaped, and in turn were shaped by, the technologies. The historical development, both the general context and the particular events concerning communications, is presented chronologically. The social needs that elicited new technologies and the consequences of their adoption are examined. Throughout the course, relevant scientific and engineering principles are explained as needed. These include, among others, the concept and effective use of spectrum, multiplexing to improve capacity, digital coding, and networking principles. There are no prerequisites, and no prior scientific or engineering knowledge is required. SEAS students may not count this course as a technical elective.

ENGI/CHEN E4020x Safeguarding intellectual and business property

Lect: 3. 3 pts. Professor Pearlman.

Designed for both University engineering students and engineers in industry to provide a broad background in those aspects of the law that are most frequently encountered in a professional engineering career. Topics include patents, protection of know-how, contracts, employer-employ-

ee rights, confidential relationships, unfair competition, trademarks, and the like. Principles of law are illustrated by case studies.

IEOR E4998x and y Managing technological innovation and entrepreneurship

Lect: 3. 3 pts. Professor McGourty.

This course will focus on the management and consequences of technology-based innovation. The course explores how new industries are created, how existing industries can be transformed by new technologies, the linkages between technological development and the creation of wealth and the management challenges of pursuing strategic innovation.

URBS V3310x Science and technology in urban environments

Lect: 3. 3 pts. Professors Cross and McGourty.

Prerequisite: Students must have declared their concentration/major. The course examines the role of science and technology in urban settings, using examples from modern cities. It explores how technology shapes towns and cities, and how urban environments—including politics, economics, culture, and the natural environment—have influenced the development, acceptance, and application of technology. An essential part of the course work is participation in a community-based learning project, working with local nonprofit organizations.

This listing of courses has been selected with specific engineering program requirements in mind. For information on these courses and additional courses offered by these departments, please consult the bulletins of Columbia College, the School of Continuing Education, the School of General Studies, and the Graduate School of Arts and Sciences.

BIOLOGICAL SCIENCES

BIOL C2005x Introductory biology, I: biochemistry, genetics, and molecular biology

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 Introductory biology, II: cell biology, development, and physiology

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.

BIOL C3501 Biochemistry: structure and metabolism

Lect: 3. Recit: 1. 4 pts. B. Stockwell and L. Tong.

Prerequisites: One year of college-level biology and one year of organic chemistry, or the instructor's permission. Biochemistry, organic chemistry, and structural biology. Structure and function of both proteins and small molecules in biological systems. The first half of the course covers protein structure and enzyme kinetics. The second half of the course will focus on the organic chemistry involved in metabolic pathways.

BUSINESS

BUSI W3021x and y Introduction to marketing management

3 pts. Instructor to be announced.

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, stu-

dents 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. L. Brus, R. Friesner, R. Gonzalez, G. Parkin, and J. Valentini.

Only students with scheduling conflicts need report to the Chemistry Department (340 Havemeyer) during registration. Preparation equivalent to one year of high school chemistry is assumed and concurrent registration in MATH V1101. 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 separate courses, students are expected to take the two terms sequentially. The order of presentation of the topics may differ from the order presented here and from year to year. Recitation section required.

CHEM C1500x or y General chemistry laboratory

Lab: 3 pts. S. Hansen and J. Ulichny.

Prerequisite or corequisite: CHEM C1403. Fee \$140. An introduction to basic techniques of modern experimental chemistry, including quantitative procedures and chemical analysis.

CHEM C1604x Second semester general chemistry (intensive)

Lect: 3.5 pts. G. Flynn

Prerequisite: A grade of B or better in CHEM C1403 or F1403 or acceptable performance on the department placement exam. Corequisite:

MATH V1102. Topics include gases (kinetic theory of gases); binary collision model for chemical reactions; chemical kinetics; acid-base equilibria; thermochemistry (thermodynamics I); spontaneous processes (thermodynamics II); chemical bonding in polyatomic molecules. Recitation section required.

CHEM C2507y Intensive general chemistry laboratory

Lab: 3 pts. L. Avila.

Prerequisite: CHEM C1604 or C3045 and the instructor's permission. Fee: \$140. 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. R. Breslow and J. Leighton.

Prerequisite: A grade of 5 on the Chemistry Advanced Placement Examination and an acceptable grade on the department placement exam. Not open to students who have taken other courses in college-level chemistry. Premedical students may take CHEM C3045, C3046, and C3545 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 expected to enroll concurrently in CHEM C2507, the intensive general chemistry laboratory course. Recitation section required.

CHEM C3071y Introduction to inorganic chemistry

Lect: 3 pts. Not given in 2009–2010.

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: 4 pts. A. Cacciuto and D. Reichman.

Prerequisites: CHEM C1403-C1404 or C3045-C3046; PHYS C1401-C1402, or the equivalent; MATH V1101-V1102 or V1207-V1208. Recommended parallel: CHEM C3085-C3086. Elementary but comprehensive treatment of the fundamental laws governing the behavior of individual atoms and molecules and collections of them. C3079: The thermodynamics of chemical systems at equilibrium and the chemical kinetics of nonequilibrium systems. C3080: The quantum mechanics of atoms and molecules, the quantum

statistical mechanics of chemical systems and the connection of statistical mechanics to thermodynamics. Recitation section required.

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: \$125 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 Supervised independent research

Lab: 4 pts. J. Valentini.

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. Laboratory 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. D. Sames and S. Snyder.

Prerequisites: CHEM C1404 (or C1604) and C1500 or their equivalents. 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. Recitation section required.

CHEM C3543x and y Organic chemistry (laboratory)

Lab: 3 pts. A. Ghurbanyan.

Prerequisite: CHEM C1500. Corequisite: CHEM C3443. Students planning to take a full year of laboratory should enroll in CHEM C3543 and C3546. Laboratory fee: \$125. Techniques of experimental organic chemistry, with emphasis on understanding fundamental principles underlying the experiments and methodology of solving laboratory problems involving organic molecules.

CHEM C3545x Organic chemistry (laboratory)

Lab: 3 pts. A. Ghurbanyan.

Prerequisites: CHEM C3045, C3046, and C2407. Laboratory fee: \$125. The course covers the same material as CHEM C3543, but is intended for those students who have taken CHEM C3045-C3046.

CHEM C3546y Advanced organic chemistry (laboratory)

Lab: 3 pts. A. Ghurbanyan.

Prerequisite: CHEM C3543 or C3545.

Corequisite: C3444. Laboratory fee: \$125.

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 Earth, origin, evolution, processes, future

Lect: 3. Lab: 3.4 pts. Professors Mutter and Nettles.

Students who wish to take only the lectures should register for EESC V1411. What is the nature of our planet and how did it form? From geochemical and geophysical perspectives we explore Earth's internal structure, its dynamical character expressed in plate tectonics, and ask if its future behavior can be known.

EESC V1030x Oceanography

3 pts. Professor Hoenisch.

Explore the geology of the sea floor, understand what drives ocean currents and how ocean ecosystems operate. Case studies and discussions centered on ocean-related issues facing society.

EESC V1201y Environmental risks and disasters

3 pts. Professor Ekstrom.

Prerequisites: High-school science and mathematics. An introduction to risks and hazards in the environment. Different types of hazards are analyzed and compared: natural disasters, such as tornados, earthquakes, and meteorite impacts; acute and chronic health effects caused by exposure to radiation and toxic substances such as radon, asbestos, and arsenic; long-term societal effects due to environmental change, such as sea level rise and global warming. Emphasizes the basic physical principles controlling the hazardous phenomena and develops simple quantitative methods for making scientifically reasoned assessments of the threats (to health and wealth) posed by various events, processes, and exposures. Discusses methods of risk mitigation and sociological, psychological, and economic aspects of risk control and management.

EESC W3018y Weapons of mass destruction

3 pts. 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. Professor Walker.

Prerequisite: Physical chemistry or the instructor's permission. Thermodynamics as applied to earth systems.

EESC W4050x Global assessment and monitoring using remote sensing

3 pts. Offered in alternate years. Professor Small.

Prerequisite: permission of the instructors. Recommended preparation: some college-level physics or math. Enrollment limited to 24 students. General introduction to fundamentals of remote sensing and image processing. Example applications in the Earth and environmental sciences are explored through the analysis of remote sensing imagery in a state-of-the-art visualization laboratory. Lab required.

EESC W4076y Geologic mapping

3 pts. Professors Walker and Anders.

Field work on weekends in April and for two weeks in mid-May, immediately following the end of examinations. Estimated expenses: \$250. The principles and practice of deciphering geologic history by observing rocks in the field, making geological maps, constructing geological cross-sections, and writing short reports.

EESC W4085x Geodynamics

3 pts. Offered in alternate years. Professor Buck.

Prerequisites: Calculus, differential equations, introductory physics. Physical processes that control plate tectonics and the evolution of planetary interiors and surfaces; analytical descriptions of these processes; weekly physical model demonstrations.

EESC W4113x Introduction to mineralogy

3. Lab: 3. 4 pts. Offered in alternate years.

Professor Walker.

Prerequisites: Introductory geology or the equivalent and elementary college physics and chemistry, or the instructor's permission. Elementary crystallography and crystal structures, optical properties of minerals, mineral associations and phase equilibria, economic minerals. Laboratory: identification of minerals in hand specimens, chemical and physical tests, and use of the petrographic microscope.

EESC W4230y Crustal deformation

3 pts. Professors Anders and Scholz.

Prerequisites: Introductory geology and one year of calculus. Recommended preparation: higher levels of mathematics. Introduction to the deformation processes in the Earth's crust. Fundamental theories of stress and strain; rock behavior in both brittle and ductile fields; earthquake processes; ductile deformation; large-scale crustal contractional and extensional events.

EESC W4300x The Earth's deep interior

3 pts. Professor Ekstrom.

Prerequisites: Calculus, differential equations, one year of college physics, and EESC W4950 or its equivalent. An introduction to properties of the Earth's mantle, fluid outer core, and solid inner core. Current knowledge of these features is explored, using observations of seismology, heat flow, gravity, and geomagnetism, plus information on the Earth's bulk composition.

EESC W4701x or y. Introduction to igneous petrology

4 pts. Offered in alternate years. 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 laboratory course. Compositional characteristics of igneous and metamorphic rocks and how they can be used as tools to investigate earth processes. Development of igneous and metamorphic rocks in a plate-tectonic framework.

EESC W4885y The chemistry of continental waters

3 pts. Offered in alternate years. Instructors to be announced.

Recommended preparation: A solid background in basic chemistry. Introduction to geochemical cycles involving the atmosphere, land, and bio-

sphere; chemistry of precipitation, weathering reactions, rivers, lakes, estuaries, and groundwaters; stable isotopes and radioactive tracers of transport processes in continental waters.

EESC W4924y Introduction to atmospheric chemistry

3 pts. Offered in alternate years. Professor Shindell.

A survey of trace gas photochemistry important in the Earth's atmosphere. Major topics are composition, including biogenic and anthropogenic inputs, and chemical processes, including reaction kinetics and photochemistry. Specific applications to tropospheric air quality, including smog, acid rain, and stratospheric ozone, including the Antarctic ozone hole, are covered, with an emphasis on the response to anthropogenic pollutants and climate change.

EESC W4925x Principles of physical oceanography

3 pts. Professor Gordon.

Recommended preparation: A solid background in mathematics, physics, and chemistry. Physical properties of seawater, water masses and their distribution, sea-air interaction influence on the ocean structure, basic ocean circulation pattern, relation of diffusion and advection with respect to distribution of ocean properties, and introduction to ocean dynamics.

EESC W4926y. Principles of chemical oceanography

3 pts. Offered in alternate years.

Professors Anderson and Hoenisch.

Recommended preparation: A solid background in mathematics, physics, and chemistry. Given in alternate years. Factors controlling the concentration and distribution of dissolved chemical species within the sea. Application of tracer and natural 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 W4941x or y Principles of geophysics

3 pts. Offered in alternate years. Instructor to be announced.

Prerequisite: Calculus through MATH V1202 and physics through PHYS C1007. The structure and properties of the Earth as inferred from geophysical investigations: gravity, isostasy, earthquakes, seismic exploration, geomagnetism,

marine geophysics, satellite observations, tides. Recommended for nongeophysics majors or those with little previous geophysics background.

EEEC W4947y Plate tectonics

3 pts. *Professor Abers.*

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.

EEEC W4949x Introduction to seismology

3 pts. *Offered in alternate years. Professors Ekstrom and Menke.*

Prerequisites: Elementary college physics and mathematics (including calculus). Basic methods of seismogram analysis. Classification of seismic waves and elementary theory of body waves and normal modes. Elementary aspects of seismic prospecting, earthquake source theory, instrumentation, discrimination between explosions and earthquakes, inversion of seismic data to infer Earth structure, earthquake engineering, earthquake insurance and hazards mitigation, estimation of seismic risk, and earthquake prediction.

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.

COCI C1101-C1102 Introduction to contemporary civilization in the West

4 pts.

Taught by members of the Departments of Anthropology, Architecture, Classics, English and Comparative Literature, French, German, History, Italian, Journalism, Middle East and Asian Languages and Cultures, Philosophy, Political Science, Religion, Slavic Languages, Sociology, and Spanish; members of the Society of Fellows in the Humanities; and Senior Scholars. Major works by over twenty authors, ranging from Plato to modern writers. Students are expected to write at least three papers, to complete two examinations each semester, 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.

ENGL C1010x or y University writing

3 pts. *The staff.*

Teaches general techniques and strategies for academic reading and writing. Students read and discuss a range of published essays, complete regular reading and writing exercises, write several longer essays, and undertake a collaborative research and writing project designed by the class. Students placed in C1010 whose names fall in the first part of the alphabet must take the course in the fall. Students whose names fall in the second part of the alphabet take the course in the spring. The alphabet will be split somewhere between K and O. The exact place for the split will be posted before fall registration.

Global Core

The Global Core requirement consists of courses that examine areas not the primary focus of Literature Humanities and Contemporary Civilization and that, like other Core courses, are broadly introductory, interdisciplinary, and temporally or spatially expansive. Courses in the Global Core are organized around a set of primary texts or artifacts, which may range from texts of literate traditions to media (e.g. film), ritual performances or oral sources, produced in the regions of the world in question. Global Core courses fall into two categories: those that focus on a specific culture or civilization, tracing its appearance and/or existence across a significant span of time and sometimes across more than one present-day country or region; and those that address several world settings or cultures comparatively (and may include Europe and the West), in terms of a common theme, a set of analytic questions, or interactions between different world regions. Students must complete two courses from the Global Core List of Approved Courses for a letter grade.

HUMA C1001x-C1002y Masterpieces of Western literature and philosophy

4 pts.

Taught by members of the Departments of Classics, English and Comparative Literature, French, German, Italian, Middle East and Asian Languages and Cultures, Philosophy, Religion, Slavic Languages, and Spanish; and members of the Society of Fellows in the Humanities. Major 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, to complete two examinations each semester, and to participate actively in class discussions.

HUMA W1121x or y Masterpieces of Western art

3 pts.

Popularly known as "Art Hum," this course teaches students how to look at, think about, and engage in critical discussion of the visual arts. Not a historical survey, but an analytical study of

a limited number of monuments and artists ranging from early Athens to the present, the course focuses on the formal structure of works of architecture, sculpture, painting, and other media, as well as the historical contexts in which these works were made and understood.

HUMA W1123x or y Masterpieces of Western music

3 pts.

Popularly known as "Music Hum," this course aims to instill in students a basic comprehension of the many forms of the Western musical imagination. The course involves students actively in the process of critical listening, both in the classroom and in concerts. Although not a history of Western music, the course is taught in chronological format and includes masterpieces by Josquin des Prez, Monteverdi, Bach, Handel, Mozart, Haydn, Beethoven, Verdi, Wagner, Schoenberg, Stravinsky, Louis Armstrong, and Duke Ellington, among others.

MATHEMATICS

Courses for First-Year Students

Depending on the program, completion of Calculus III or IV satisfies the basic mathematics requirement. Normally students who have taken an AP Calculus course begin with either Calculus II or Calculus III. Refer to the AP guidelines on page 14 for placement information. The sequence ends with *MATH E1210: Ordinary differential equations*.

Students who wish to transfer from one calculus course to another are allowed to do so beyond the date specified on the Academic Calendar. They are considered to be adjusting their level, not changing their program. They must, however, obtain the approval of the new instructor and the Center for Student Advising before reporting to the Registrar.

MATH V1101 Calculus I

Lect. 3 pts.

Functions, limits, derivatives, introduction to integrals.

MATH V1102 Calculus II

Lect. 3 pts.

Prerequisite: Calculus I or the equivalent. Methods of integration, applications of integrals, series, including Taylor's series.

MATH V1201 Calculus III

Lect. 3 pts.

Prerequisite: Calculus II or the equivalent. Vector algebra, complex numbers and exponential, vector differential calculus.

MATH V1202 Calculus IV*Lect: 3 pts.*

Prerequisite: Calculus II and III. Multiple integrals, line and surface integrals, calculus of vector fields, Fourier series.

MATH V1207x-V1208y Honors math A-B*Lect. and recit. 4 pts. M. Thaddeus.*

Prerequisite: Score of 5 on the Advanced Placement BC calculus exam. The second term of this course may not be taken without the first. Multivariable calculus and linear algebra from a rigorous point of view.

MATH E1210x or y Ordinary differential equations*Lect: 3 pts. T. Perutz.*

Prerequisite: MATH V1201 or the equivalent. Special differential equations of order one. Linear differential equations with constant and variable coefficients. Systems of such equations. Transform and series solution techniques. Emphasis on applications.

MATH V2010 x and y Linear algebra*Lect: 3 pts.*

Prerequisite: MATH V1201 or the equivalent. Vector spaces, linear transformations, matrices, quadratic and hermitian forms, reduction to canonical forms.

MATH V2500y Analysis and optimization*Lect: 3 pts. H. Pinkham.*

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. Chiu-chu Liu.*

Prerequisite: MATH V1202. An elementary course in functions of a complex variable. Fundamental properties of the complex numbers, differentiability, Cauchy-Riemann equations, Cauchy integral theorem, Taylor and Laurent series, poles, and essential singularities. Residue theorem and conformal mapping.

MATH V3027x Ordinary differential equations*Lect: 3 pts. P. Daskalopoulos.*

Prerequisite: MATH V1201 or the equivalent. Equations of order one, linear equations, series solutions at regular and singular points, boundary value problems. Selected applications.

MATH V3028y Partial differential equations*Lect: 3 pts. P. Daskalopoulos.*

Prerequisite: MATH V3027 or the equivalent. Introduction to partial differential equations. First-order equations. Linear second-order equations, separation of variables, solution by series expansions. Boundary value problems.

MATH W4032x Fourier analysis*Lect: 3 pts. M. Lipyanskiy.*

Prerequisite: MATH V1201 and linear algebra, or MATH V1202. Fourier series and integrals, discrete analogues, inversion and Poisson summation, formulae, convolution, Heisenberg uncertainty principle. Emphasis on the application of Fourier analysis to a wide range of disciplines.

MATH W4041x-W4642y Introduction to modern algebra*Lect: 3 pts. P. Gallagher.*

The second term of this course may not be taken without the first. Prerequisite: MATH V1202 and V2010 or the equivalent. Groups, homomorphisms, rings, ideals, fields, polynomials, and field extensions. Galois theory.

MATH W4061x-W4062y Introduction to modern analysis*Lect: 3 pts. D. De Silva.*

The second term of this course may not be taken without the first. Prerequisite: MATH V1202 or the equivalent. Real numbers, metric spaces, elements of general topology. Continuous and differentiable functions. Implicit functions. Integration, change of variables. Function spaces. Further topics chosen by the instructor.

MATH W4065x Honors complex variables*Lect: 3 pts. K. Tignor.*

Prerequisite: MATH V1207, V1208, or W4061. A theoretical introduction to analytic functions. Holomorphic functions, harmonic functions, power series, Cauchy-Riemann equations, Cauchy's integral formula, poles, Laurent series, residue theorem. Other topics as time permits: elliptic functions, the gamma and zeta functions, the Riemann mapping theorem, Riemann surfaces, Nevanlinna theory.

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. Professors Dodd and Hughes.*

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. Professors Dodd and Hughes.*

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 Brooijmans.*

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 physics.

PHYS C1493x Introduction to experimental physics*Lab and lecture: 3 pts. Lect: Tues., 3:10–4:00 p.m.*

Lab: 3 hours weekly to be arranged. Instructor to be announced.

Prerequisites: PHYS C1401 and C1402.

Laboratory work associated with the two prerequisite lecture courses. Experiments in mechanics, thermodynamics, electricity, magnetism, optics, and wave motion. (Students cannot receive credit for both PHYS C1493 and C1494.)

PHYS C1494y Introduction to experimental physics*Lab and lecture: 3 pts. Lect: Tues., 3:10–4:00 p.m.*

Lab: 3 hours weekly to be arranged. Instructor to be announced.

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 Christ.*

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. Professor Weinberg.*

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 Kim.

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: Tues., 3:10–4:00 p.m. Lab: 3 hours weekly to be arranged. Instructor to be announced.

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 Cole.

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 W3002y From quarks to the cosmos: applications of modern physics

Lect: 3.5 pts. Professor Marka.

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 Blaer.

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 Nicolis.

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 Aprile.

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 W3083y Electronics laboratory

Lab: 3 pts. Professor Parsons.

Registration is limited to the capacity of the laboratory. Corequisite or prerequisite: PHYS W3003 or W3007. A sequence of experiments in solid-state electronics, with introductory lectures.

PHYS G4003y Advanced mechanics

Lect: 3 pts. Professor Pontón.

Prerequisite: Differential and integral calculus, differential equations, and PHYS W3003 or the equivalent. Lagrange's formulation of mechanics, calculus of variations and the Action Principle, Hamilton's formulation of mechanics, rigid body motion, Euler angles, continuum mechanics, introduction to chaotic dynamics.

PHYS G4018y Solid-state physics

Lect: 3 pts. Professor Uemura.

Prerequisites: PHYS G4021 and 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 Halpin-Healy.

Prerequisite: Differential and integral calculus. Highlights of complex analysis, differential equations, integral equations, Green's functions, special functions, Fourier and other transforms, approximation methods, group theory and representations, differential geometry and manifolds. Emphasis is placed on applications to physical problems.

PHYS G4021x-G4022y Quantum mechanics, I and II

Lect: 3 pts. Professor Mueller.

Prerequisite: PHYS C2601 or C2802, or the equivalent. The formulation of quantum mechanics in terms of state vectors and linear operators, three-dimensional spherically symmetric potentials, the theory of angular momentum and spin, time-independent and time-dependent perturbation theory, scattering theory, identical particles. Selected phenomena from atomic physics, nuclear physics, and elementary particle physics are described and then interpreted using quantum mechanical models.

PHYS G4023x Thermal and statistical physics

Lect: 3 pts. Professor Heinz.

Prerequisite: PHYS G4021 or the equivalent. Thermodynamics, kinetic theory, and methods of statistical mechanics; energy and entropy; Boltzmann, Fermi, and Bose distributions; ideal and real gases; blackbody radiation; chemical equilibrium; phase transitions; ferromagnetism.

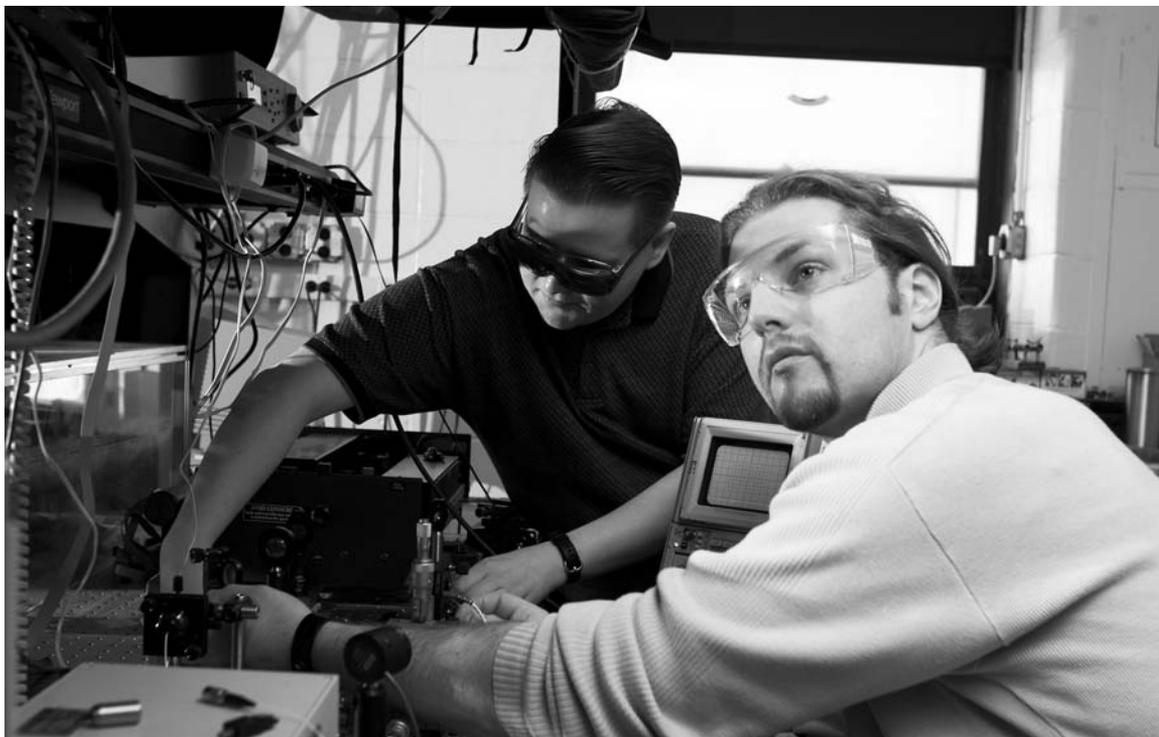
PHYS G4040x General relativity

Lect: 3 pts. Not given in 2009–2010.

Prerequisites: PHYS G4003 and W3007. Tensor algebra, tensor analysis, introduction to Riemann geometry. Motion of particles, fluid, and fields in curved spacetime. Einstein equation. Schwarzschild solution; test-particle orbits and light bending. Introduction to black holes, gravitational waves, and cosmological models.

STATISTICS

Engineering students interested in a survey of the mathematical theory of probability and statistics should consider the pair STAT W3105: Probability theory and W3107: Statistical inference. Students seeking a quicker overview that focuses more on probability theory should consider SIEO W4150. STAT W4105 and W4107 are the equivalent of W3105 and W3107, respectively; but graduate students may not register for W3105 and W3107. STAT W4109 (6 pts) covers the same material as W3105 and W3107 in a single semester. STAT W4315: Linear regression models takes W3105 and



W3107 as prerequisites; like other advanced offerings in statistics, it covers both theory and practical aspects of modeling and data analysis. Advanced offerings in probability theory, stochastic processes, and mathematical finance generally take STAT W3105 as a prerequisite; advanced offerings in statistical theory and methods generally take STAT W4107 and, in several cases, W4315 as prerequisites; an exception is STAT W4220: Data mining, which has a course in computer programming as prerequisite and STAT W3107 as corequisite. STAT 4201 is a high-level survey of applied statistical methods.

Please note that STAT W3000 has been renumbered as W3105 and STAT W3659 has been renumbered as W3107. For a description of the following course offered jointly by the Departments of Statistics and Industrial Engineering and Operations Research, see “Industrial Engineering and Operations Research”:

SIEO W4150x and y Introduction to probability and statistics
3 pts. *I. Hueter and L. Wright.*

Prerequisites: MATH V1101 and V1102 or the equivalent. A quick calculus-based tour of the fundamentals of probability theory and statistical inference. Probabilistic models, random variables, useful distributions, expectations, laws of large numbers, central limit theorem. Statistical inference: point and confidence interval estimation, hypothesis tests, linear regression. Students seeking a more thorough introduction to probability and statistics should consider STAT W3105 and W3107.

STAT W3105x Introduction to probability

3 pts. *Instructor to be announced.*

Prerequisites: MATH V1101 and V1102 or the equivalent. A calculus-based introduction to probability theory. Topics covered include random variables, conditional probability, expectation, independence, Bayes' rule, important distributions, joint distributions, moment-generating functions, central limit theorem, laws of large numbers, and Markov's inequality.

STAT W3107y Introduction to statistical inference

3 pts. *Instructor to be announced.*

Prerequisite: STAT W3105 or W4105, or the equivalent. Calculus-based introduction to the theory of statistics. Useful distributions, law of large numbers and central limit theorem, point estimation, hypothesis testing, confidence intervals maximum likelihood, likelihood ratio tests, nonparametric procedures, theory of least squares, and analysis of variance.

STAT W4201x and y Advanced data analysis
3 pts. *D. Alemayehu and instructor to be announced.*

Prerequisite: A one-term introductory statistics course. This is a course on getting the most out of data. The emphasis will be on hands-on experience, involving case studies with real data and using common statistical packages. The course covers, at a very high level, exploratory data analysis, model formulation, goodness-of-fit testing, and other standard and nonstandard statistical procedures, including linear regression, analysis of variance, nonlinear regression, generalized linear models, survival analysis, time series analysis, and modern regression methods. Students will be expected to propose a data set of their choice for use as case study material.

STAT W4240x Data mining

3 pts. *D. Madigan.*

Prerequisite: COMS W1003, W1004, W1005, W1007, or the equivalent. Corequisite: STAT W3107. Data mining is a dynamic and fast-growing field at the interface of statistics and computer science. The emergence of massive datasets containing millions or even billions of observations provides the primary impetus for the field. Such datasets arise, for instance, in large-scale retailing, telecommunications, astronomy, computational and statistical challenges. This course will provide an overview of current research in data mining and will be suitable for graduate students

from many disciplines. Specific topics covered include databases and data warehousing, exploratory data analysis and visualization, descriptive modeling, predictive modeling, pattern and rule discovery, text mining, Bayesian data mining, and causal inference.

STAT W4290 y Statistical methods in finance

3 pts. Instructor to be announced.

Prerequisites: STAT W4105 and W4107. This is a master-level course introducing statistical methodologies in quantitative finance. Financial applications and statistical methodologies are intertwined in all lectures, with several research topics being introduced through problems in a term project. Lecture notes by the instructor will be distributed. The course will cover linear regression with applications to single and multi-factor pricing models, multivariate analysis and their applications in Markowitz's portfolio management, estimation and modeling of volatilities, calculation of value-at-risk, nonparametric methods with applications to option pricing and interest rate markets.

STAT W4315x and y Linear regression models

3 pts. Instructor to be announced.

Prerequisites: STAT W3107 or the equivalent, MATH V2110 or the equivalent. Corequisites: MATH V1101, V1102, and V2110. Simple and multiple regression, including testing, estimation and confidence procedures, modeling, regression diagnostics and plots, polynomial regression, fixed effects ANOVA and ANCOVA models, non-linear regression, multiple comparisons, co-linearity and confounding, model selection. Emphasis on geometric approach to the theory and the use of a statistical package to analyze data.

STAT W4325x Generalized linear models

3 pts. Instructor to be announced.

Statistical methods for rates and proportions, ordered and nominal categorical responses, contingency tables, odds-ratios, exact inference, logistic regression, Poisson regression, generalized linear models.

STAT W4335x Sample surveys

3 pts. Instructor to be announced.

Introductory course on the design and analysis of sample surveys. How sample surveys are conducted, why the designs are used, how to analyze survey results, and how to derive from first principles the standard results and their generalizations. Discussions include detail surveys from areas including public health, social work, opinion polling, and other topics of interest.

STAT W4413x Nonparametric statistics

3 pts. Instructor to be announced.

Prerequisite: STAT W4107. Statistical inference without parametric model assumption. Hypothesis testing using ranks, permutations, and order statistics. Semi-parametric analysis of censored survival data. Analysis of discrete outcomes. Contingency tables. Applications.

STAT W4437x and y Time series analysis

3 pts. Instructor to be announced.

Prerequisite: STAT W4315 or the equivalent. Least-squares smoothing and prediction, linear systems, Fourier analysis and spectral estimation. Impulse response and transfer function. Fourier series, the fast Fourier transform algorithm, autocorrelation function, and spectral density. Univariate Box-Jenkins modeling and forecasting. Emphasis on practical applications in examples from the physical sciences, social sciences, and business. Computing is an integral part of the course.

STAT W4543y Survival analysis

3 pts. Instructor to be announced.

Prerequisite: STAT W4315 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, regression analysis with lifetime data. Extensive use of the computer to analyze data. Applications in clinical trials and actuarial science.

STAT W4606x and y Elementary stochastic processes

3 pts. M. Brown and instructor to be announced.

Prerequisite: STAT W4105 or the equivalent. Review of elements of probability theory. Poisson processes. Exponential distribution. Renewal theory. Wald's equation. Introduction to discrete time Markov chains and applications to queueing theory, inventory models, branching processes.

STAT W4635y. Stochastic processes for finance

3 pts. Instructor to be announced.

Prerequisites: STAT W3105 or the equivalent. This course covers theory of stochastic processes applied to finance. It covers concepts of martingales, Markov chain models, Brownian motion. Stochastic integration, Ito's formula as a theoretical foundation of processes used in financial modeling. It also introduces basic discrete and continuous time models of asset price evolutions in the context of the following problems in finance: portfolio optimization, option pricing, spot rate interest modeling.

STAT W4840x Theory of interest

3 pts. N. Rajah.

No prerequisite. Introduction to the mathematical theory of interest as well as the elements of economic and financial theory of interest. Topics include rates of interest and discount; simple, compound, real, nominal, effective, dollar (time)-weighted; present, current, future value; discount function; annuities; stocks and other financial instruments; definitions of key terms of modern financial analysis; yield curves; spot (forward) rates; duration; immunization; and short sales. The course will cover determining equivalent measures of interest, discounting, accumulating, determining yield rates, and amortization.

Campus and Student Life



The Fu Foundation School of Engineering and Applied Science attracts and admits an exceptionally interesting, diverse, and multicultural group of students, and it takes steps to provide a campus environment that promotes the continued expansion of each student's ideas and perspectives. Starting with the residence halls, in which nearly all first-year undergraduate students live, the University assigns rooms to both Engineering and Columbia College undergraduate students, ensuring that all students will live either with or near a student attending the other program.

Once students have moved into their new campus home they will find themselves part of a residential system that offers undergraduates a network of social and academic support. Designed to make students aware of the vast number of social and academic opportunities available to them at the University, these networks provide an umbrella of comprehensive advising to help students articulate and realize their goals while at Columbia. More information about the residence halls can be found in the chapter "Housing and Residence Life" in this bulletin.

DIVISION OF STUDENT AFFAIRS

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 pro-

grams, it is also small enough to promote the close interaction among students, faculty, and administration that has created a strong sense of community on campus.

With its mission of providing a wide range of services designed to enhance the student experience from the time of admission through graduation, the Division of Student Affairs is the hub of undergraduate student life. Admissions, Financial Aid and Educational Financing, Center for Student Advising, Residential Programs, Office of Multicultural Affairs, Parent and Family Programs, Office of Judicial Affairs and Community Standards, Events and Communications, Student and Alumni Programs, Student Development and Activities, and Office of Student Group Advising are integral components of the Division. The integrated effort of these units assures that individual students receive support in both their academic and cocurricular pursuits. The Division of Student Affairs is responsible for assisting students in all matters beyond actual course instruction and helping to create a special spirit and sense of community for students.

CENTER FOR STUDENT ADVISING

The Center for Student Advising reflects the mission of the University in striving to support and challenge the intellectual and personal growth of its students and by creating a developmental, diverse, and open learning environment. Individually and collaboratively, each center:

- provides individual and group academic advisement, exploration, and counseling

- provides information on preprofessional studies, study abroad, and major declaration and completion, as well as various leadership, career, graduate school, and research opportunities; refers to additional campus resources
- designs and facilitates programming to meet the unique developmental needs of each class and to enhance community among students, faculty, and administrators
- interprets and disseminates information regarding University policies, procedures, resources, and programs
- educates and empowers students to take responsibility in making informed decisions

Each student is assigned to an advising dean who advises in his or her academic area of interest. When a student declares a major, a faculty member is appointed to guide him or her for the next two years. Advising deans regularly refer students to their academic departments to receive coordinated expert advice in their engineering course selections.

Preprofessional Advising

The Office of Preprofessional Advising works closely with the Center for Student Advising and with the Center for Career Education to provide information for students who plan a career in law or the health professions. The Office advises and assists students throughout their four years, but works most closely with students during their application year and with alumni who apply for admission after graduation. Information sheets, forms, and helpful resources are available in

the Office of Preprofessional Advising. Students will work with their advising deans as primary preprofessional advisers; these advisers will be instrumental in writing committee evaluations for some professional schools.

COMMUNITY DEVELOPMENT

The Community Development team works to foster a vibrant and welcoming undergraduate community through organizational advising, leadership development, advocacy, diversity education, civic engagement, and community programming. The team includes the Office of Student Development and Activities, the Office of Multicultural Affairs, the Office of Student Group Advising, and the Office of Residential Programs. Knowing that students' learning continues beyond the classroom, Columbia University strongly encourages students to become involved in programs and activities to enhance their educational experience and personal growth. A wide array of student organizations addresses both student interests and professional concerns, including the arts, politics, identity, culture, and religion. Joining such groups offers an exciting and dynamic opportunity to develop leadership skills that will serve students well throughout their lives.

Student Organizations

Programs and activities at Columbia are shaped primarily by students who assume leadership and volunteer positions in hundreds of organizations across the campus. The Engineering

Student Council and its associated class councils are the elected representative body of undergraduates with The Fu Foundation School of Engineering and Applied Science. Its members represent student interests on committees and projects addressing a wide range of issues facing the Columbia community and help shape the quality of life for Columbia students.

Working in conjunction with the Student Council, the Activities Board at Columbia (ABC), Student Governing Board (SGB), Inter-Greek Council (IGC), Community Impact (CI), Club Sports, and Interschool Governing Board (IGB) oversee the management and funding of over 300 student organizations.

The ABC provides governance for over 160 recognized student organizations, including cultural organizations, performance-based and theatrical groups, media and publications groups, competition and special interests groups and preprofessional organizations and societies. The preprofessional organizations and societies are of special interest to engineering students. These societies reflect the range of academic disciplines and interests to be found among students and include the Asian-American Society of Engineers, National Society of Black Engineers, the Society of Women Engineers, the American Institute of Aeronautics and Astronautics, and the Biomedical Engineering Society, just to name a few.

The SGB provides governance for approximately 100 recognized student organizations that are faith-based, spiritual, political, activist, and humanitarian and that encourage open interreligious

and political dialogue at Columbia University's Morningside Campus. The InterSchool Governing Board recognizes student organizations whose membership spans across the various undergraduate and graduate schools.

For more information on the Inter-Greek Council (IGC), see Residential Programs, below. For more information on Club Sports, see Intercollegiate Athletics Program (page 210), and for more information on Community Impact see Office of the University Chaplain (page 209). All the governing groups provide networking, leadership, and professional development opportunities for students.

Columbia University graduate students can participate in and enjoy hundreds of diverse, University-affiliated social, religious, cultural, academic, athletic, political, literary, professional, public service, and other organizations. At SEAS, graduate students are encouraged to become active members of the Engineering Graduate Student Council (EGSC). The EGSC is a recognized group that consists of representatives from each of the nine academic departments at SEAS. The objectives of the EGSC are to foster interaction among graduate engineering students, to serve as a voice for graduate engineering students, and to sponsor social and educational events of interest to the graduate engineering community.

Office of Student Development and Activities

The Office of Student Development and Activities (SDA) provides programs and

services designed to support a wide range of co-curricular activities that help build a sense of community, support responsible student governance and student group involvement, and further students' leadership development and personal growth.

Student Development and Activities staff members advise student organizations recognized through the Activities Board of Columbia (ABC), as well as the student governments of The Fu Foundation School of Engineering and Applied Science and Columbia College. SDA serves as resources for event planning, organizational leadership, and budgeting. The Office of Student Development and Activities offers leadership training workshops and helps networking among student leaders and administrative offices. In addition, the SDA administers the Urban New York Program, the New Student Orientation Program, the Columbia Urban Experience Program, and the Columbia Outdoor Orientation Program.

Orientation

All new students are required to participate in an orientation program that is designed to acquaint them with the University and its traditions, the administration and faculty of The Fu Foundation School of Engineering and Applied Science, upperclass students, and New York City. The New Student Orientation Program (NSOP) for new undergraduate students begins the week prior to the start of the fall semester. NSOP is intended to assist all new students with the transition to college life.

Orientation is busy, exciting, and a lot of fun, but it is also a week in which important academic decisions are made. Scheduled into the program are information sessions and opportunities to meet with academic advisers. Through large group programs and small group activities, student will be introduced to faculty members, deans, resident advisers, and other students. NSOP includes walking tours of New York City, social events, and information sessions on University services and co-curricular opportunities. During NSOP, new students have the campus to themselves. This provides students with a unique opportunity to

make friends and settle into life at Columbia before classes begin.

Undergraduate students may e-mail nsop@columbia.edu or call 212-854-5808 for additional information on NSOP.

Orientation for graduate students is scheduled during the week prior to the beginning of each semester. For more information on orientation for graduate students, contact the Office of Graduate Student Services.

Office of Student Group Advising

The Office of Student Group Advising (OSGA) is committed to supporting the programming of our faith-based, spiritual, political, activist, and humanitarian student organizations. In reaching to fulfill this commitment, OSGA provides programming in leadership skills, program development, and organizational management to all undergraduate student organizations recognized by the Student Governing Board (SGB) and organizations recognized by the Interschool Governing Board (IGB). OSGA assists students in their development as individuals, community members, and leaders.

Issues of social responsibility and civic engagement are central to the mission of OSGA and the student organizations that OSGA supports. OSGA strives to encourage open dialogue at Columbia University's Morningside Campus and seeks to find connections among student groups. The Office of Student Group Advising works to enhance the undergraduate educational experience by fostering a dynamic and enriching University community, supporting responsible student governance and co-curricular activities, and offering programs and opportunities focused on civic and community engagement. Through advising, the office encourages critical thinking and the free exchange of ideas by all of the student organizations it supports.

Office of Multicultural Affairs

The Office of Multicultural Affairs is devoted to promoting a just society and exploring issues of interculturalism and diversity within and beyond the Columbia University community. By promoting forums that address diversity issues,

self-discovery takes place along with a greater awareness and appreciation of cultural history within and between communities on campus. We endeavor to empower students, faculty, and staff with the tools to be able to successfully navigate their environments and thus be able to positively change and impact the community at large.

Programs and services provided by Multicultural Affairs include the Columbia Mentoring Initiative, a program connecting incoming students with returning students, and returning students with alumni; 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' social justice goals.

Residential Programs

The Residential Programs staff, supervised by the Assistant Dean of Community Development and Residential Programs, includes 8 professional staff, 13 graduate students, and 130 undergraduates who contribute to the growth, well-being, and personal and intellectual development of students. The staff strives to enhance the quality of residential life by cultivating an atmosphere conducive to educational pursuits and the development of community within the student body. These contributions form an integral part of a Columbia education by stimulating mutual understanding and by fostering an atmosphere based on the appreciation of the differences and similarities characterizing such a diverse cultural community.

The undergraduate student staff, resident advisers (RAs), and community advisers (CAs) serve as role models for their residents. They facilitate discussions about community standards, provide community building programs, and serve as a resource for the residents. Their RAs/CAs serve as the front line of a layered on-call system and are trained to respond to the variety of issues that emerge in community life. As backup, they have graduate assistants (GAs), associate directors (ADs), and a dean-on-duty.

The Faculty in Residence Program allows students, alumni, and faculty to meet formally and informally throughout the year. Faculty members in residence in three residence halls 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. In addition, the faculty member in residence partners with the SEAS alumni office to provide opportunities for students to network and gain exposure to a variety of careers.

Begun in fall 2006, the Gateway Residential Initiative allows SEAS first-years, sophomores, juniors, and seniors to live together clustered in the Living Learning Center (LLC) housed in Hartley and Wallach Halls. This initiative seeks to bridge the academic and co-curricular experience for SEAS students. Mentorship between students, connection among the class years, and alumni interaction are the foundations for the success of the program.

Fraternities and Sororities

Fraternities and sororities have brownstones near the campus and some of the organizations without brownstones have a suite within the residence halls. There is a full-time Assistant Director for Greek Life and Leadership Development.

The InterGreek Council (IGC) is the self-governing student organization that provides guidelines and support to the three Greek councils: The Interfraternity Council (IFC), Panhellenic Council, and Multicultural Greek Council (MGC). There are thirty-three recognized Greek organizations whose membership totals over one thousand undergraduates.

Fraternity and sorority members share in service, scholastic, philanthropic, cultural, and leadership experiences. This active and vibrant community adds to the diversity of the residential experience.

OFFICE OF JUDICIAL AFFAIRS AND COMMUNITY STANDARDS

The Office of Judicial Affairs and Community Standards was created to assist students in the maintenance of a safe, honest, and responsible campus

community. To achieve this goal, the Office of Judicial Affairs partners with various offices on campus to create programs designed to educate students regarding the potential impact of their actions on both their individual lives and the community at large. In addition, the Office of Judicial Affairs and Community Standards works with student groups to facilitate the development of skills and processes students can use to hold each other accountable when they encounter inappropriate behavior. The Office of Judicial Affairs and Community Standards also holds students accountable for inappropriate behavior through the Dean's Discipline process when necessary.

OFFICE OF THE UNIVERSITY CHAPLAIN

The Office of the University Chaplain is located in the Earl Hall Center and includes the United Campus Ministries, the Common Meal Program, and "Music at St. Paul's." The mission of the Center is to build community within the University and with its neighbors while providing students with an opportunity to explore the relationship between faith and learning. The Center is as diverse as the university it serves. United Campus Ministries, which includes denominations of Christian, Jewish, Islamic, and Eastern practices, provides students with individual counseling, religious and nonreligious group support, referrals, and personal assistance.

The University Chaplain is the director of the Earl Hall Center. As University Chaplain, Jewell 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 former Dean of Columbia's Graduate School of Architecture, Planning and Preservation. Architectural features of Lerner Hall, such as the glass facade and ramps, allow the campus to clearly view the activities within the building, and offer those within Lerner scenic views of the campus.

Undergraduate students are likely to visit Lerner to check the mail from the 7,000 student mailboxes located along the ramps. Students may check their e-mail in Lerner's computer center or by plugging in their laptop computers at one of Lerner's Ethernet-outfitted lounges.



Students will also visit Lerner to interact with one another in various ways. They may strategize and plan events with their student organizations in one of the student club offices, or in the meeting rooms designated for student club usage. Students may also meet friends in one of Lerner's two dining locations, for an event in the auditorium, in various lounges, or in one of the building's multipurpose spaces that are ideal for exercise classes.

In addition to providing spaces for student interaction, Lerner is home to the Columbia University Bookstore. Lerner also features retail services, including a travel agency, a copy center, and an electronic banking center. Included in the building are orchestra/band rehearsal and art exhibition spaces, and various administrative offices (Student Affairs, Student Services, Residential Programs, Judicial Affairs, Multicultural Affairs, Center for Student Advising, Financial Aid, and Educational Financing). These offices also include Student Development and Activities, the Double Discovery Center, Columbia TV, WKCR, Disability Services, Counseling and

Psychological Services, and Columbia's Alice! The Health Education Program.

OFFICE OF GRADUATE STUDENT SERVICES

The Office of Graduate Student Services at The Fu Foundation School of Engineering and Applied Science is integral to the School's teaching, research, and service mission, and works to enhance the educational opportunities available to students. This Office provides leadership for the integration of educational programs and services that enhance recruitment, retention, and quality of campus life for graduate students at SEAS. It strives to demonstrate sensitivity and concern in addressing the needs of the School's population. The Office is dedicated to providing service to prospective, new, and continuing students pursuing a graduate education in engineering or applied science.

INTERCOLLEGIATE ATHLETICS PROGRAM

Columbia has a long tradition of success in intercollegiate athletics, and The Fu

Foundation School of Engineering and Applied Science has always been an active participant in these programs. While Columbia's intercollegiate athletic program is governed by Ivy League regulations, Columbia is also a member of the Eastern College Athletic Conference and the National Collegiate Athletic Association. Columbia sponsors men's varsity teams in baseball, basketball, cross-country, fencing, football, golf, rowing (heavy-weight and lightweight), soccer, swimming and diving, tennis, track and field (indoor and outdoor), and wrestling.

Women in all undergraduate divisions of Columbia and in Barnard College compete together as members of University-wide athletic teams. The arrangement, called a consortium under NCAA rules, is one of only three in the nation and the only one on a Division I level. Currently, there are women's varsity teams in archery, basketball, cross-country, fencing, field hockey, golf, lacrosse, rowing, soccer, softball, swimming and diving, tennis, track and field (indoor and outdoor), and volleyball.

Columbia's commitment to success in intercollegiate sporting competition

has been matched by the determination of alumni and administrators to upgrade the University's sports facilities. The Baker Field Athletics Complex, a few miles up the Hudson River on the northern tip of Manhattan, has been completely rebuilt and expanded. The complex features a precast concrete football stadium capable of seating 17,000 spectators; an Olympic-quality synthetic track; a 3,500-seat soccer stadium; softball and baseball fields; and an Astroturf field hockey field. At Columbia's Dick Savitt Tennis Center at the Baker Athletics Complex there are six hard tennis courts, all of which are covered by a state-of-the-art 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 Center houses most indoor sports and is available to all registered students. Major athletic facilities on campus include two full-size gymnasiums for basketball, volleyball, and badminton; eight squash and handball courts; the eight-lane Uris pool with three diving boards; a fully equipped three-level exercise and weight room facility; two aerobic dance/martial arts rooms; a fencing room; a wrestling room; an indoor running track; and two fully equipped saunas.

Eligibility for Intercollegiate Athletics

Any student in the Engineering School who is pursuing the undergraduate program or an approved combined program toward a first degree is eligible for intercollegiate athletics. To be eligible for athletic activities, the student must:

- be a candidate for a bachelor's degree
- be registered for at least 12 points of credit
- make appropriate progress toward the degree as defined by the NCAA, the Ivy League, and Columbia University. These criteria are monitored by the Director of Compliance and certified by the Office of the Registrar.
- have attended the University for not more than eight terms
- not have completed the requirements for the bachelor's degree

Questions about athletic eligibility should be referred to the appropriate academic adviser or the Director of Compliance in the Department of Intercollegiate Athletics and Physical Education.

Recreational Programs

In addition to the activity courses (see page 13), the Physical Education Department offers a comprehensive Intramural and Club Sports Program. Through intramurals, the student has the opportunity to participate in both individual and team sports. Individual activities function through tournaments, while the team activities feature both league and play-off competition. Club sports are designed to allow groups of individuals

who share a common athletic interest to organize and collectively pursue this activity. Clubs are organized on recreational, instructional, and competitive levels, and their activities range from informal play to regular practice or instruction and intercollegiate and tournament competition. A list of the intramural activities and sports clubs as well as all information regarding the program can be obtained in the Intramural Office, 331 Dodge Fitness Center or on the Web site, www.gocolumbiaions.com.

CAMPUS SAFETY AND SECURITY

At Columbia University, the safety and well-being of our students, faculty, and staff is a priority. Columbia's campuses and their environs are safe and have a very low crime rate for an urban university.

The University is required by federal law to publish an annual security report containing information with respect to campus security policies and statistics on the incidence of certain crimes on and around our campuses. This information is available at the Web site for the United States Department of Education (ope.ed.gov/Security/search.asp); by requesting a copy of the report from: Campus Crime Report, Department of Public Safety, Columbia University, 111 Low Library, Mail Code 4301, 535 West 116th Street, New York, NY 10027 (Attn: Mr. Rocco Osso); or at the Web site for Public Safety (www.columbia.edu/cu/publicsafety).

UNIVERSITY HOUSING

Undergraduate Housing

The residence halls are an important focus for campus life outside the classroom, with the University housing over 95 percent of the undergraduate population in residence halls on or near the campus. A trained Residential Programs staff lives with the students in the halls. They work to create an atmosphere conducive to educational pursuits and the development of community among the diverse student body. Throughout the year the Residential Programs staff presents programs in the residence halls and off campus that are both social and educational.

Columbia guarantees housing for all undergraduate students (except transfers) who have filed their intent to reside on campus by the stated deadline and who have continuously registered as full-time students. Each spring, continuing students participate in a room-selection process to select their accommodations for the next academic year. Students who take an unauthorized leave of absence are placed on the nonguaranteed wait list upon their return and are on the wait list for each subsequent year.

A variety of residence hall accommodations are available to Columbia students. Carman, John Jay, Wien, Furnald, McBain, Schapiro, and Broadway Residence Hall are traditional corridor-style residence halls, and all but Wien, John Jay, and Carman have kitchens on each floor. East Campus, 47 Claremont, Hartley-Wallach Living Learning Center, Hogan, River, Ruggles, 600 West 113th Street, Watt, and Woodbridge offer suite-style living, and all have kitchens. All resi-

dence hall rooms are either single or double. Single and double rooms are available in all halls except Carman, which has only doubles, and Hogan, which is all singles.

The residence halls are also home to a variety of Special Interest Communities. These communities provide an opportunity for students with a common interest to live together and develop programs in their area of interest. The themes may vary from year to year. The current communities are Symposium House, GreenBorough, Metta House, Pan African House, Casa Latina, Community Health House, 114 Rue de Fleurus, Students for a Substance Free Space, and Q-House, among others. First-year students are not eligible to live in Special Interest Communities but are welcome to attend events.

Upper-class Columbia students also have the option of living in certain Barnard College halls. Rooms in Barnard and Columbia halls are chosen by a room selection process, which takes place each spring.

For more information, please visit the housing Web site at www.columbia.edu/cu/housing.

Graduate Housing

Graduate students have a number of housing opportunities in the Morningside Heights neighborhood. The three main sources are University Apartment Housing (UAH), International House, and off-campus listings. UAH operates Columbia-owned apartments and dormitory-style suites in the Morningside area within walking distance of the campus. For further information, see UAH's Web site at www.columbia.edu/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 www.ihouse-nyc.org.

There are also a number of off-campus housing opportunities. The University operates Off-Campus Housing Assistance (OCHA), which lists rooms and apartments in rental properties not owned or operated by the University. Only students with a valid ID or admission acceptance letter are permitted to use the facility. OCHA is open throughout the winter and summer vacation periods except academic holidays. Students should call 212-854-2773 for office hours. OCHA also operates a Web page at www.columbia.edu/cu/ire/ocha. There is also a list of alternative housing opportunities maintained by the Office of Graduate Student Services in 524 S. W. Mudd. Students are sent the Alternative Housing flyer in their orientation packets.

UAH applications are sent along with acceptance packets from the Office of Graduate Student Services. They are also available in the Office of Graduate Student Services and the UAH Office. Additional information is also available on the Columbia Students Page: www.columbia.edu/cu/students. Graduate housing through UAH is processed for the fall and spring terms

only. Summer sublets are also available through individual referrals. The UAH Office maintains an active listing for those interested.

Due to the growing demand for housing, graduate housing is no longer guaranteed, but every effort is made to accommodate interested students. It is critical that housing applications be submitted as soon as possible and that instructions in the acceptance packet be followed. 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 50 and 250 miles from campus). All continuing students and applications from Zone 3 areas (within 50 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 dining plans, ranging from 210 meals and 150 Columbia Dining Dollars per term to 115 meals and 500 Dining Dollars per term.

The dining plans are transacted through Columbia's ID Card, called the Columbia Card, which serves as a convenient way to enjoy dining all over campus without carrying cash.

Meals

The meals portion of the dining plan enables students to help themselves to unlimited servings of food served buffet-style in John Jay Dining Hall. Brunch and dinner are served Monday through Sunday.

Dining Dollars

In addition to meals, Dining Dollars comprise the other portion of the first-year dining plan. Each Dining Dollar is equal to one dollar and operates as a declining balance account, much like a debit card.

Columbia Dining Services maintains twelve dining facilities conveniently located on campus. Each of the locations accepts Dining Dollars, an alternative to cash payment that is accessed by the Columbia Card (student ID card).

With Dining Dollars, students will enjoy the ease and flexibility of cashless transactions as well as the savings of sales tax on all food purchases. Dining Dollars will roll over from year to year until graduation.

Upperclass and Graduate Students

Many upperclass and graduate students who dine on campus open a Dining Dollars account; however, some choose to enroll in an upperclass/graduate student dining plan.

Dining Services offers four plans—150 meals per term, 100 meals per term, 75 meals per term, or 50 meals per term. All plans are accessed by the

Columbia Card and can be used for meals in John Jay Dining Hall for brunch and dinner.

Kosher Dining Plan

All students who participate in a dining plan, including first year, upperclass, General Studies, or graduate students are eligible for the Columbia Kosher Dining Plan. Signing up for this dining plan allows access to a restricted kosher area within John Jay Dining Hall as well as Express Meals to go. CU kosher meals can also, for an additional charge, be exchanged for a kosher meal at Barnard's Hewitt Hall (kosher to kosher only). To sign up, the student selects a plan from either the First Year Dining Plan or the Upperclass Dining Plan options, according to the student's status, then elects to enroll in the Kosher Dining Plan. The addition of the Kosher Dining Plan adds 10 percent to the cost of the selected plan. Visit the H&D Customer Service Center in 118 Hartley Hall (enrollment allowed at any point throughout the term) to sign up.

Locations/Menus/Hours

Locations, menus, and hours of all campus dining facilities can be found at www.columbia.edu/cu/dining.

HEALTH SERVICES AND INSURANCE

Health Services at Columbia provides integrated and accessible services and programs that support the well-being of the campus community and the personal and academic development of students. We offer a variety of programs and serv-

ices specifically designed to meet students' health needs. We are comprised of more than 100 individuals: medical providers, nutritionists, disability specialists, health educators, therapists, psychiatrists, peer counselors, student personnel, support staff, and administrative professionals. Our programs are arranged in five departments.

Primary Care Medical Services

(PCMS) provides comprehensive care for routine, urgent, and chronic medical needs of students. We also provide sexual health, reproductive, and gynecological services, travel medicine, LGBTQ health care, confidential HIV testing, immunizations, and specialist referrals. Through our Open Communicator function, students can make appointments online and view their primary care provider information (bios and photos are available online). When Primary Care is closed, a clinician-on-call can provide telephone advice about urgent medical conditions. John Jay Hall, 3rd and 4th floors.

Counseling and Psychological

Services (CPS) offers short-term individual and couples counseling for students and their partners, student life support groups, medication consultation, training, and emergency consultation. Students are encouraged to make appointments and to select a CPS clinician (bios and photos are available online). When CPS is closed, a clinician-on-call can provide telephone advice about urgent mental health concerns. Alfred Lerner Hall, 8th floor.

Alice! Health Promotion Program seeks to help students achieve their personal and academic goals by disseminating useful, current health information in a straightforward and accessible manner, connecting students to appropriate resources, cultivating healthy attitudes and behaviors that encourage students to make informed decisions about their health, and fostering a culture that values and supports a healthy community. Alice! provides workshops and programs for students, and runs Go Ask Alice!, a health question-and answer Web site. Wien Hall, 1st floor.

Office of Disability Services (ODS)

coordinates reasonable accommodations and support services for eligible students, including assistive technology, networking groups, academic skills

workshops, and consultation with a learning specialist. Students seeking reasonable accommodations or support services from ODS are required to register with the office and provide disability documentation before receiving services. Registration and documentation guidelines are available online. Alfred Lerner Hall, 7th floor.

Sexual Violence Prevention and

Response Program (SVPRP) provides comprehensive and integrated education, support, and advocacy about sexual and relationship violence. Through innovative programming and community collaboration, SVPRP empowers students to heal from sexual violence, make informed decisions, and take action to end sexual and relationship violence. Alfred Lerner Hall, Room 301.

All Health Services programs adhere to strict standards of confidentiality in compliance with state and federal laws.

Contact Health Services at Columbia

www.health.columbia.edu
212-854-2284

On-Campus Emergency Resources

CAVA (Ambulance): 212-854-5555
Rape Crisis/Anti-Violence Support Center: 212-854-HELP, 212-854-WALK
Public Safety: 212-854-5555

Off-Campus Emergency Resources

St. Luke's-Roosevelt Hospital
Emergency Room 212-523-3335
Psychiatric Emergency 212-523-3347

Your Health at Columbia

Columbia students have access to comprehensive health care through a network of on- and off-campus services. On-campus medical and counseling appointments are covered through the Health Service Program. Off-campus medical services, such as emergency room visits or prescriptions, are covered through a student's insurance plan. Columbia requires all full-time and residential students to enroll in both the Health Service Program and an acceptable insurance plan. To meet the insurance requirement, students may enroll in the Columbia Student Medical Insurance Plan or provide proof of comparable insurance coverage.

Health Service Program covers on-campus services, including routine and urgent medical appointments, short-term mental health counseling, disability services, educational programs, and sexual violence services. The Health Service Program also provides supplemental coverage for emergency health care, outpatient chemical dependency treatment, and outpatient mental health care. The Health Service Program is mandatory for all full-time students, and the fee will automatically appear on students' E-bill. Students pay no additional charge for accessing on-campus services.

Columbia Student Medical Insurance

Plan covers off-campus medical services. The plan has two levels: Comprehensive and Basic. All full-time students are automatically enrolled in and billed for the Basic insurance plan, but may upgrade to the Comprehensive plan online. Students may submit a request to waive the insurance requirement online by providing proof of comparable insurance coverage (alternate plans must meet Columbia's criteria for comparable coverage, available online). The Columbia Plan includes local, national, and worldwide health coverage, and discounts on dental and vision care.

Part-time students are encouraged to enroll in the Columbia Plan. Enrolling in the Columbia Plan will automatically enroll students in the Health Service Program, as the two plans are meant to work together to provide comprehensive medical care.

Immunization Requirements All students must fulfill two New York State public health immunization requirements **before registering for classes.**

Students must document immunity to measles, mumps, and rubella (MMR) **and** make an informed decision about receiving the meningitis vaccine. The Columbia MMR documentation form is available online—complete the form, then mail, fax, or bring it to the Immunization Office. Students record their meningitis decision online. Directions for completing each requirement are available at our Web site.

Insurance and Immunization Questions

www.health.columbia.edu
E-mail: hs-enrollment@columbia.edu

Scholarships, Fellowships, Awards, and Prizes



FELLOWSHIPS

H. Dean Baker Fellowship (1982)

Awarded to support deserving graduate students in mechanical engineering.

Boris A. Bakhmeteff Research Fellowship in Fluid Mechanics

Provides a stipend for the academic year, with tuition exemption to be arranged by the recipient's department, to a candidate for a doctoral degree in any department at Columbia University whose research is in fluid mechanics.

Quincy Ward Boese Fellowships

Predoctoral fellowships awarded annually to students studying under the Faculty of Engineering and Applied Science.

Roy S. Bonsib Memorial Fellowship (1957)

Awarded to worthy students for advanced study or research in engineering.

Arthur Brant Fellowship (1997)

Gift of Arthur Brant. Awarded to graduate students of the Henry Krumb School of Mines in the field of applied geophysics.

Samuel Willard Bridgham-William Petit Trowbridge Fellowship

A combined fellowship awarded annually for research.

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.

Chiang Chen Fellowship (2004)

Chiang Chen Industrial Charity Foundation. Awarded to students in mechanical engineering.

Professor Bergen Davis Fellowship

Gift of Dr. Samuel Ruben. To be awarded to a student in chemical engineering and applied chemistry upon the recommendation of the senior professor in chemical engineering active in electrochemistry research.

George W. Ellis Fellowships

Awarded annually for graduate study in any division of the University. Open to graduate students who are residents of the state of Vermont or who have been graduated from a Vermont college or university.

Michael Frydman Endowed Fellowship (2000)

To support a fellowship to a deserving master's student in the financial engineering program of the Department of Industrial Engineering and Operations Research.

Robert F. Gartland Fellowship

Awarded annually for graduate study in the Department of Industrial Engineering and Operations Research. Preference is given to students who are native-born U.S. citizens and who intend to pursue a career in business or finance.

GEM Fellowship

The GEM fellowship provides African-Americans, Hispanic Americans, and Native Americans access to graduate education. The fellowship includes tuition, fees, a stipend, and a paid summer internship. Applicants for this fellowship must be engineering or applied science majors.

Governor's Committee on Scholarship Achievement

One year awards based on financial need. Renewal is based on academic progress, financial need, and availability of funds. The student applies directly to the GCSA; the awards are matched by the School and are not in supplement to initial School awards.

Carl Gryte Fellowship (2007)

Gift from friends of Professor Carl Campbell Gryte. Awarded to needy and deserving graduate students.

Daniel and Florence Guggenheim Fellowships

Two fellowships for the study of engineering mechanics in the Institute of Flight Structures.

M. D. Hassialis Memorial Fellowship (2002)

Gift of former students of the late Krumb Professor Emeritus Hassialis. Awarded to graduate students of the Henry Krumb School of Mines in the field of Earth resources economics and management.

Higgins Fellowships

Fellowships awarded annually to first-year graduate students.

Leta Stetter Hollingworth Fellowship

Awarded annually to women who are graduates of the University of Nebraska, with preference given to those who were born in Nebraska or received their earlier education there. Holders are eligible to apply for reappointment for one year. A gift of Harry L. Hollingworth in memory of his wife.

Edward J. Ignall Research Fellowship

Awarded annually to encourage and help support the research activities of a graduate student in the Department of Industrial Engineering and Operations Research who is selected by the department chair. Gift of family, friends, and former students in memory of Professor Edward J. Ignall.

George M. Jaffin Fellowship

Awarded for graduate study and research leading to the Ph.D. degree in orthopedic biomechanics by the Department of Bioengineering of the Hospital for Joint Diseases, Orthopedic Institute, and the Department of Mechanical Engineering. It carries tuition exemption and a twelve-month stipend of up to \$10,000.

Herbert H. Kellogg Fellowship (1988)

Funded by former students and friends of Professor Emeritus H. H. Kellogg and the generous contribution of Professor Kellogg. Awarded to graduate students of the Henry Krumb School of Mines in the field of mineral engineering and chemical metallurgy.

Otto Kress Fellowship (1990)

Bequest of Mrs. Florence T. Kress in memory of her husband, Otto Kress. Awarded to postgraduate students.

Henry Krumb Fellowships

Annual fellowships in mining engineering, metallurgy, and ore dressing.

John F. T. Kuo Fellowship (1992)

Established by Dr. I. J. Won and other students of Professor Emeritus Kuo for the support of graduate students in applied geophysics.

Charles and Sarah Lapple Fellowship (2004)

Bequest of Charles (1936, 1937) and Sarah Lapple. Awarded to support deserving students in the Department of Chemical Engineering.

Kuo and Grace Li Memorial Fellowship (1993)

Gift from the Li Foundation Inc. Awarded to deserving graduate students interested in mining, mineral resources, metallurgy, and materials science.

Ralph H. McKee Fellowship (1979)

Bequest of Ralph H. McKee. Income to be used for fellowships and/or scholarships in the fields of mathematics or chemical engineering.

Benjamin Miller Memorial Fellowship

Awarded to a graduate student in the Department of Industrial Engineering and Operations Research. Preference will be given to students concerned with work in government-industry regulatory policy, procurement procedures and trade regulations.

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.

Anthony Pesco Fellowship (2006)

Gift of Dr. Anthony Pesco (1982, 1983, 1987) to support graduate students in the Chemical Engineering Department who wish to pursue careers in academia.

Piyasombatkul Fellowship (2007)

Gift from Mr. and Mrs. Chatchai Piyasombatkul. Preference for students from Southeast Asia or Presidential Fellow candidates.

Presidential Distinguished Fellowships

These fellowships are awarded annually to selected incoming Ph.D., Eng.Sc.D., and master's/Ph.D. students. Fellowships include tuition plus an annual stipend of \$24,000 for up to four years, including three months of summer research. All applications for admission are considered for these new fellowships.

Queneau Fellowship Fund

Donated by Bernard R. Queneau. Awarded to a deserving graduate student in the Department of Earth and Environmental Engineering.

David M. Rickey Endowed Fellowship (2000)

Gift of David M. Rickey (1979). Awarded to students studying electrical engineering under the holder of the David M. Rickey Professorship.

Lydia C. Roberts Graduate Fellowships

Awarded annually. Open to persons born in Iowa who have been graduated from an Iowa college or university. In addition to the stipend, the fellow is reimbursed the cost of traveling once from Iowa to New York City and back. Special provisions: holders may not concentrate their studies in law, medicine, dentistry, veterinary medicine, or theology, and each holder must, when accepting the award, state that it is his or her purpose to return to Iowa for at least two years after completing studies at Columbia; holders are eligible for reappointment.

Leo Rubinstein Endowed Fellowship (2005)

Bequest of Leo Rubinstein (1963) and gift of Frederick Rubinstein. Awarded to deserving students studying applied mathematics or industrial design.

Frank E. Stinchfield Fellowship in Orthopedic Biomechanics

Awarded for graduate study and research in the Department of Mechanical Engineering through the Orthopedic Research Laboratory of the Department of Orthopedic Surgery, College of Physicians and Surgeons, it carries tuition exemption and a twelve-month stipend of up to \$15,000.

Nickolas and Liliana Themelis Fellowship in Earth and Environmental Engineering (2000)

Gift of Nickolas and Liliana Themelis.

Theodore and Jennifer Tsung Fellowship

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

Cvi Abel Memorial Scholarship (2003)

Gift of Jack Abel.

Aigrain Family Scholarship (2008)

Gift of Jacques and Nicolleta Aigrain, parents, Class of 2008.

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).

Edwin W. and Mary Elizabeth Bright Scholarship in Mechanical Engineering (1985)

Gift of Edwin W. (1942) and Mary Elizabeth Bright. Awarded to a deserving mechanical engineering student who is a native-born U.S. citizen.

Lewis G. Burnell Memorial Scholarship (2001)

Gift of Roger W. Burnell in memory of his father, Lewis G. Burnell. Income to award an annual scholarship to a needy and deserving undergraduate student in The Fu Foundation School of Engineering and Applied Science.

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).

Samuel J. Clarke Scholarship (1960)

Bequest of Agnes Robertson Clarke.

Class of 1885 (1910)

Gift of the Class of 1885 School of Mines in commemoration of the twenty-fifth anniversary of their graduation.

Class of 1889 (1939)

Gift of the Class of 1889 College and Engineering.

Class of 1900 (1940)

Gift of the Class of 1900 College and Engineering.

Class of 1902 (1952)

Gift of the Class of 1902 College and Engineering.

Class of 1906 (1940)

Gift of the Class of 1906 in honor of Frank D. Fackenthal (1906).

Class of 1907 (1937)

Gift of the Class of 1907. Preference is given to sons and descendants of class members.

Class of 1909 (1959)

Gift of the Class of 1909 in honor of John J. Ryan.

Class of 1913 (1963)

Gift of the Class of 1913 in commemoration of the fiftieth anniversary of their graduation.

Class of 1914 (1937)

Gift of the Class of 1914 College and Engineering for a pre-engineering or prearchitecture student.

Class of 1950 Endowed Scholarship (2000)

Gift of members of the Class of 1950 in commemoration of the fiftieth anniversary of their graduation. Awarded to a deserving undergraduate.

Class of 1951 Endowed Scholarship (2001)

Gift of members of the Class of 1951 in commemoration of the fiftieth anniversary of their graduation. Awarded to a deserving undergraduate.

Class of 1952 Endowed Scholarship (2002)

Established by Alexander Feiner to be awarded to a deserving undergraduate.

Hugo Cohn Scholarship (1984)

Awarded annually with preference given to electrical engineering students. Gift of Hugo Cohn (1909).

Herbert J. Cooper Scholarship (1999)

Gift of Mrs. Deborah Cooper and the Estate of Herbert J. Cooper (1946). Awarded to a deserving undergraduate.

Milton L. Cornell Scholarship (1958)

Gift of various donors in memory of Milton L. Cornell.

Paul and Lillian Costallat Scholarship (1972)

Gift of Paul and Lillian Costallat.

Frederick Van Dyke Cruser Scholarship (1980)

Bequest of Maude Adelaide Cruser. For students in chemical engineering with financial need.

Cytryn Family Endowed Scholarship (2002)

Gift of the Cytryn Family Fund to provide financial aid to deserving undergraduates.

Frank W. Demuth Scholarship (1965)

Bequest of Frank W. Demuth (1914).

Freda Imber Dicker Endowed Scholarship Fund (2000)

Gift of Dr. Stanley Dicker (1961) in honor of the hundredth anniversary of his mother's birth (March 5, 1900).

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.

Brooke Lynn Elzweig Scholarship (2002)

Gift of Gary Elzweig (1977). Income to support an annual scholarship for a deserving undergraduate student with high financial need.

Jack B. Freeman Scholarship (1994)

Supports an undergraduate at SEAS who also plays varsity baseball. Gift of Jack B. Freeman (1955).

Pier-Luigi Focardi Scholarship (1964)

Bequest of Clara G. Focardi.

Ford/EOC Scholarship

Designated for minorities and women. Preference is given to Ford employees, their spouses, or children.

Z. Y. Fu Scholarship (1993)

Gift of The Fu Foundation for undergraduate scholarship support for the School of Engineering and Applied Science.

General Motors Scholarship

Designated for minorities and women. Preference is given to General Motors employees, their spouses, or children.

Ben and Ethelyn Geschwind Endowed Scholarship (2004)

Gift of Benjamin and Ethelyn (1984) Geschwind. Awarded to a deserving undergraduate in the School of Engineering.

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-Graham 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.

Haight Family Scholarship (2004)

Gift of Deborah E. Haight (2000). Awarded to a talented and deserving undergraduate.

Ralph W. Haines Scholarship (2002)

Gift of Ralph W. Haines (1969) for needy and deserving students in The Fu Foundation School of Engineering and Applied Science.

A. A. Halden Scholarship (1962)

Established by bequests from Dorothy C. Halden and Barbara Schwartz in memory of Alfred A. Halden.

The Hamann Scholarship (1970)

Bequest of Adolf M. Hamann (1910).

Alfred M. and Cornelia H. Haring Scholarship (1965)

Gift of the Aeroflex Foundation for an annual scholarship in the School of Mines.

H. Field Haviland Scholarship Fund (1988)

Scholarships to be awarded equally between The Fu Foundation School of Engineering and Applied Science and Columbia College. Bequest of Henry F. Haviland (1902).

Harold T. Helmer Scholarship (1965)

Bequest of Harold T. Helmer.

David Bendel Hertz College/Engineering Interschool Scholarship (1989)

Gift of David B. Hertz (1939). Awarded in alternate years to the College and to the Engineering School to a student electing to receive a B.A. from Columbia College and a B.S. from The Fu Foundation School of Engineering and Applied Science.

Edward Gurnee Hewitt Scholarship (1980)

Bequest of Mary Louise Cromwell.

Prentice Hiam Memorial Scholarship (2007)

Gift of Atul Khanna (1983). Preference given to international students.

James T. Horn Scholarship (1938)

Gift of Sarah L. and Mary T. Horn, in memory of their brother, James T. Horn (1884).

Richard and Janet Hunter Scholarship (2000)

Gift of Richard (1967) and Janet Hunter. Scholarship awarded to 3-2 program participants entering the School of Engineering and Applied Science, with preference given to graduates from Whitman College.

Jonathan Lewis Isaacs Memorial Scholarship (2001)

This scholarship was endowed in 2001 by Gary F. Jonas '66 and Jonathan L. Isaacs '66 as the Future Entrepreneurs Scholarship to acknowledge the thirty-fifth anniversary of their graduation from Columbia School of Engineering and Applied Science. On April 30, 2003, Mr. Isaacs died at the young age of fifty-seven, and the scholarship was then renamed in his memory by Gary F. Jonas, with the support of Jon's wife, Charlotte Isaacs.

Sheldon E. Isakoff Endowed Scholarship Fund (2000)

Gift of Sheldon E. (1945) and Anita Isakoff. Awarded to a deserving chemical engineering undergraduate.

Alfred L. Jaros Memorial Scholarship (1967)

Gift of various donors, in memory of Alfred L. Jaros (1911).

Cavalier Hargrave Jouet Scholarship (1941)

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.

Leung Endowed Scholarship (2006)

Gift of Lawrence Leung. Awarded annually to a deserving undergraduate.

James F. Levens Scholarship (1973)

Bequest of Ola Levens Poole for students in chemical engineering and applied chemistry.

George J. Lewin Scholarship (1965)

Gift of George J. Lewin (1917) and friends. Preference given to hearing-impaired students.

Alvin and Richard H. Lewis Scholarship

Gift of Alvin and Helen S. Lewis in memory of their son, Richard Lewis (1963).

James M. and Elizabeth S. Li Endowed Scholarship (2006)

Gift of James (1968, 1970, 1976) and Elizabeth Li. Awarded to students majoring in industrial engineering and operations.

Robert D. Lilley Memorial Scholarship and Fellowship (1988)

For students who are in their final year of the 3-2 Combined Plan Program and who have a commitment to community service.

Bruce and Doris Lister Endowed Scholarship (2000)

Gift of Bruce A. Lister (1943, 1947) to support a needy and deserving undergraduate student in The Fu Foundation School of Engineering and Applied Science.

Anna Kazanjian and Guy Longobardo Scholarship (2007)

Gift of Anna Kazanjian (1949, 1952) and Guy (1949, 1950, 1962) Longobardo. Preference given to students studying mechanical engineering.

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.

Henry Michel Scholarship (2005)

Gift of Mrs. Mary-Elizabeth Michel in memory of Henry Michel (1949). Scholarship awarded to deserving undergraduate students with preference given to civil engineering majors.

Stuart Miller Endowed Scholarship in Engineering (2003)

Gift of Stuart Miller, to be used to provide support for an undergraduate engineering student.

John K. Mladinov Scholarship (1994)

Gift of Barbara P. Mladinov in honor of her husband, John K. Mladinov (1943). Awarded to a deserving undergraduate with a minor in liberal arts.

Frank C. Mock and Family Scholarship (1987)

Bequest of Frank C. Mock (1913). For students in electrical engineering with financial need.

New Hope Foundation Scholarship (2006)

Gift of Lee and Margaret Lau. Awarded to a deserving undergraduate with preference to students from Ontario, Canada, or mainland China.

A. Peers Montgomery Memorial Scholarship (1990)

Gift of the family of A. Peers Montgomery (1926).

John J. Morch Scholarship (1963)

Bequest of John J. Morch.

Seeley W. Mudd Scholarship (1958)

Gift of the Seeley W. Mudd Foundation. Several awarded annually for maintenance, not for tuition. Recipient must be a U.S. citizen, and his or her grandfather must have been born a U.S. citizen. Special application required.

Mary Y. Nee Endowed Scholarship (2008)

Gift of Mary Yuet-So Nee (1984).

Frederick Noel Nye Scholarship (1971)

Bequest of Frederick Noel Nye (1927).

Parker Family Endowed Scholarship (2001)

Gift of Peter D. Parker (1972, 1974). Income to award an annual scholarship to a needy and deserving undergraduate student in The Fu Foundation School of Engineering and Applied Science.

Robert I. Pearlman Scholarship (1989)

Gift of Robert I. Pearlman (1955). Awarded annually to students in the School of Engineering and Applied Science. Preference is given to students from single-parent households.

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.

Kevin T. Roach Endowed Scholarship (2003)

Gift of Kevin T. Roach (1977). Income to provide tuition assistance to undergraduate students in engineering at Columbia University.

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.

Norman A. Schefer Scholarship (1999)

Gift of Norman A. Schefer (1950) and Fay J. Lindner Foundation. Awarded annually to a deserving and talented student at the School of Engineering.

Samuel Y. Sheng Scholarship (2007)

Gift of Samuel Y. Sheng (1951). Awarded to students who demonstrate academic excellence.

Mark Schlowsky-Fischer Scholarship (2005)

Gift of George Schlowsky (1965) in memory of Mark Schlowsky-Fischer (1997). Scholarship awarded to deserving undergraduate students with preference given to computer science majors.

Ralph J. Schwarz Scholarship (1993)

Gift of the Class of 1943 and other donors in memory of Ralph J. Schwarz (1943). To be awarded to academically outstanding students who require financial aid.

David C. and Gilbert M. Serber Memorial Scholarship (1950)

Gift of the Serber family, for a student in civil engineering, in honor of David Serber (1896).

Varsha H. Shah Scholarship (2003)

Gift of Hemant and Varsha Shah to support undergraduate female minority students.

Jared K. Shaper Scholarship

For deserving and qualified candidates for degrees in engineering.

Edith Shih Interschool Scholarship Fund (2008)

Gift of Edith Shih, Esq. (Teachers College 1977–1978).

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).

Gene F. Straube Fund (2007)

Gift of Gene F. Straube (SEAS 1950, CC 1949). The fund shall provide scholarships to undergraduate students who graduated from a high school or prep school in northern California, and who are pursuing studies in electrical engineering, computer engineering, or computer science.

Steve Tai and Kin-Ching Wu Endowed Scholarship Fund (2001)

Gift of Steve Tai (1980) for an annual scholarship to a needy and deserving undergraduate student at The Fu Foundation School of Engineering and Applied Science.

Tai Family Scholarship (2003)

Gift of Timothy Tai to be used to support Asian students demonstrating financial need and outstanding academic potential, with preference given to Hong Kong, Taiwanese, mainland Chinese, and Chinese-American applicants for admission. A T. Tai Family Scholar will be named in a first-year class, and with suitable academic achievement and continuing need, would retain that honor until graduation.

Grace C. Townsend Scholarship (1941)

Bequest of Miss Grace C. Townsend.

Theodosios and Ekaterine Typaldos Endowed Scholarship Fund (2000)

Gift of Andreas (1969) and Renee Typaldos and the Community Foundation of New Jersey. Awarded to deserving undergraduates. Preference is given to Greek-American students.

Upton Fellowship

For the children of employees of D. C. Heath and Company of Lexington, Massachusetts.

Kenneth Valentine Memorial Scholarship (1986)

Bequest of Julia H. Valentine, in memory of Kenneth Valentine (1914). Awarded annually with preference given to students in chemical engineering.

Frank Vanderpoel Scholarship (1936)

Bequest of Frank Vanderpoel.

William E. Verplanck Scholarship (1957)

Gift of Mrs. T. Bache Bleecker and Edward F. Verplanck (1912) in memory of their father, William E. Verplanck (1876).

Arnold Von Schrenk Scholarship (1943)

Bequest of Mrs. Helen von Schrenk in memory of her husband, Arnold von Schrenk.

George Wascheck Scholarship

Bequest of George Wascheck (1926).

J. Watumull Scholarship (1989)

For students in the Graduate School of Arts and Sciences and in the Engineering School who are of East Indian ancestry.

Wells and Greene Scholarship

Bequest of Josephine Wells Greene.

Herbert A. Wheeler Scholarship (1923)

Gift of Herbert A. Wheeler.

Frederick C. Winter Scholarship (1966)

Gift of various donors in memory of Frederick C. Winter (1943).

William F. Wurster Scholarship (1974)

Awarded to a student of chemical engineering and applied chemistry. Gifts of William F. Wurster (1913).

Robert H. and Margaret H. Wyld Scholarship

Gift of Robert H. (1904) and Margaret H. Wyld.

Max Yablick Memorial Scholarship (1986)

Bequest of Max Yablick (1914). Awarded annually with preference given to graduates of Hebrew day schools and to students in the Combined Plan Program with Yeshiva University.

Theresa Ann Yeager Memorial Scholarship (1983)

Gift of the family of Theresa Ann Yeager (1981) to support a woman who is enrolled in The Fu Foundation School of Engineering and Applied Science.

RESIDENCE HALL SCHOLARSHIPS**Class of 1887 Mines Residence Scholarship**

Awarded annually to a third-year degree candidate, with preference given to descendants of members of the Class of 1887 Mines.

Class of 1896 Arts and Mines Scholarship

Awarded annually to a degree candidate in Columbia College, the Engineering School, or the Graduate School of Architecture and Planning, with preference given to descendants of members of the Class of 1896 Arts and Mines.

Class Of 1916 College and Engineering Fund

Gift of the Class of 1916 College and Engineering.

ANNUAL GIFT FELLOWSHIPS AND SCHOLARSHIPS

Each year the University receives gifts of money, some of which are renewals, for fellowships and scholarships. The fellowships and scholarships made available in recent years as a result of such gifts are:

Asian Columbia Alumni Association Scholarship (1999)

General financial aid for Asian students.

Columbia-Whitman Memorial Scholarship

Awarded from time to time to a Whitman College preengineering junior for study in the Columbia Engineering School toward the B.S. degree. Maximum value: full tuition and fees for the academic year. The holder may apply for renewal.

Con Edison Minority and Female Scholarship Program

To aid deserving and promising minority or female students from within the Con Edison service territory who will be pursuing a career in engineering, by providing a renewable scholarship of at least \$1,500 and a job internship. Financial need must be demonstrated.

Consolidated Natural Gas Company Fellowship

For graduate students in chemical engineering and applied chemistry.

DuPont Fellowship

In chemical engineering.

Everard A. Elledge Memorial Scholarship (1985)

Gift of Carol G. Elledge, in memory of Everard A. Elledge (1942).

Ioannou Scholarship (1999)

Donated by Constantine and Cecilia Ioannou, Constantine D & B, Ltd. Awarded to a deserving undergraduate, preference given to a Greek-American student.

Moses and Hannah Malkin Scholarship Fund Gift (2004)

Gift of Moses and Hannah Malkin for an undergraduate engineering scholarship.

Monsanto Chemical Company Scholarship

Open to students in Barnard College, Columbia College, and the Engineering School who are pursuing a program of study in chemical engineering or directed toward it.

Louis Morin Scholars and Fellows (2000)

Gift of the Louis Morin Charitable Trust. Designated for Jewish undergraduates, Ph.D.s, and postdocs.

The National Action Council for Minorities in Engineering Inc. Incentive Grants Program

Renewable grants ranging from \$250 to \$2,500 for minority students in good academic standing who continue to have financial need. These awards supplement the funds a student raises through work, family, schools, foundations, and government grant programs.

New York Chapter of the American Society for Metals Scholarship

In metallurgy.

Procter and Gamble Fellowship

In chemical engineering and applied chemistry.

Benjamin A. Tarver Jr. Memorial Fund (2002)

Gifts of Benjamin A. Tarver Sr. and various donors in memory of Benjamin A. Tarver Jr. (2004), who passed away on April 8, 2002.

The 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.

Zvi Galil Award for Improvement in Engineering Student Life

Given annually to the student group that most improves engineering student life during the academic year. Established in honor of Zvi Galil, dean of the School from 1995 to 2007.

Jewell M. Garrelts Award

Awarded to an outstanding graduating senior who will pursue graduate study in the department that was so long and successfully shepherded by Professor Jewell M. Garrelts. This award is made possible by gifts from alumni and friends of Professor Garrelts and from the Garrelts family in honor of an outstanding engineer, educator, and administrator.

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.

Yuen-huo Hung and Chao-chin Huang Award in Biomedical Engineering

This award has been endowed to honor the grandfathers of Professor Clark T. Hung in the Department of Biomedical Engineering. His paternal grandfather, Yuen-huo Hung, was a surgeon in Taipei who was renowned for his practice of medicine and for his compassion toward patients. Professor Hung's maternal grandfather, Chao-chin Huang, was a famous politician in Taiwan who dedicated his life to the citizens of his country, serving as mayor of Taipei, speaker of the Taiwan Provincial Assembly, and consul general to the United States. This award is given to a graduating doctoral student in the Department of Biomedical Engineering who embodies the collective attributes of these distinguished individuals. This student will have demonstrated great potential for making significant contributions to the fields of biomedical engineering and public health, and for serving as an ambassador of biomedical engineering.

Illig Medal

Established in 1898 by a bequest from William C. Illig, E.M., 1882, and awarded by the faculty to a member of the graduating class for commendable proficiency in his or her regular studies.

Eliahu I. Jury Award

Established 1991 for outstanding achievement by a graduate student in the areas of systems communication or signal processing.

Charles Kandel Award

Medal and cash prize presented annually by the Columbia Engineering School Alumni Association to that member of the graduating class who has best promoted the interests of the School through participation in extracurricular activities and student-alumni affairs.

The Andrew P. Kosoresow Memorial Award for Excellence in Teaching and Service

Awarded each year by the Department of Computer Science to up to three computer science students for outstanding contributions to teaching in the department and exemplary service to the department and its mission.

Dongju Lee Memorial Award

Established in 2005 by family and friends in memory of Dongju Lee (DJ), graduate student in the Department of Civil Engineering and Engineering Mechanics, 1999–2003. A certificate and cash prize awarded annually by the department to a doctoral student specializing in 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 outstanding promise of personal development leading to a career in construction engineering and management.

The James F. Parker Memorial Award (Mechanical Engineering Design Award)

James F. Parker served and represented Columbia engineering students as their dean from 1975 to 1984. He also distinguished himself in the pursuit and analysis of two-dimensional art. In recognition of his special combination of talents and their integration, the School of Engineering and Applied Science salutes the graduating student who has distinguished her- or himself as a designer. A person of creative and innovative inclination receives the James Parker Medal, as evidenced by outstanding performance in courses integrating engineering analysis and design.

Robert Peele Prize

A prize of \$500 awarded from time to time to that member of the graduating class in mining engineering who has shown the greatest proficiency in his or her course of studies.

Claire S. and Robert E. Reiss Prize

Gift of Robert Reiss, InterVentional Technologies Inc. Awarded to a graduating senior in biomedical engineering judged by faculty most likely to contribute substantially to the field.

Francis B. F. Rhodes Prize

Established in 1926 by Eben Erskine Olcott of the Engineering Class of 1874, in memory of his classmate, Francis Bell Forsyth Rhodes, School of Mines, 1874, and awarded from time to time to the member of the graduating class in materials science and metallurgical engineering who has shown the greatest proficiency in his or her course of study.

School of Engineering and Applied Science Scholar/Athlete Award

Presented from time to time by the Office of the Dean to that graduating student who has distinguished himself or herself as a varsity athlete and scholar.

School of Engineering Student Activities Award

This award is presented to an undergraduate degree candidate in The Fu Foundation School of Engineering and Applied Science who by virtue of his or her willingness, energy, and leadership has significantly contributed to the co-curricular life of the School.

Robert Simon Memorial Prize

The Robert Simon Memorial Prize was established in 2001 to honor Robert Simon, a Columbia alumnus who spent a lifetime making valuable contributions to computational and mathematical sciences, and is awarded annually by the Department of Applied Physics and Applied Mathematics to the doctoral student who has completed the most outstanding dissertation. Should no dissertation qualify in a given year, the prize may be awarded to either the most outstanding student who has completed a Master of Science degree in the department or to the most outstanding graduating senior in the department.

Richard Skalak Memorial Prize

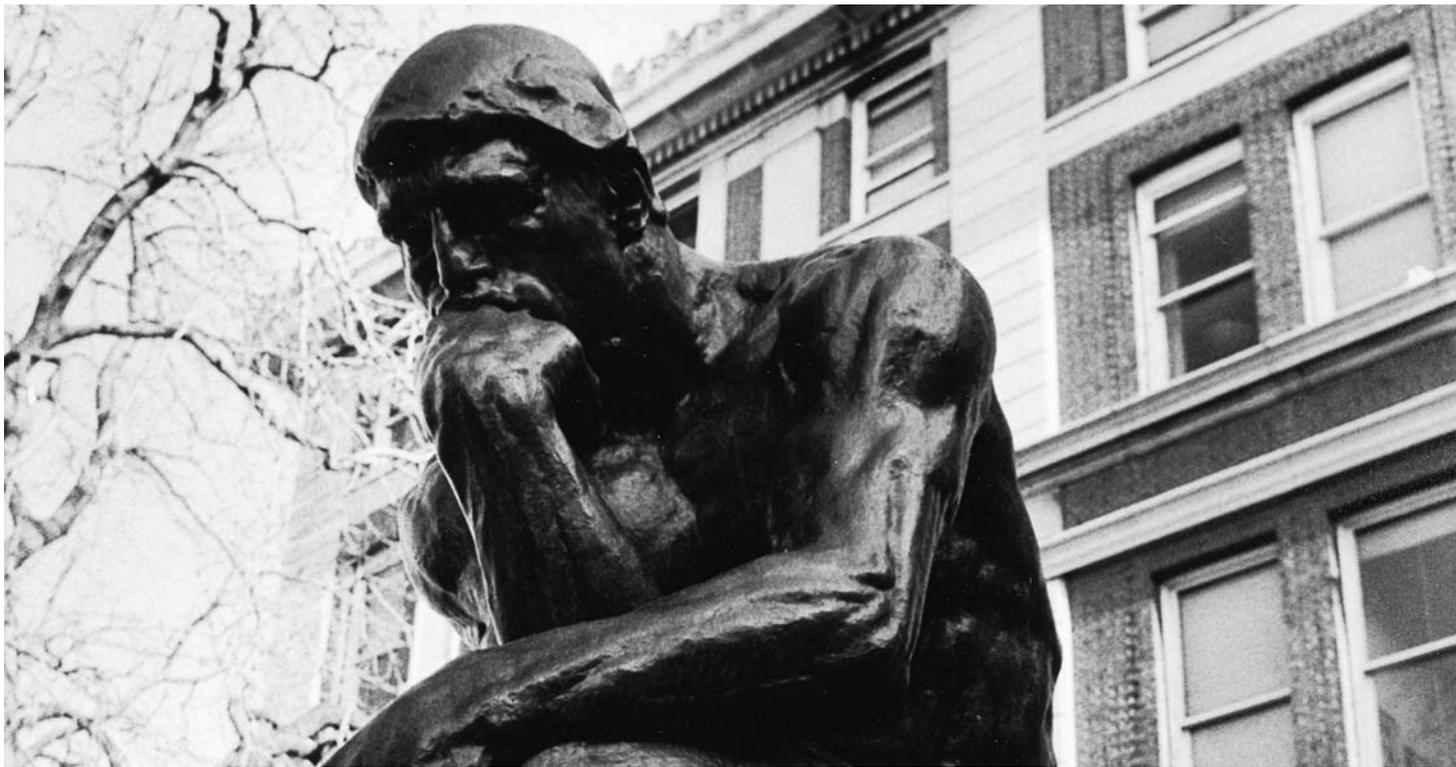
The Richard Skalak Memorial Prize was founded in recognition of the pioneering contributions of Richard Skalak to the development of the biomedical engineering program at Columbia University. Dr. Skalak was an inspirational teacher and scholar who taught students and colleagues to appreciate the value of broad interactions between engineering and medicine, particularly in the fields of cardiovascular mechanics, tissue engineering, and orthopedics. The Richard Skalak Memorial Prize is awarded annually to a senior biomedical engineering student who exemplifies the qualities of outstanding engineering scholarship and breadth of scientific curiosity that form the basis for lifelong learning and discovery.

George Vincent Wendell Memorial Medal

Established in 1924 by the friends in the alumni and faculty of the late Professor George Vincent Wendell to honor and perpetuate his memory; a certificate and medal awarded annually by choice of the class and the faculty to that member of the graduating class who best exemplifies his ideals of character, scholarship, and service.

Undergraduate Citation in Civil Engineering

University and School Policies, Procedures, and Regulations



REGISTRATION AND ENROLLMENT

Registration is the mechanical process that reserves seats in particular classes for eligible students. It is accomplished by following the procedures announced in advance of each term's registration period.

Enrollment is the completion of the registration process and affords the full rights and privileges of student status. Enrollment is accomplished by the payment or other satisfaction of tuition and fees and by the satisfaction of other obligations to the University.

Registration alone does not guarantee enrollment; nor does registration alone guarantee the right to participate in class. In some cases, students will need to obtain the approval of the instructor or of a representative of the department that offers a course. Students should check this bulletin, their registration instructions, the Directory of Classes, and also with an adviser for all approvals that may be required.

To comply with current and anticipated Internal Revenue Service mandates, the University requires all students who will be receiving financial aid or payment through the University payroll system to report their Social Security number at the time of admission. Newly admitted students who do not have a Social Security number should obtain one well in advance of their first registration. International students should consult the International Students and Scholars Office, located at 524 Riverside Drive (212-854-3587), for further information.

Special billing authorization is required of all students whose bills are

to be sent to a third party for payment. Students who are not citizens of the United States and who need authorization for special billing of tuition and/or fees to foreign institutions, agencies, or sponsors should go to the International Students and Scholars Office with two copies of the sponsorship letter.

University Regulations

Each person whose enrollment has been completed is considered a student of the University during the term for which he or she is enrolled unless his or her connection with the University is officially severed by withdrawal or for other reasons. No student enrolled in any school or college of the University shall at the same time be enrolled in any other school or college, either of Columbia University or of any other institution, without the specific authorization of the dean or director of the school or college of the University in which he or she is first enrolled.

The privileges of the University are not available to any student until enrollment has been completed. Students are not permitted to attend any University course for which they are not officially enrolled or for which they have not officially filed a program unless they have been granted auditing privileges.

The University reserves the right to withhold the privileges of registration and enrollment or any other University privilege from any person who has outstanding financial, academic, or administrative obligations to the University.

Continuous registration until completion of all requirements is obligatory for each degree. Students are exempted from the requirement to register continuously only when granted a voluntary or medical leave of absence by their Committee on Academic Standing (for undergraduate students) or the Office of Graduate Student Services (for graduate students).

Registration Instructions

Registration instructions are announced in advance of each registration period. Students should consult these instructions for the exact dates and times of registration activities. Students must be sure to obtain all necessary written course approvals and advisers' signatures before registering. Undergraduate students who have not registered for a full-time course load by the end of the add period will be withdrawn from the School, as will graduate students who have not registered for any course work by the end of the add period. International students enrolled in graduate degree programs must maintain full-time status until degree completion.

DEGREE REQUIREMENTS AND SATISFACTORY PROGRESS

Undergraduate

Undergraduate students are required to complete the School's degree requirements and graduate in eight academic terms. Full-time undergraduate registration is defined as at least 12 semester credits per term. However, in order to complete the degree, students must be

averaging 16 points per term. Students may not register for point loads greater than 21 points per term without approval from the Committee on Academic Standing.

To be eligible to receive the Bachelor of Science degree, a student must complete the courses prescribed in a faculty-approved major/program (or faculty-authorized substitutions) and achieve a minimum cumulative grade-point average (GPA) of 2.0. While the minimum number of academic credits is 128 for the B.S. degree, some programs of the School require a greater number of credits in order to complete all the requirements. Undergraduate engineering degrees are awarded only to students who have completed at least 60 points of course work at Columbia.

Undergraduates in the programs accredited by the Engineering Accreditation Commission of the ABET (chemical engineering, civil engineering, Earth and environmental engineering, electrical engineering, and mechanical engineering) satisfy ABET requirements by taking the courses in prescribed programs, which have been designed by the departments so as to meet the ABET criteria.

Attendance

Students are expected to attend their classes and laboratory periods. Instructors may consider attendance in assessing a student's performance and may require a certain level of attendance for passing a course.

Graduate

A graduate student who has matriculated in an M.S. program or is a special student is considered to be making normal progress if at the completion of 9 credits, he or she has earned a cumulative GPA of 2.5. Candidates in the Doctor of Engineering Science (Eng.Sc.D.) and professional programs are expected to achieve a 3.0 grade point average at the completion of 9 points of course work.

Thereafter, graduate students are considered to be making minimum satisfactory progress if they successfully complete at least 75 percent of all courses they have registered for as candidates for the degree with grades of C- or better. Students placed on academic probation because of their grades are nonetheless considered to be making minimum satisfactory progress for their first term on probation (see chapter "Academic Standing," following). Degree requirements for master's and professional degrees must be completed within five years; those for the doctoral degrees must be completed within seven years. A minimum cumulative grade-point average of 2.5 (in all courses taken as a degree candidate) is required for the M.S. degree; a minimum GPA of 3.0 is required for the professional degree and the Doctor of Engineering Science (Eng.Sc.D.) degree. The minimum residence requirement for each Columbia degree is 30 points of course work completed at Columbia.

Changes in Registration

A student who wishes to drop or add courses or to make other changes in his or her program of study after the add/drop period must obtain the signature of his or her adviser. A student who wishes to drop or add a course in his or her major must obtain department approval. The deadline for making program changes in each term is shown in the Academic Calendar. After this date, undergraduate students must petition their Committee on Academic Standing; graduate students must petition the Office of Graduate Student Services. For courses dropped after these dates, no adjustment of fees will be made. Failure to attend a class without officially dropping the class will result in a grade indicating permanent unofficial withdrawal (UW).

Transfer Credits

Undergraduate students may obtain academic credit toward the B.S. degree by completing course work at other accredited institutions. Normally, this credit is earned during the summer. To count as credit toward the degree, a course taken elsewhere must have an equivalent at Columbia and the student must achieve a grade of at least C. The institution must be an accredited four-year college. To transfer credit, a student must obtain prior approval from his or her adviser and the department before taking such courses. A course description and syllabus should be furnished as a part of the approval process. Courses taken before the receipt of the high school diploma may not be credited

toward the B.S. degree. A maximum of 6 credits may be credited toward the degree for college courses taken following the receipt of a high school diploma and initial enrollment.

Graduate students are not eligible for transfer credits.

Examinations

Midterm examinations: Instructors generally schedule these in late October and mid-March.

Final examinations: These are given at the end of each term. The Master University Examination Schedule is available online and is confirmed by November 1 for the fall term and April 1 for the spring term. This schedule is sent to all academic departments and is available for viewing on the Columbia Web site. Students should consult with their instructors for any changes to the exam schedule. Examinations will not be rescheduled to accommodate travel plans.

Note: If a student has three final examinations scheduled during one calendar day, as certified by the Registrar, an arrangement may be made with one of the student's instructors to take that examination at another, mutually convenient time during the final examination period. This refers to a calendar day, not a twenty-four-hour time period. Undergraduate students unable to make suitable arrangements on their own should contact their adviser. Graduate students should contact the Office of Graduate Student Services.

Transcripts and Certifications

The University abides by the provisions of the Federal Family Educational Rights and Privacy Act (FERPA) of 1974. This act ensures a wide range of rights, including but not limited to information about student records that the University maintains, who maintains them, who has access to them, and for what purposes access is granted. The act also permits the University to release "directory information" without a student's consent. In addition, the act guarantees students access to their records and restricts the access of others.

Students who wish to restrict access to their directory information may do so on the Morningside campus at the

Student Service Center, 205 Kent. The guidelines are available on ColumbiaWeb. Questions about the interpretation of the guidelines should be referred to the University's General Counsel, 412 Low Library.

You may obtain an official transcript of your academic record at Columbia University by writing to:

Student Service Center
Columbia University
Mail Code 9202
1150 Amsterdam Avenue
New York, NY 10027
Attention: Transcripts

Please include the following information with your request: current and former names; personal identification number (PID) if known; schools attended and dates of attendance; degrees awarded and dates awarded; number of transcripts desired and complete address for each; your current address and telephone number; your signature authorizing the release of your transcript. You may also order transcripts in person at 205 Kent Hall on the Morningside campus (9:00 a.m.–5:00 p.m., Monday–Friday). Currently enrolled students may order transcripts for themselves and for colleges and universities via the Student Services Web page at www.columbia.edu/cu/students. There is no charge for issuing transcripts; however, all students pay a one-time transcript fee of \$75 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.

Currently enrolled students may order certifications of their enrollment and degrees in person or on the Student Services Web page as described above. Certifications are provided while you wait if you come to 205 Kent to request them. There is no charge for certifications.

The Student Service Center no longer handles requests by noncurrent students, by alumni, or by third parties. Their requests should be made either by calling the National Student Clearinghouse: 703-742-4200; by e-mail: degreeverify@studentclearinghouse.org; or by regular mail: National Student

Clearinghouse, 13454 Sunrise Valley Drive, Suite 300, Herndon, VA 20171.

Report of Grades

Students are notified by e-mail when grades are submitted. Grades can then be viewed the following day by using the Student Services Online feature located on the Student Services home page at www.columbia.edu/students. If you need an official printed report, you must request a transcript (please see Transcripts and Certifications above).

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 advising dean. The deadline is the last day of class in the semester of enrollment. Students requesting an INC must gain permission from both the Committee on Academic Standing (CAS) and the instructor. Graduate students should contact their instructor. If granted an INC, students must complete the required work within a period of time stipulated by the instructor but not to exceed one year. After a year, the INC will be automatically changed into an F or contingency grade.

The mark of YC (year course): a mark given at the end of the first term of a course in which the full year of work must be completed before a qualitative grade is assigned. The grade given at the end of the second term is the grade for the entire course.

The mark of CP (credit pending): given only in graduate research courses in which student research projects regularly extend beyond the end of the term. Upon completion, a final qualitative grade is then assigned and credit allowed. The mark of CP implies satisfactory progress.

The mark of MU (make-up examination): given to a student who has failed the final examination in a course but 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 adminis-

tered as soon as the instructor can schedule it.

The mark of P/F (pass/fail): this grading option is designed to allow students to extend their academic inquiry into new areas of study. No course taken for pass/fail may be used to satisfy a student's program and degree requirements. The P/F option does not count toward degree requirements for graduate students.

Credit for Internships

Students who participate in noncompensated off-campus internships may have the internships noted on their transcripts. Approval for this notation may be obtained from your adviser. Formal notification from the employer is required. Graduate students may petition the office of Graduate Student Services for this notation.

Name Changes

Students may change their name of record only while currently enrolled in the University. There is no charge for this service, but students must submit a name change affidavit to the Student Service Center. Affidavits are available from this office. When you graduate or cease to enroll in the University, your name of record is considered final and may not be changed unless you enroll again at the University.

GRADUATION

Columbia University awards degrees three times during the year: in February, May, and October. There is one commencement ceremony in May. Only students who have completed their requirements for the degree may participate in graduation ceremonies.

Application or Renewal of Application for the Degree

In general, students pick up and file an application for a degree at their schools or departments, but there are several exceptions. Candidates for master of science and professional degrees must pick up and file their application for the degree with the Student Service Center, 205 Kent Hall. Candidates for doctoral and master of philosophy degrees

should inquire at their departments but must also follow the instructions of the Dissertation Office, 107 Low Library.

General deadlines for applying for graduation are November 1 for February, December 1 for May, and August 1 for October. (When a deadline falls on a weekend or holiday, the deadline moves to the next business day.) Doctoral students must deposit their dissertations two days before the above conferral dates in order to graduate.

Students who fail to earn the degree by the conferral date for which they applied must file another application for a later conferral date.

Diplomas

There is no charge for the preparation and conferral of an original diploma. If your diploma is lost or damaged, there will be a charge of \$100 for a replacement diploma. Note that replacement diplomas carry the signatures of current University officials. Applications for replacement diplomas may be requested by calling the Student Service Center, Graduation, Degree Audit, and Diploma Division, 212-854-4400.

ACADEMIC 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, in consultation with the departments, 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. Undergraduates who take a medical leave of absence are guaranteed

housing upon their return. A medical leave of absence for a graduate student is granted by the Office of Graduate Student Services. Documentation from a physician or counselor must be provided before such a leave is granted. In order to apply for readmission following a medical leave, a student must submit proof of recovery from a physician or counselor. A medical leave is for a minimum of one year and 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. For the complete policy, consult your advising dean.

VOLUNTARY LEAVE OF ABSENCE

A voluntary leave of absence may be granted by the Committee on Academic Standing to undergraduate students who request a temporary withdrawal from The Fu Foundation School of Engineering and Applied Science for a nonmedical reason. Students considering a voluntary leave must discuss this option in advance with their advising dean. Voluntary leaves are granted for a period of one calendar year only; VLOAs will not be granted for one semester, or for more than one year. Students must be in good academic standing at the time of the leave, and must be able to complete their major and degree in eight semesters. Students may not take courses for transferable credit while on leave. Finally, students who choose to take voluntary leaves are not guaranteed housing upon return to the University. International students should contact the International Students and Scholars Office to ensure that a leave will not jeopardize their ability to return to SEAS.

LEAVE FOR MILITARY DUTY

Any student who is a member of the National Guard or other reserve component of the armed forces of the United States or of the state-organized militia and is called or ordered to active duty will be granted a military leave of absence for the period of active duty and for one year thereafter. Upon return from military leave of absence, the student will be restored to the educational status attained prior to being called or ordered to such duty without loss of academic credits earned, scholarships or grants awarded, or tuition or other fees paid prior to the commencement of active duty. The University will credit any tuition or fees paid for the period of the military leave of absence to the next enrollment period or will refund the tuition and fees paid to the student, at the student's option. Students returning from military duty are guaranteed housing.

Students in need of a military leave of absence should contact the Dean of Students for their school.

INVOLUNTARY LEAVE OF ABSENCE POLICY

The Dean of Students or his/her designee may place a student on an involuntary leave of absence for reasons of personal or community safety. This process will be undertaken only in extraordinary circumstances when there is compelling information to suggest that the student is engaging in or is at heightened risk of engaging in behavior that could lead to serious injury to others, including as a result of physical or psychological illness. In addition, the involuntary leave process may be initiated if, based on an individualized assessment from Counseling and Psychological Services or other University personnel, it is determined that there is a significant risk that the student will harm him/herself, and that the risk cannot be elimi-

nated or reduced to an acceptable level through reasonable and realistic accommodations and/or on-campus supports.

This policy will not be used in lieu of disciplinary actions to address violations of Columbia University rules, regulations, or policies. A student who has engaged in behavior that may violate rules, regulations, or policies of the University community may be subject to the Dean's Discipline Process of his/her particular school. A student may be required to participate in the disciplinary process for his/her school coincident with placing the student while on an involuntary leave of absence. A student who is placed on an involuntary leave of absence while on academic and/or disciplinary status will return on that same status.

Before an involuntary leave is considered, efforts may be made to encourage the student to take a voluntary medical leave of absence. These procedures are described in the Medical Leave of Absence Policy on page 232. A readmission process may still be required of a student electing a voluntary medical leave to determine his/her readiness to return to school. A student will not be deemed ready to return to school if returning may increase the risk of self-harm and/or harm to others.

International students are advised that an involuntary leave of absence will likely affect their student visa status and should consult with the International Students and Scholars Office (ISSO).

When safety is an immediate concern, the Dean of Students or his/her designee may remove a student from the campus pending final decision on an involuntary leave. If this action is deemed necessary, the student will be given notice of the removal. An opportunity to be heard by the Dean of Students and, if desired, appeal the final decision will be provided at a later time.

For the complete policy and guidelines, consult your advising dean in the Center for Student Advising.

REQUIRED MEDICAL LEAVE FOR STUDENTS WITH EATING DISORDERS

With eating disorders, a medical leave is sometimes necessary to protect the safety of a student. Usually this is because the student's illness is advanced enough to require hospitalization or intensive day treatment beyond the scope of University medical and psychological resources. A medical leave is also sometimes deemed necessary when an individual student's eating disorder has negatively impacted the integrity of the University's learning environment.

Before an involuntary medical leave is considered, efforts will be made to encourage the student to take a voluntary medical leave, thus preserving, to the extent possible, confidentiality and privacy. The policy will be invoked only in extraordinary circumstances, when a student is unable or unwilling to request a voluntary medical leave of absence.

For the complete policy and guidelines, consult your advising dean in the Center for Student Advising.

READMISSION

Students seeking readmission to The Fu Foundation School of Engineering and Applied Science must submit evidence that they have achieved the purposes for which they left. Consequently, specific readmission procedures are determined by the reasons for the withdrawal. Further information for undergraduate students is available in the Center for Student Advising. Graduate students should see the Office of Graduate Student Services.

Students applying for readmission should complete all parts of the appropriate readmission procedures by June 1 for the autumn term or October 1 for the spring term.

LIFE IN THE ACADEMIC COMMUNITY

The Fu Foundation School of Engineering and Applied Science within Columbia University is a community. Admitted students, faculty, and administrators come together and work through committees and other representative bodies to pursue and to promote learning, scholarly inquiry, and free discourse. As in any community, principles of civility and reasoned interaction must be maintained. Thus, methods for addressing social as well as academic behaviors exist.

RULES OF UNIVERSITY CONDUCT

The Rules of University Conduct (Chapter XLIV of the Statutes of the University) provide special disciplinary rules applicable to demonstrations, rallies, picketing, and the circulation of petitions. These rules are designed to protect the rights of free expression through peaceful demonstration while at the same time ensuring the proper functioning of the University and the protection of the rights of those who may be affected by such demonstrations.

The Rules of University Conduct are University-wide and supersede all other rules of any school or division. Minor violations of the Rules of Conduct are referred to the normal disciplinary procedures of each school or division ("Dean's Discipline"). A student who is charged with a serious violation of the Rules has the option of choosing Dean's Discipline or a more formal hearing procedure provided in the Rules.

All University faculty members, students, and staff members are responsible for compliance with the Rules of

University Conduct. Copies of the full text are available at the Office of the University Senate, 406 Low Memorial Library.

DISCIPLINE

The continuance of each student upon the rolls of the University, the receipt of academic credits, graduation, and the conferring of the degree are strictly subject to the disciplinary powers of the University.

Although ultimate authority on matters of student discipline is vested in the Trustees of the University, the Dean of the School and his staff are given responsibility for establishing certain standards of behavior for SEAS students beyond the regulations included in the Statutes of the University and for defining procedures by which discipline will be administered.

We expect that in and out of the classroom, on and off campus, each student in the School will act in an honest way and will respect the rights of others. Freedom of expression is an essential part of University life, but it does not include intimidation, threats of violence, or the inducement of others to engage in violence or in conduct which harasses others. We state emphatically that conduct which threatens or harasses others because of their race, sex, religion, disability, sexual orientation, or for any other reason is unacceptable and will be dealt with very severely. If each of us at Columbia can live up to these standards, we can be confident that all in our community will benefit fully from the diversity to be found here. Any undergraduate student who believes he

or she has been victimized should speak with an adviser in the Center for Student Advising, a member of the Residential Programs staff, or a member of the Office of Judicial Affairs and Community Standards; graduate students should speak with an officer in the Office of Graduate Student Services.

While every subtlety of proper behavior cannot be detailed here, examples of other actions that would subject a student to discipline are:

- dishonesty in academic assignments or in dealings with University officials, including members of the faculty
- knowingly or recklessly endangering the health or safety of others
- intentionally or recklessly destroying, damaging, or stealing property
- possession, distribution, or use of illegal drugs
- possession of weapons
- refusal to show identification at the request of a University official; failure to respond to the legitimate request of a University official exercising his or her duty
- threatening, harrasing, or abusing others
- violating local, state, or federal laws
- violating the "Rules of University Conduct" (copies of which are available in 406 Low Library and other locations mentioned above)
- violating the rules of the residence halls as outlined in the "Guide to Living"; this also applies to all fraternity and sorority housing
- violating the University's Alcohol Policy
- violating the University's Sexual Assault Policy (see page 239)
- violating the rules governing Columbia

University Information Technology (CUIT) policies and procedures

- selling or otherwise commercializing notes (whether taken in class by a student or distributed to the class by an instructor), syllabi, exams, or content on a University or individual faculty member Web site that is not accessible to anyone outside of the University community
- representing any commercial interest on campus or operating any business on campus without authorization from the Associate Dean of Career Services

DISCIPLINARY PROCEDURES

Many policy violations that occur in the Residence Halls rules are handled by the Associate Directors of Residential Programs. Some serious offenses are referred directly to the Office of Judicial Affairs and Community Standards. Violations in University Apartment Housing are handled by building managers and housing officials. Some incidents are referred directly to the School's housing liaison in the Office of Graduate Student Services.

Most violations of rules concerning fraternities or sororities as organizations are handled by the Assistant Director of Greek Life and Leadership. Some serious offenses are referred directly to the Office of Judicial Affairs and Community Standards.

In matters involving rallies, picketing, and other mass demonstrations, the Rules of University Conduct outlines procedures.

The Office of Judicial Affairs (located within the Division of Student Affairs) is responsible for all disciplinary affairs

concerning undergraduate students that are not reserved to some other body. The Office of Graduate Student Services is responsible for all disciplinary affairs concerning graduate students that are not reserved to some other body.

Dean's Discipline Process for Undergraduate Students

The purpose of the Dean's Discipline process is twofold. First, it is used to determine the accused student's responsibility for the alleged violation(s) of SEAS or University policy(ies). In addition, it is an opportunity for the student to engage in a meaningful conversation regarding his or her role as a member of the Columbia community. The Dean's Discipline process is not an adversarial process, nor is it a legalistic one, and therefore the technical rules of evidence applicable to civil and criminal court cases do not apply.

After a complaint is received a student may be removed from housing and/or placed on interim suspension by the Student Affairs staff if it is determined that the student's behavior makes his or her presence on campus a danger to the normal operations of the institution, or to the safety of himself or herself or others or to the property of the University or others.

When a complaint is received, the Office of Judicial Affairs and Community Standards determines whether Dean's Discipline is an appropriate response or if the complaint should be referred elsewhere. If Dean's Discipline is to occur, a student is informed in writing of the complaint made against him/her and of the next step in the process. At the

hearing, at least two members of the staff of the Dean of Student Affairs present the accused student with the information that supports the allegation that he/she has violated SEAS or University policy(ies). The student is then asked to respond and will be given an opportunity to present information on his or her behalf.

At the conclusion of the hearing, the hearing administrators will make a determination, based on all of the information available to them, regarding whether the accused student is responsible for the violation(s). The standard of proof that the hearing administrators will use to make this determination is the preponderance of the evidence standard. This standard allows for a finding of responsibility if the information provided shows that it is more likely than not that a violation of Columbia policy(ies) occurred. If the student is found responsible, the degree of seriousness of the offense and the student's previous disciplinary record, if any, will determine the severity of the sanction that will be issued. The student will be notified of the outcome of the hearing in writing.

A student found responsible after a hearing has the right to request an appeal of the decision and the resulting sanctions. There are three grounds upon which an appeal of the decision may be made. A student found responsible for the violation of Columbia policy(ies) may request a review of the decision if (1) the student has new information, unavailable at the time the hearing; (2) the student has concerns with the process that may change or affect the outcome of the decision; or (3) the student feels that the sanction issued is too severe. The

request for review must be made in writing to the individual indicated in the decision letter and must be received within ten calendar days (or as indicated in the hearing outcome letter) after the student receives notice of the hearing outcome. For more information about the discipline process for undergraduate students, please visit the Office of Judicial Affairs and Community Standards Web site at www.studentaffairs.columbia.edu/judicialaffairs.

Discipline Process for Graduate Students

When sufficient evidence exists, a student is charged with a particular offense and a hearing is scheduled. Present at a hearing for graduate students are the charged student and at least two members of the Office of Graduate Student Services staff. At the hearing, the student is presented with the evidence that supports the accusation against him or her and is asked to respond to it. The student may then offer his or her own evidence and suggest other students with whom the deans or their designee might speak. On the basis of the strength of the evidence and the student's response, the deans or their designee reach a determination and notify the student of their decision after the hearing. The student can be exonerated, found guilty of the accusations, or found not guilty due to insufficient evidence; if he or she is found to have committed an infraction, the penalty can range from a warning to disciplinary 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.

Confidentiality

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 crime of violence may be disclosed both to the accuser and the accused.

ACADEMIC DISHONESTY

Academic dishonesty includes but is not limited to intentional or unintentional dishonesty in academic assignments or in dealing with University officials, including faculty and staff members.

Here are the most common types of academic dishonesty:

- plagiarism (the use of words, phrases, or ideas belonging to another, without properly citing or acknowledging the source)
- cheating on examinations
- unauthorized collaboration on an assignment
- receiving unauthorized assistance on an assignment
- copying computer programs
- forgery
- submitting work for one course that has already been used for another course
- unauthorized distribution of assignments and exams
- lying to a professor or University officer
- obtaining advance knowledge of exams or other assignments without permission

A student alleged to have engaged in academic dishonesty will be subject to the Dean's Discipline process (see page 233).

Students found responsible for academic dishonesty may face reports of such offenses on future recommendations for law, medical, or graduate school. The parents or guardians of students found responsible may also be notified.

ACADEMIC INTEGRITY

Academic integrity defines a university and is essential to the mission of education. At Columbia students are expected to participate in an academic community that honors intellectual work and respects its origins. In particular, the abilities to synthesize information and produce original work are key components in the learning process. As such, academic dishonesty is one of the most serious offenses a student can commit at Columbia and can be punishable by dismissal.

Students rarely set out with the intent of engaging in academic dishonesty. But classes are challenging at Columbia, and students will often find themselves pressed for time, unprepared for an

assignment or exam, or feeling that the risk of earning a poor grade outweighs the need to be thorough. Such circumstances lead some students to behave in a manner that compromises the integrity of the academic community, disrespects their instructors and classmates, and deprives them of an opportunity to learn. In short, they cheat. If you ever find yourself in such circumstances, you should immediately contact your instructor and your adviser for advice. Just keep in mind how hard you have worked to get to this point in your academic career, and don't jeopardize your Columbia education with a moment of unwise decision making.

The easiest way to avoid the temptation to cheat in the first place is to prepare yourself as best you can. Here are some basic suggestions to help you along the way:

- Understand what your instructors deem as academic dishonesty and their policy on citation and group collaboration.
- Clarify any questions or concerns about assignments with instructors as early as possible.
- Develop a timeline for drafts and final edits of assignments and begin preparation in advance.
- Avoid plagiarism: acknowledge people's opinions and theories by carefully citing their words and always indicating sources.
- Utilize the campus's resources, such as the advising centers and Counseling and Psychological Services, if you are feeling overwhelmed, burdened, or pressured.
- Assume that collaboration in the completion of assignments is prohibited unless specified by the instructor.

Plagiarism and Acknowledgment of Sources

Columbia has always believed that learning to write effectively is one of the most important goals a college student can achieve. Students will be asked to do a great deal of written work while at Columbia: term papers, seminar and laboratory reports, and analytic essays of different lengths. These papers play a major role in course performance, but more important, they play a major role in intellectual development. Plagiarism, the use of words, phrases, or ideas belonging to another, without properly citing or

acknowledging the source, is considered one of the most serious violations of academic integrity and is a growing problem on university campuses.

One of the most prevalent forms of plagiarism involves students using information from the Internet without proper citation. While the Internet can provide a wealth of information, sources obtained from the Web must be properly cited just like any other source. If you are uncertain how to properly cite a source of information that is not your own, whether from the Internet or elsewhere, it is critical that you do not hand in your work until you have learned the proper way to use in-text references, footnotes,

and bibliographies. Faculty members are available to help as questions arise about proper citations, references, and the appropriateness of group work on assignments. You can also check with the Undergraduate Writing Program. Ignorance of proper citation methods does not exonerate one from responsibility.

Personal Responsibility, Finding Support and More Information

A student's education at Columbia University is comprised of two complementary components: a mastery over intellectual material within a discipline and the overall development of moral character and personal ethics.

Participating in forms of academic dishonesty violates the standards of our community at Columbia and severely inhibits a student's chance to grow academically, professionally, and socially. As such, Columbia's approach to academic integrity is informed by its explicit belief that students must take full responsibility for their actions, meaning you will need to make informed choices inside and outside the classroom. Columbia offers a wealth of resources to help students make sound decisions regarding academics, extracurricular activities, and personal issues. If you don't know where to go, see your advising dean.

RESERVATION OF UNIVERSITY RIGHTS

This bulletin is intended for the guidance of persons applying for or considering application for admission to Columbia University and for the guidance of Columbia students and faculty. The bulletin sets forth in general the manner in which the University intends to proceed with respect to the matters set forth herein, but the University reserves the right to depart without notice from the terms of this bulletin. The bulletin is not intended to be, and should not be regarded as, a contract between the University and any student or other person.

ATTENDANCE

Students are held accountable for absences incurred owing to late enrollment.

RELIGIOUS HOLIDAYS

It is the policy of the University to respect its members' religious beliefs. In compliance with New York State law, each student who is absent from school because of his or her religious beliefs will be given an equivalent opportunity to register for classes or make up any examination, study, or work requirements that he or she may have missed because of such absence due to religious beliefs, and alternative means will be sought for satisfying the academic requirements involved.

Officers of administration and of instruction responsible for scheduling of academic activities or essential services are expected to avoid conflict with reli-

gious 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 234.

THE FEDERAL FAMILY EDUCATIONAL RIGHTS AND PRIVACY ACT (FERPA)

See "Transcripts and Certifications," page 230.

COLUMBIA UNIVERSITY OMBUDS OFFICE

The Ombuds Office is a neutral and confidential resource for informal conflict resolution, serving the entire Columbia University community—students, faculty, and employees.

For further information, contact Ombuds Officer Marsha Wagner or Associate Ombuds Officer Bathabile K. S. Mthombeni at 660 Schermerhorn Extension; telephone: 212-854-1234; e-mail: ombuds@columbia.edu; Web site: www.columbia.edu/cu/ombuds. On Wednesdays the Ombuds Officer is at the Columbia Medical Center office, 101 Bard Hall, 50 Haven Avenue; telephone: 212-304-7026

OFFICE OF EQUAL OPPORTUNITY AND AFFIRMATIVE ACTION

The University's Office of Equal Opportunity and Affirmative Action (EOAA) has overall responsibility for the University's equal opportunity and nondiscrimination policies and has been designated to coordinate compliance activities under these policies and applicable federal, state, and local laws. Students, faculty, and staff may contact the EOAA Office to inquire about their rights under the University's policies, request mediation or counseling, or seek information about filing a complaint. Complaints by students against students are governed by the Equal Educational Opportunity and Student Nondiscrimination Policies and Procedures on Discrimination and Harassment, which are available online at www.columbia.edu/cu/vpaa/eoaa/docs/student_discrim.html. Complaints by students against employees are governed by the Equal Employment Opportunity and Nondiscrimination Policies and Procedures on Discrimination, Discriminatory Harassment and Sexual Harassment, which are available online at www.columbia.edu/cu/vpaa/eoaa/docs/nondispol.html. All students and applicants for admission are protected from coercion, intimidation, interference, or retaliation for filing a complaint or assisting in an investigation under any of the applicable policies and laws. For further information, contact Susan Rieger, Associate Provost, Office of Equal Opportunity and Affirmative Action, Columbia University, 103 Low Library,

MC 4333, 535 West 116th Street, New York, NY 10027; 212-854-5511.

Equal Educational Opportunity and Student Nondiscrimination Policies

Columbia University is committed to providing a learning environment free from unlawful discrimination and harassment and to fostering a nurturing and vibrant community founded upon the fundamental dignity and worth of all of its members. Consistent with this commitment and with applicable laws, it is the policy of the University not to tolerate unlawful discrimination or harassment in any form and to provide students who feel that they are victims of discrimination or harassment with mechanisms for seeking redress. Columbia University does not discriminate against any person in the administration of its educational policies, admissions policies, scholarship and loan programs, and athletic and other University-administered programs or permit the harassment of any student or applicant on the basis of race, color, sex, gender (including gender identity and expression), pregnancy, religion, creed, marital status, partnership status, age, sexual orientation, national origin, disability, military status, or any other legally protected status. Nothing in this policy shall abridge academic freedom or the University's educational mission. Prohibitions against discrimination and harassment do not extend to statements or written materials that are germane to the classroom subject matter.

Definitions

For purposes of these policies and procedures, discrimination, discriminatory harassment, and sexual harassment are defined as follows:

Discrimination is defined as (1) treating members of a protected class less favorably because of their membership in that class; or (2) having a policy or practice that has a disproportionately adverse impact on protected class members.

Discriminatory harassment is defined as substantially interfering with an individual's educational experience by subjecting him or her to severe or threatening conduct or to repeated humiliating or abusive conduct, based on his or her membership in a protected class. This includes sexual harassment, which is described below in further detail.

Unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature constitute **sexual harassment** when: (1) submission to such conduct is made either explicitly or implicitly a term or condition of an individual's education; or (2) submission to or rejection of such conduct by an individual is used as the basis for academic decisions affecting that individual; or (3) such conduct has the purpose or effect of unreasonably interfering with an individual's academic performance or creating an intimidating, hostile, demeaning, or offensive academic or living environment.

Romantic Relationship Advisory Statement

Consensual, romantic relationships between faculty and other employees and students are generally not considered sexual harassment and are not prohibited by University policy. These relationships, however, are susceptible to being characterized as nonconsensual, and even coercive, if there is an inherent power differential between the parties, and can lead to complaints of sexual harassment. The full text of the Romantic Relationship Advisory Statement may be found online at www.columbia.edu/cu/vpaa/eoaa/docs/romance.html.

DISABILITY ACCOMMODATION

Students seeking an accommodation for a disability should contact the Office of Disability Services at 212-854-2388.

UNIVERSITY PROCEDURES REGARDING ISSUES OF DISCRIMINATION AND DISCRIMINATORY HARASSMENT

Any person who believes that he or she has been the subject of discrimination or discriminatory harassment may initially choose to deal with the alleged offender directly. The University also offers several options for those seeking the intervention of the offices and individuals who are authorized to respond to their complaints. These include informal counseling, mediation, and formal processes for having their complaints reviewed.



Confidential Guidance and Counseling

The University has crafted a “safe haven” for those individuals who want to approach a knowledgeable person for confidential advice or to solicit feedback regarding their interpretation of events. Individuals who wish to take advantage of this option may contact either the University Ombuds Officer (see www.columbia.edu/cu/ombuds), or a member of the University Panel on Discrimination and Sexual Harassment (see www.columbia.edu/cu/ombuds). These officers are not authorized to conduct formal investigations.

Mediation

Students may choose to resolve their complaints through mediation by the Office of Equal Opportunity and Affirmative Action, the University Ombuds Office, or the Mediation Clinic at Columbia Law School. Mediation is an informal, voluntary, and confidential process whereby parties can participate in a search for a fair and workable solution. Guidelines for mediation by the EOAA

Office or the Mediation Clinic may be found on the Web at www.columbia.edu/cu/vpaa/eoaa/docs/mediation.pdf.

Formal Complaint Procedures

Procedure for Complaint against Another Student

Dean's Discipline

Student complaints of discrimination or discriminatory harassment against another student should be filed with the Dean of the school in which the accused student is enrolled. Complaints against students are investigated under the appropriate Dean's Discipline procedure of the accused student's school. Students found to have engaged in discrimination or discriminatory harassment will be subject to discipline up to and including expulsion.

Procedure for Complaint against a Student Organization

Students who wish to file a complaint of discrimination or discriminatory harassment against a student organization should do so in consultation with the Dean of Students of their own school.

Procedure for Complaint against a Member of the Faculty or Staff

Office of Equal Opportunity and Affirmative Action

Student complaints of discrimination or discriminatory harassment against a University employee should be filed with the Office of Equal Opportunity and Affirmative Action. These complaints will be processed under the Equal Employment Opportunity and Nondiscrimination Policies and Procedures on Discrimination, Discriminatory Harassment and Sexual Harassment.

Grievances Procedures

Students should consult SEAS policies on Student Grievances, Academic Concerns and Complaints (see page 242) for the appropriate procedure to complain about a faculty member's conduct in an instructional setting. The policy may be found online at: www.engineering.columbia.edu/about_seas/grievances.php.

SEXUAL ASSAULT POLICY

On February 25, 2000, the University Senate adopted a Sexual Misconduct Policy and Disciplinary Procedure that can be used as an alternative to Dean's Discipline; the policy and procedure have been renamed the Sexual Assault Policy and the Disciplinary Procedure for Sexual Assault respectively. The policy prohibits sexual assault by any student and is University wide, applying to all students in all schools of the University, including Teacher's College and Barnard College. The Disciplinary Procedure for Sexual Assault is an option that applies to all students with the exception of students within the Law School, Jewish Theological Seminary, and/or Union Theological Seminary. Complaints of sexual assault for these schools are addressed through Dean's Discipline. If the student being accused attends CC/SEAS, the Disciplinary Procedure for Sexual Assault will be the exclusive mechanism for filing a complaint.

Copies of the policy and procedure are available from the Administrative Coordinator of the Disciplinary Procedure for Sexual Assault, 701A Lerner, Mail Code 2617, 2920 Broadway, New York, NY 10027; telephone: 212-854-1717; fax: 212-854-2728; www.columbia.edu/cu/dpsa. The policy and procedure can also be found in the Office of the Dean of Students of every school.

Policy

The University's Policy on Sexual Assault requires that standards of sexual conduct be observed on campus, that violations of these standards are subject to discipline, and that resources and structures be sufficient to meet the physical and emotional needs of individuals who have experienced sexual assault. Columbia University's policy defines sexual assault as nonconsensual, intentional physical contact of a sexual nature, such as unwelcome physical contact with a person's genitals, buttocks, or breasts. Sexual assault occurs when the act is committed either by (a) physical force, violence, threat or intimidation; (b) ignoring the objections of another person; (c) causing another's intoxication or impairment through the use of drugs or alcohol; or (d) taking advantage of another person's incapacitation, state of intimidation, helplessness, or other inability to consent.

Complaint Resolution Options

Three University-based options are available for resolution of complaints of sexual assault against a student:

1. Dean's Discipline within the school of the charged student;
2. the University's Disciplinary Procedure for Sexual Assault ; or

3. mediation through an accredited mediator affiliated with the University, such as the Ombuds Officer.

Complaints may also be filed with the New York City Police Department.

Choosing to pursue a disciplinary action can be a difficult and confusing decision. The Manager of the Disciplinary Procedure for Sexual Assault is available to assist you in understanding your options for complaint resolution, as are trained peer advocates from the Rape Crisis/Anti-Violence Support Center.

Helen Arnold, Manager
Disciplinary Procedure for Sexual Assault
hva2002@columbia.edu
701A Lerner, Mail Code 2617
2920 Broadway
New York, NY 10027
212-854-1717
fax: 212-854-2728
www.columbia.edu/cu/dpsa

Complaints about nonstudent members of the University community should be directed to the Office of Equal Opportunity and Affirmative Action at Columbia, the Dean of Studies Office at Barnard, or the Office of the Associate Dean at Teachers College.

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.

A. COMPLAINTS ABOUT FACULTY AND STAFF ACADEMIC MISCONDUCT

In fulfilling their instructional responsibilities, faculty are expected to treat their students with civility and respect. They "should make every effort to be accurate and should show respect for the rights of others to hold opinions differing from their own. They should confine their classes to the subject matter covered by the course and not use them to advocate any cause" (2000 *Faculty Handbook*). A fuller description of faculty rights and obligations may be found in the *Faculty Handbook*, which is online at www.columbia.edu/cu/vpaa/fhb/main.html. Students who feel that members of the Engineering faculty have not met those obligations may take the following steps (the procedure below also applies to complaints against instructional and administrative staff):

1. Students are encouraged to seek a resolution to their complaints about faculty misconduct by talking directly with the faculty member. If they feel uncomfortable handling the situation

in this manner, they may ask for help from a departmental faculty mediator, who will assist students with complaints about faculty members, other academic personnel, or administrators.

The name of the faculty mediator is posted in the department office and on the departmental Web page. Students may also ask the department chair or administrator to direct them to the faculty mediator. The faculty mediator tries to resolve any issue by informal meetings with the student and others, including faculty as seems appropriate. Students who are dissatisfied with the outcome may request a meeting with the department chair. The chair will review the mediator's recommendation and seek informally to resolve the student's complaint.

2. Students may bring their concerns to the University's Ombuds Officer, who serves as an informal, confidential resource for assisting members of the University with conflict resolution. The Ombuds Officer provides information, counseling, and referrals to appropriate University offices and will also mediate conflicts if both parties agree. The Ombuds Officer does not have the authority to adjudicate disputes and does not participate in any formal University grievance proceedings. Further information on the Ombuds Office may be found at www.columbia.edu/cu/ombuds/.
3. Students may seek a grievance hearing if informal mediation fails. The grievance procedures students should follow will depend upon the school within which the faculty member is

appointed and the nature of the alleged misconduct.

If the faculty member holds an appointment in SEAS, the student may use the procedures described below to address the issues listed below. If the faculty member belongs to another school, students must use the procedure of that school. They may, however, ask for help from the departmental faculty mediator, chair, and the School's deans in identifying and understanding the appropriate procedures.

Conduct that is subject to formal grievance procedure includes:

- failure to show appropriate respect in an instructional setting for the rights of others to hold opinions differing from their own;
- misuse of faculty authority in an instructional setting to pressure students to support a political or social cause; and
- conduct in the classroom or another instructional setting that adversely affects the learning environment.

Formal grievance procedure at SEAS

If the informal mediation mentioned above failed, the student should compose and submit to the Vice Dean of the School a written statement documenting the grievance and should also include a description of the remedy sought. This should be done no later than 30 working days after the end of the semester in which the grievance occurred.

The Vice Dean will review the complaint to determine if a grievance hearing

is warranted. If so, the Vice Dean will convene an ad hoc committee consisting of the Assistant Dean for Graduate Student Services (graduate students) or the Associate Dean of Student Affairs (undergraduate students), who acts as chair; a faculty member chosen by the Vice Dean; and a student chosen by one of the student councils (an undergraduate or a graduate student to correspond to the status of the student grieving).

The faculty member is given the student's letter of complaint and invited to submit a written response. The Committee reviews both statements and is given access to any other written documents relevant to the complaint. It will normally interview both the grievant and the faculty member and may, at its discretion, ask others to provide testimony. The merits of the grievance are evaluated within the context of University and SEAS school policy.

The investigative committee serves in an advisory capacity to the Dean of the School. It is expected to complete its investigation in a timely manner and submit a written report to the Dean, who may accept or modify its findings and any recommendations it may have made to remedy the student's complaint. The Dean will inform both the student and the faculty member of his decision in writing.

The committee ordinarily convenes within 10 working days of receiving the complaint from the Vice Dean and ordinarily completes its investigation and sends the Dean its report within 30 working days of convening. The Dean

normally issues his or her decision within 30 working days of receiving the committee's report.

The Dean may discipline faculty members who are found to have committed professional misconduct. Any sanctions will be imposed in a manner that is consistent with the University's policies and procedures on faculty discipline. In particular, if the Dean believes that the offense is sufficiently serious to merit dismissal, he or she can initiate the procedures in Section 75 of the University Statutes for terminating tenured appointments, and nontenured appointments before the end of their stated term, for cause.

Either the student or the faculty member may appeal the decision of the Dean to the Provost. Findings of fact, remedies given the student, and penalties imposed on the faculty member are all subject to appeal. A written appeal must be submitted to the Provost within 15 working days of the date of the letter informing them of the Dean's decision.

Normally, the Provost will take no longer than 30 working days to evaluate an appeal. The Provost usually confines his or her review to the written record but reserves the right to collect information in any manner that will help to make his or her decision on the appeal.

The Provost will inform both the student and the faculty member of his or her decision in writing. If the Provost decides that the faculty member should be dismissed for cause, the case is subject to further review according to the procedures in Section 75 of the University Statutes, as noted above.

Otherwise the decision of the Provost is final and not subject to further appeal.

All aspects of an investigation of a student grievance are confidential. The proceedings of the grievance committee are not open to the public. Only the student grievant and the faculty member accused of misconduct receive copies of the decisions of the Dean and the Provost. Everyone who is involved with the investigation of a grievance is expected to respect the confidentiality of the process.

B. DISPUTES OVER GRADES OR OTHER ACADEMIC EVALUATIONS

The awarding of grades and all other academic evaluations rests entirely with the faculty. If students have a concern relating to a particular grade or other assessment of their academic work, the student first should speak with the instructor of the class to understand how the grade or other evaluation was derived and to address the student's specific concern.

If the students do not feel comfortable speaking with the class instructor about the matter, they should then bring the issue to the attention of their class dean (undergraduate students) or department chair (graduate students).

If the students are unable thus to resolve the matter to their satisfaction and believe that a procedural issue is involved, they should bring the matter to the attention of the Vice Dean. The Vice Dean will work with the student and the faculty to determine whether there has been a procedural breach and if so, take immediate steps to remedy the matter. If the Vice Dean, together with appropriate faculty other than the instructor, decides that there is no need for further action, the student will be informed and the decision will be final.

C. DISCRIMINATION AND SEXUAL HARASSMENT

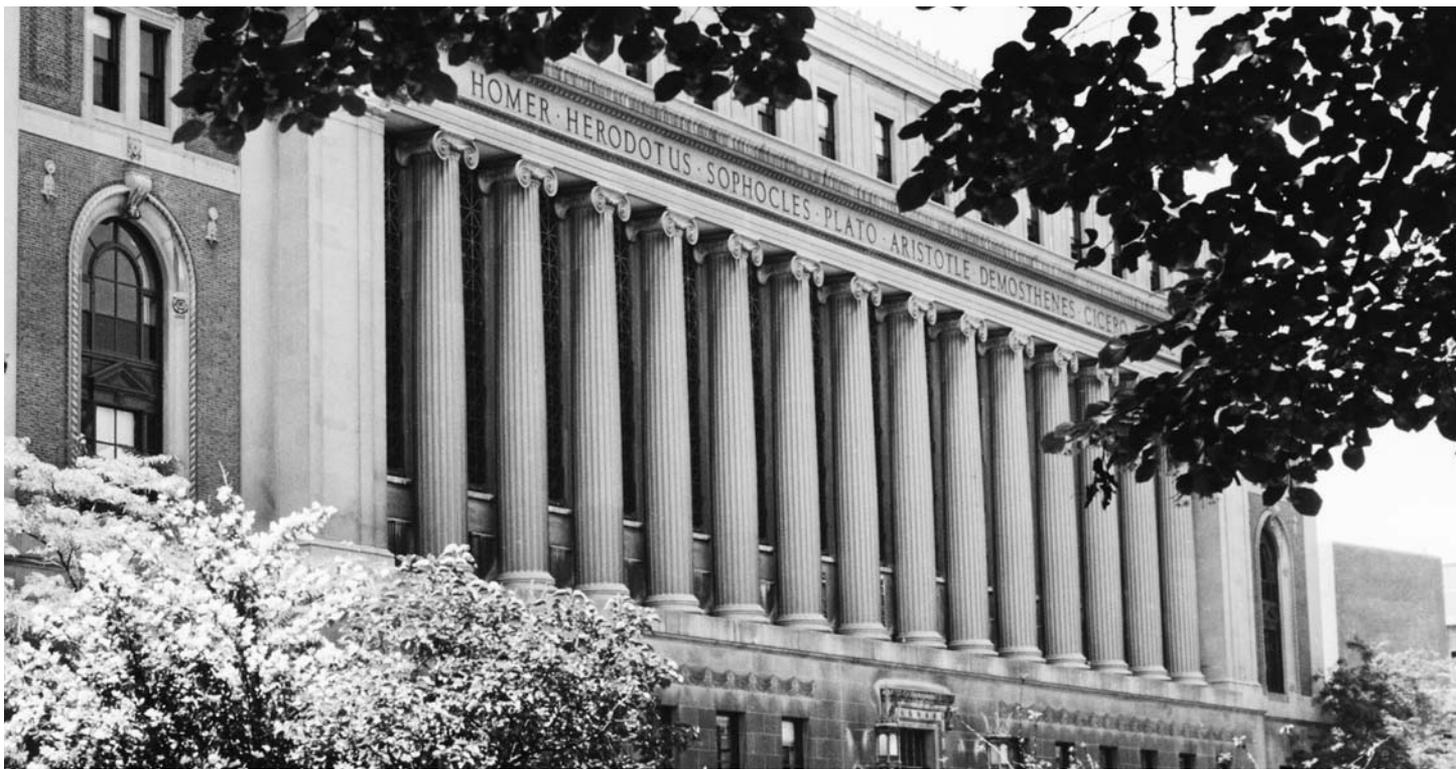
If the alleged misconduct involves discrimination and sexual harassment, a student should file a complaint with the Associate Provost for Equal Opportunity

and Affirmative Action. The procedures for handling such complaints are described in the statement Discrimination and Sexual Harassment Policy and Procedure, which is on the Web at www.columbia.edu/cu/vpaa/eoaa/docs/discrim_sexharass.html.

D. SCIENTIFIC OR SCHOLARLY MISCONDUCT

Complaints against the School's faculty that allege scientific or scholarly misconduct are evaluated using other procedures. These are contained in the Columbia University Institutional Policy on Misconduct in Research, available at www.columbia.edu/research/policy_misconduct.pdf.

Directory of University Resources



ADMISSIONS (GRADUATE)

See Graduate Student Services

ADMISSIONS (UNDERGRADUATE)

212 Hamilton, 212-854-2522
Mail Code 2807

Jessica Marinaccio, *Dean of Undergraduate Admissions*
jm996@columbia.edu

Peter Johnson, *Director of Admissions*
pvj1@columbia.edu

Alice Huang, *Senior Associate Director*
ah704@columbia.edu

Joanna May, *Director of Outreach and Admissions Operations*
jm2638@columbia.edu

Meaghan McCarthy, *Director of Visitor Relations and On-Campus Programming*
mm3359@columbia.edu

ADVISING CENTERS

See Center for Student Advising

ALICE!, COLUMBIA UNIVERSITY'S HEALTH EDUCATION PROGRAM

See Health Services at Columbia

CENTER FOR CAREER EDUCATION

East Campus, Lower Level
212-854-5609
Mail Code 5727
www.careereducation.columbia.edu
careereducation@columbia.edu

CENTER FOR STUDENT ADVISING

Monique Rinere, *Dean of Advising*

Lavinia Lorch, *Senior Assistant Dean*
lel52@columbia.edu

Andrew Plaa, *Senior Assistant Dean*
ap50@columbia.edu

Sunday Coward, *Assistant Dean*
sfc15@columbia.edu

Ellen Richmond, *Assistant Dean*
ecr13@columbia.edu

Nathaniel Wood, Jr., *Assistant Dean*
nw4@columbia.edu

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www.health.columbia.edu

Appointments: 212-854-2284

Clinician on Call (for after-hours
medical and psychological consultation
(Sept. 1–May 31): 212-854-9797

Enrollment/Immunization Office
Wien Hall, 212-854-7210
Mail Code 3712

Emergency Medical Services (CAVA)
212-854-5555 or 99 from a campus phone

Gay Health Advocacy Project (GHAP), including HIV Testing
212-854-7970

Student Medical Insurance Plan
Administrators: Chickering Benefit
Planning Insurance Agency, Inc.
1-800-859-8471
www.aetnastudenthealth.com

Travel Medicine Clinic (CU on the Road):
212-854-2284

Alice!, Columbia University's Health Promotion Program

Wien Hall, 212-854-5453
Mail Code 3711
www.alice.columbia.edu

Presents a wide range of health education and skill-building programs, including Go Ask 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.
www.health.columbia.edu/docs/about_us/cps.html

Office of Disability Services

700 Lerner, Voice: 212-854-2388
TDD: 212-854-2378
Mail Code 2605

Coordinates services, programs, and policies to support and arrange appropriate accommodations for students with disabilities.

Rape Crisis/Anti-Violence Support Center (RC/AVSC)

112 Hewitt (Barnard Quad)
Business Line: 212-854-4366
24-hour Peer Advocates:
212-854-WALK (9255)
Peer Counselors (7 days a week):
212-854-HELP (4357)

Provides services and support to survivors of sexual assault, relationship violence, childhood sexual abuse, and

other forms of violence, and assistance to the friends and loved ones of survivors.

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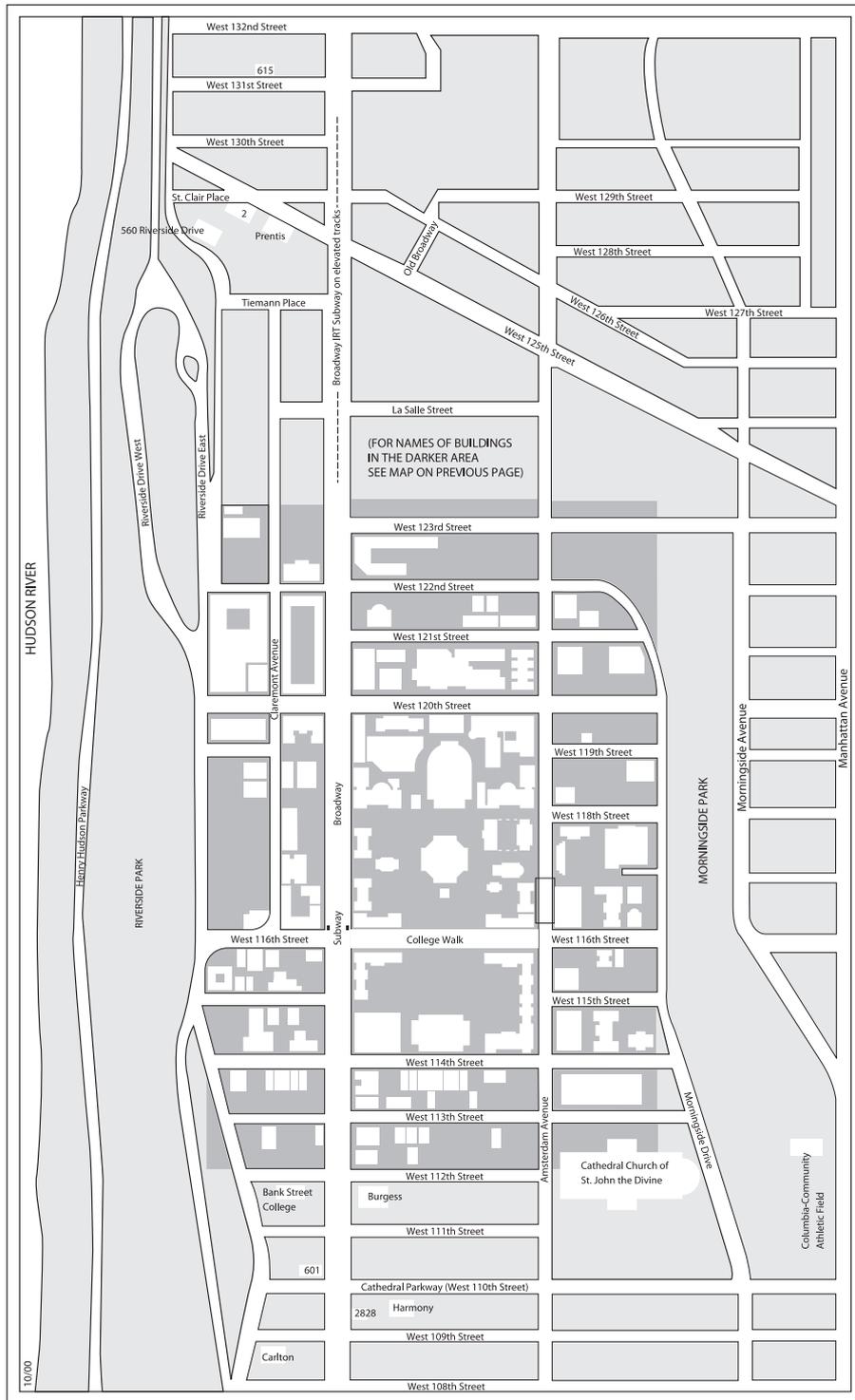
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205 Kent, 212-854-4400
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Cashiering: 212-854-1518

For quick answers to your questions,
visit: askus.columbia.edu.



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