THE ALBERT NERKEN SCHOOL OF ENGINEERING

MISSION STATEMENT

The Albert Nerken School of Engineering will create an educational culture with a commitment to excellence. We will bring together the best and brightest engineering students; we will nurture and develop their talents; we will encourage them to work and learn at their highest levels; and we will instill in them the desire and the ability to use their engineering background to fulfill their potential as knowledgeable, creative and responsible leaders in society. *cooper.edu/engineering*

OVERVIEW

With an average enrollment of about 450 undergraduate students, engineering is the largest of The Cooper Union's schools. The school maintains small class sizes in courses and laboratories in order to provide for personal attention. It offers bachelor of engineering (B.E.) degree programs in chemical, civil, mechanical and electrical engineering, accredited by the EAC commission of ABET*.

In addition, the school offers a general engineering program (B.S.E.). This program empowers students to create their own curricula (within carefully set parameters) in those areas of engineering that cross traditional boundaries—for example, computer science, invention, entrepreneurship, biomedical, energy, sustainability, infrastructure, environmental, mechatronics, robotics, etc.

The B.S.E. program provides an excellent preparation for graduate work in law, medicine, business, etc.

The integrated master's program offers the opportunity to earn both a bachelor's and a master's degree in an engineering discipline at The Cooper Union within four, five or six years.

Degree programs are designed to prepare students to enter the engineering profession immediately after graduation or to pursue graduate study. An extraordinary number of Cooper Union engineering graduates have gone on to earn Ph.D. degrees at the nation's most prestigious graduate schools. Others have gone on to study in fields such as medicine, law or business. Many graduates have risen to leadership positions in industry, education and government.

The early curricula in engineering are based on intensive work in the sciences, mathematics, computer science and engineering sciences, which serve as preparation for in-depth study within the various engineering fields. Building on this strong base of mathematics and sciences, and emphasizing the integration of knowledge, these curricula are concerned with an understanding of nature, the limitations of our present knowledge and the potential for advancing that knowledge.

Strong mathematical and computer skills are developed in all engineering students.This includes the ability to mathematically model and solve problems algorithmically, in a suitable language, and to use existing commercial packages for analysis and design. Students are expected to be fluent in at least two computer languages, and many specialized packages are used both in elective and in required courses. The faculty expect assignments to be carried out using the computer in appropriate ways, both as a design tool using packages and also as a platform for original software.

Defining characteristics of the School of Engineering's programs are the emphasis on project-based learning and opportunities for undergraduate research. Students and their peers regularly join the faculty in solving real-life problems that exist in contemporary society. Multi-disciplinary teams work together, frequently cooperating with outside professionals, who act as mentors. Superior analytical abilities and thorough grounding in engineering fundamentals and design enable students to collaborate on these projects. Results may be published, presented at conferences or even patented.

A strong background in engineering design threads throughout the curriculum, starting with the first year. This design experience takes into consideration factors such as environmental issues, sustainability, economics, teamwork, societal impact, safety and political climate—showing students that a "design" is much more than a purely technological solution.

Some design problems are offered in collaboration with foreign universities to increase awareness of the global nature of the engineering profession (e.g., The Cooper Union's study abroad and international programs). Others may involve collaboration with industry or hospitals.

Diverse electives are offered so that interested students can add a background in business and entrepreneurship, additional mathematics and science or a "concentration" in an additional engineering area.

Like The Cooper Union's other schools, the Albert Nerken School of Engineering is intimately involved with the New York metropolitan area. Sometimes, the city and its infrastructure are used as a laboratory. The school also draws on the region's abundant talent and resources, including an outstanding array of engineers and scientists employed at major corporations, governmental agencies and consulting firms in the New York region. The school calls on physicians, lawyers and other specialists to collaborate on research and mentoring and to give unique insights into contemporary problems and social issues confronting modern engineers. Many of these professionals serve as adjunct faculty members who lend a dynamism to the classroom.

Students benefit from an uncommonly close interaction with devoted faculty, many of whom are loyal alumni, in a conservatory-style environment. Our faculty bring their diverse experiences to the classroom and laboratory setting and serve as role models to our students. Our students are encouraged to participate in The Cooper Union's rich seminar and cultural programs as well as to attend talks by guest speakers. They join various professional societies, many of which have chapters at The Cooper Union. Students are inspired to qualify for membership in national engineering honor

*ABET, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012

societies; many join before graduation. They also participate in student government and sports, and take advantage of the vast cultural environment offered by New York City and the neighborhood.

In preparation for their responsibilities as engineers who are affected by the dynamics of technological advances and social change, students are exposed to and challenged in the fields of social science, humanities and other general studies.

The School of Engineering strongly encourages undergraduate research activities and permits juniors and seniors to register for graduate level courses, when deemed appropriate. This enrollment does not guarantee admission to the master's program however. A Cooper Union undergraduate may declare the intent to complete an integrated degree in the second semester of the junior year or apply to the graduate program (Master of Engineering) in one of the degree-granting departments during the second semester of the senior year

Graduates of The Cooper Union are recruited regularly by major national and international corporations and graduate schools nationwide. Alumni are found in the top management and research leadership of many American corporations; hold key positions in federal, state and city agencies; and distinguish themselves on university faculties and administrations nationwide. Through their many and varied professional accomplishments, alumni have earned for the school its reputation for excellence.

FACILITIES AND RESEARCH

The Brooks Computer Center is available to all students and faculty. It provides a centralized administration and technological support for all academic computing needs, and allows students to take advantage of rapidly emerging hardware and software technologies. The center maintains an ample supply of computers of all major types—Intel™ based machines, Apple Macintosh,™ Sun Microsystems,™ IBM™ are examples. Workstations are concentrated in computer classrooms, offices, laboratories, the residence hall and special centers.

The Department of Information Technology provides a wired and wireless network resulting in a rich and reliable computing environment. It is locally accessible through the intranet, which connects all but specialized stand-alone systems. Students have access to all the major operating systems such as the varieties of Microsoft Windows,™ Solaris,™ Linux™ and Mac/OS.™

The Department of Information Technology has both formal classroom instructional facilities and informal drop-in accommodations. Currently, there exist no restrictions or charges for computer time and availability is widespread.

A full complement of applications, programming languages and Internet tools are available. Multimedia hardware includes audio/video capture and output, print and film scanners, digital cameras, CD burners and large-format color plotters.

Data communications with the outside community are maintained via multiple dedicated high-speed Internet connections. Students and faculty have access to software packages and programming languages on the local network and can download content from all Internet sites worldwide. Students are expected to pay careful attention to copyright and ethical uses of the Internet and to conduct themselves professionally at all times.

C.V. Starr Research Foundation The C.V. Starr Research Foundation, whose forerunner was established in 1976 as The Cooper Union Research Foundation, is a not-for-profit corporation and sponsors many of the externally funded research projects in the School of Engineering. By encouraging and supporting research, the foundation augments the educational opportunities for students, enhances professional development of faculty, promotes multidisciplinary research and serves the community through its research and development efforts and as a sponsor of public seminars and conferences.

Participation in research activities by faculty and students is essential to the vitality of the educational programs. In attempting to meet this objective, The C.V. Starr Research Foundation plays an important role for faculty and students having research talent who

wish to pursue sponsored research individually or in concert with other faculty and students. The foundation facilitates collaboration with other universities, hospitals, industry and government.

Projects undertaken by The C.V. Starr Research Foundation are externally funded. Faculty serve as project directors, assisted by other faculty members, outside consultants and undergraduate and graduate students of The Cooper Union.

The C.V. Starr Research Foundation supports all programs in all of the schools at The Cooper Union, both at the undergraduate and graduate levels, by providing real-life research projects throughout the curriculum. To this end, several inter-disciplinary research centers have been developed.

Each of the centers aims to draw upon the varied faculty expertise across The Cooper Union and uses laboratory resources in the School of Engineering, as well as the resources of the Schools of Art and Architecture.

Recent research sponsors of The C.V. Starr Research Foundation include Zimmer, Pfizer, EPRI, Con Edison, the National Security Agency, the City of New York Departments of Transportation, Environmental Protection and Design and Construction, Transpo, Lucent, NYSERDA, the U.S. DOE, Lenox Hill Hospital, the National Science Foundation, the National Institutes of Health, Albert Einstein, STRYKER. Verdant Technologies and the Howard Hughes Medical Institute.

The C.V. Starr Research Foundation has a proprietary interest in several new technologies, all of them patented and most of them developed at The Cooper Union. Examples include several patents in asphalt technology, a clean coal-burning technology, an innovative hydro-electric generation process, fuel-cell processes, a micro-balance sensor and several patents in telecommunications and environmental measurement devices.

The Maurice Kanbar Center for Biomedical Engineering pursues groundbreaking biomedical research in such fields as orthopedic biomechanics, medical imaging, minimally invasive surgery, tissue engineering, medical device design, ergonomics and injury rehabilitation. The center has established collaborative relationships with several hospitals and medical research institutions in the New York City area.

The Center for Innovation and Applied Technology is an interdisciplinary research and educational resource that provides answers to our technological and productivity challenges. Bold and innovative concepts are linked with successful planning and practical implementation strategies.

Innovation is the result of creative conceptualizations that are developed and brought to market. Inventors, innovators and entrepreneurs are needed to make lasting societal contributions. The center enables collaborations between the Cooper Union community and distinguished mentors from industry and other educational institutions, who contribute their time, insights and resources.

Applied skill sets are required to develop, fund and ultimately bring to market a successful product. The center provides a supportive, flexible research and learning laboratory based upon real-world problem solving.

Technology depends upon the skills of numerous disciplines and lateral thinkers. CIAT will make a difference by solving some of today's challenges and providing a forum where the disciplines can be merged.

The Center for Urban Systems and Infrastructure has started research in the areas of urban security and protective design, infrastructure rehabilitation, new energy technologies, acoustics and noise abatement and sustainable environment. Industrial partnerships have been formed with various corporations and government agencies. The Cooper Union Institute for Urban Security operates under the auspices of this center, and the following institutes are being developed:

- The Institute of Water Resources and the Environment,
- The Institute of Renewable Energy and
- The Institute for Soil Structure Interaction and the Underground Built Environment.

The Center for Materials and Manufacturing Technology engages in research in composite materials, fire-resistant and blast-resistant materials, robotics, mechatronics, nano-technologies and nano-biosensors. The center is also active in innovative product design and automation.

The Center for Signal Processing, Communications and Computer Engineering (S*PROCOM²) engages in ongoing research in biomedical signal and image processing, neuroscience, software engineering, mapping algorithms to FPGA and other specialized architectures, network security, Monte Carlo simulations and wireless communications. Other areas of interest include sensor arrays and networks, embedded control systems and cognitive systems. Partnerships and collaboration have been established with technology firms, both small and large, medical research institutions and financial firms in and around New York City.

The Center for Sustainable Engineering, Art and Architecture—Materials, Manufacturing and Minimalization (SEA²M³), SEA²M³ seeks to develop an awareness of solutions to engineering problems that preserve the integrity of the commons; it is a space where true cross-disciplinary conversation and reciprocal learning generate real solutions that can be imagined, created and implemented. Using their ability to communicate and infused with an understanding of the world, its people and cultures, students create and disseminate designs suited to, and in harmony with their place of use. SEA²M³ provides a forum within which students from the schools of engineering, art and architecture come together to develop new design criteria that yield materials, manufacturing techniques, habitats and lifestyles that are sustainable, and that, ultimately, reduce the chasm between the rich and the poor.

BACHELOR OF ENGINEERING CURRICULUM

The requirements for the bachelor's degree programs must be completed within four years of first registration, except with the explicit consent of the dean/associate dean. Requests for extension must be presented in writing to the dean's office prior to the sixth semester of registration (or the end of junior year). It is the responsibility of the student to maintain normal and reasonable progress toward the degree.

Courses may be taken at other institutions for credit with prior appropriate adviser(s) approval only. The student is responsible for all costs incurred. As a general matter, many courses simply may not be taken elsewhere (e.g., Physics I). In order to get a course pre-approved, bring as much course documentation as possible to the Chair of the appropriate department to have the course assessed. These materials must include at least the syllabus and textbook. The course must be judged to be equivalent to one taught at Cooper. Note that only grades "B" or better can be transferred (not B-) and the grade will not be factored into your G.P.A.

Additionally, ABET accreditation requires:

- one year of a combination of mathematics and sciences (some with experimental experience) appropriate to the discipline,
- one and a half years of engineering topics consisting of engineering sciences and engineering design appropriate to the student's field of study and
- a general educational component that complements the technical content of the curriculum and is consistent with the program and institutional objectives.

In order to graduate, all students must meet the following conditions:

- A minimum of 135 credits are required;
- Satisfaction of all program curricula;
- Satisfaction of the residence study requirements;
- A minimum grade point average (G.P.A.) of 2.0;
- A minimum grade point average (G.P.A.) of 2.0 for the junior and senior years combined.

Faculty Advisers All first-year students have the same faculty adviser. For subsequent years, students will be assigned one, two or more advisers each, appropriate to their field of study. Each student's program is established in consultation with his or her adviser(s); changes can only be made with approval of the adviser(s).

Humanities and Social Sciences The requirements in this area are satisfied by courses offered by The Cooper Union Faculty of Humanities and Social Sciences or by transfer credit for liberal arts courses taken at other institutions. The courses in this area are intended to provide both breadth and depth and should not be limited to a selection of unrelated introductory courses.

The Cooper Union liberal arts courses, shown elsewhere in the Faculty of Humanities and Social Sciences catalog section, have prefixes **H, S** and **HTA**. The basic courses **HSS1**–**HSS2** and **HSS3**–**HSS4** are prerequisites for all higher level courses in the same prefix family. **H** and **S** courses carry three credits each; **HTA** courses carry two credits. Engineering students should consult with the dean of Humanities and Social Sciences about choice of courses to satisfy particular interests.

Transfer credits for liberal arts courses must be approved by the dean of Humanities and Social Sciences. Courses that cannot be used to satisfy the Humanities and Social Sciences requirement are:

- language skills courses such as introductory foreign language, public speaking, report writing;
- craft and performance courses unless accompanied by theory or history;
- subjects such as accounting, finance, engineering economy, industrial management, personnel administration.

Some programs require "free electives or non-technical electives." For transfer credit for particular courses, the School of Art or the School of Architecture may be a more appropriate authority to sanction the transfer. Students who are uncertain should approach the Office of the Dean of Engineering in the first instance and be directed to the correct group of faculty.

Program Requirements The specific programs for entering students are shown in detail in the curriculum tables which are shown in "Departments and Programs" starting on page 81. From time to time, changes are made to these programs following curricular developments authorized by the faculty. Advances in technology and new technologies are closely monitored and are reflected by adjustments in all the engineering programs.

Course Substitutions and Credits A student may request to substitute for a required course or courses given in the School of Engineering provided that:

- the substitution is limited to 12 credits maximum toward the total number of credits required for graduation,
- the substitution is approved by the dean/associate dean and program adviser(s) and
- ABET accreditation requirements are not violated.

The Chemical Engineering Department does not permit the substitution of any courses.

The number of academic credits for each course generally is based on the following relationship:

- 1 credit per contact hour in class
- ½ credit per contact hour of laboratory

This relationship was established on the basis that generally two hours of preparation are expected of the student for every contact hour in class or project activities and generally one hour of preparation is expected for every contact hour of laboratory.

Residence Study Requirement A candidate for a bachelor's degree must be enrolled during the entire academic year immediately preceding the granting of the degree and must carry at least 12 credits per semester during that period. Also, the candidate must have been enrolled for a minimum of four semesters at The Cooper Union as a full-time student for the bachelor's degree.

MASTER OF ENGINEERING CURRICULUM AND REQUIREMENTS

The integrated bachelor/master of engineering program is intended to integrate work at the undergraduate and graduate levels and prepare graduates for entry into the engineering profession at an advanced level or for further graduate study. The school offers master's degrees in chemical engineering, civil engineering, electrical engineering and mechanical engineering.

Admission Procedure Please refer to the "Application and Admission Information" section, page 9.

GENERAL REQUIREMENTS

Applicants are expected to have a superior undergraduate record and to have given evidence of ability for independent work. Students are accepted on an academically competitive basis subject to the availability of an adviser and of suitable available facilities. Students are accepted into the graduate program in their major either with a "thesis" or "undeclared" classification. Undeclared students have to declare whether they plan to pursue the thesis or non-thesis option by the time they complete 9 credits. Students may complete the degree requirements as part-time or full-time students in consultation with their adviser.

Cooper Union Undergraduates A Cooper undergraduate degree does not guarantee admission to the graduate program. To be considered for admission to the master's program, one must be a currently enrolled Cooper Union undergraduate, with a minimum 3.0 grade point average according to the major. A Cooper Union undergraduate may declare the intent to complete an integrated degree in the second semester of the junior year or apply to the graduate program (Master of Engineering) in one of the degree-granting departments during the second semester of the senior year.

Students should consult the respective departments regarding specific policies or requirements for admission into the graduate program.

Graduates of Other Colleges The School of Engineering may admit outstanding students or qualified practicing professionals, on a tuition basis, into the master's degree programs. To be considered for admission, a student should have completed an engineering baccalaureate program that is accredited by the Accreditation Board for Engineering and Technology (ABET). Applicants must submit official transcripts. Graduates of foreign institutions whose native language is not English are required to submit scores of the Test of English as a Foreign Language (TOEFL). Admitted students may be required to register for advanced engineering courses to make up for any deficiencies.

DEGREE REQUIREMENTS

Credit Requirements A minimum of 30 graduate level credits beyond the baccalaureate degree must be completed at The Cooper Union (in addition to possible undergraduate deficiencies) for both the thesis requiring M.E. Program and the non-thesis M.E. Program. All graduate level credits, including possibly cross-listed upper level undergraduate credits, must be approved by a student's academic adviser(s).

The 30 credits offered for the thesis program degree must satisfy the following distribution:

- **Major** minimum 12 credits: A coherent concentration of graduate-level courses in the chosen field.
- **Complete a minimum of 12 further credits** of graduate level courses.
- **Thesis Project** 6 credits

The 30 credits offered for the non-thesis program degree must satisfy the following distribution along with a special project requirement:

- **Major** minimum 18 credits: A coherent concentration of graduate-level courses in the chosen field.
- **Complete a minimum of 12 further credits** of graduate level courses.
- **Special Projects requirement can be fulfilled in one of two ways:**
  - Complete a graduate level independent study course (up to 3 credits)
  - Submission to the Dean's office a report that has already satisfied requirements for a graduate level course in which a grade of "B" or higher was received. This report will have to meet structure and formatting requirements specified by the Dean's office.

Each of the engineering departments may have more specific guidelines for the distribution for the M.E. degree.

Grade Requirement A minimum overall grade point average of 3.0 is needed in all courses used to satisfy the 30 credit master's degree requirement.

Appropriate Excess Credits Taken as an Undergraduate For Cooper Union baccalaureate holders, any credits of appropriate level, taken as undergraduates in excess of their bachelor's degree requirement, may be applied to the master's degree, subject to the above cross-listing requirements and advisory approval.

Time Limitation For students that began their program prior to the Fall 2014 semester, the requirements for the master of engineering program must be completed within two years of admission except for extraordinary circumstances that require the express consent of the dean or associate dean of engineering. Requests for such extension must be presented in writing to the Office of the Dean in the final semester of the second year. Thesis adviser's approval is also required. Master's students who receive approval to extend their studies beyond two years will be assessed a maintenance of matriculation fee of $3,000 per semester.

Program of Study A complete program of study is designed by the student with the assistance and approval of the academic adviser(s) and approved by the Office of the Dean of Engineering.

Thesis/Project

- Each student is required to submit a thesis or project in their area of study, equivalent to a maximum of six credits (400 level), for partial fulfillment of the master of engineering requirements. This project must be discussed with and approved by an adviser prior to being started.
- The thesis or project must be successfully presented orally by the student and submitted in written form.

Fellowships One source of funding available to students wishing to pursue graduate study in engineering is the Enders Fund, governed by the will of Henry C. Enders and administered by the New York Community Trust. This fellowship is available to engineering graduates of The Cooper Union who plan to do graduate work in either chemistry, chemical engineering, chemistry-based environmental engineering or chemistry-based bioengineering and, who have satisfactorily completed all of the chemistry courses required of Cooper Union chemical engineering graduates. Recipients are selected by the joint faculties of chemistry and chemical engineering.

HONORS AND SPECIAL PROGRAMS

Dean's List The Office of Admissions and Records determines a Dean's List twice a year, at the end of each semester, on the basis of the record of the completed grade in every subject at the official end of the grading period. To qualify, a student must have a 3.5 or better semester grade point average for a study program of at least 12 credits during that semester with no grade lower than **C** and no grades of Incomplete (**I**).*

Course Overload An overload in the first year consists of a credit total greater than the standard load for that semester in a student's respective program. A student having a grade point average of 3.0 or better may elect to take an overload of one course in any given semester. In all other cases of overload, approval of the student's academic adviser(s) and the written approval of the dean/associate dean of engineering must be obtained. Overload beyond 21.5 credits also requires the written permission of the dean/associate dean and no overload is permitted for students with a prior semester G.P.A. of less than 3.0 or a cumulative G.P.A. of less than 3.0. Requests for overloads must be submitted to the dean/associate dean during the add period of that semester, and only after all grades from the previous semester(s) have been entered.

Graduation with Honors Each graduating senior in the School of Engineering who has achieved an overall cumulative rating of 3.8 or higher is awarded the degree with the notation summa cum laude. Magna cum laude requires a G.P.A. of 3.7 or higher and cum laude requires at least a 3.5 G.P.A.

Curricular Transfers Students wishing to change their course of study should first discuss their interests with the current adviser(s) in both the current and the new speciality areas. Transfer is at the discretion of the dean's office and the receiving department. It may be affected by the student's grades and availability of program resources. Students who request a change in major must consult with the policies of the department they wish to transfer into. It becomes effective when the required petition form, approved by the dean or associate dean of engineering, has been delivered to the Office of Admissions and Records. First-year students may not change their area of study until the end of the year when two semesters' grades are available. A G.P.A. of 3.0 or better is required for approval to transfer curriculum.

Transfer Credit Students, at their own expense, desiring to register for courses at another institution for transfer credit to The Cooper Union must have appropriate advance approval. For courses in mathematics, sciences or engineering, this approval is to be obtained from:

- the department responsible for the course at The Cooper Union and
- the dean or associate dean of engineering.

For liberal arts courses, approval is to be obtained from the dean of Humanities and Social Sciences. In order that transfer credits from another school be accepted, a grade of **B*** or better is required. An exception may be granted in special circumstances only upon formal appeal to the Academic Standards Committee.

Transfer credit is never granted for paid summer internships or work experience or paid or unpaid research.

Pre-Medical, Pre-Law or Pre-Business Studies Upon completion of the engineering degree, some graduates may decide to attend medical, dental, business or law school. Most of the prerequisites for such a course of action are offered at The Cooper Union. For medical school or dentistry, students are advised to take one year of organic chemistry and one year of biology. For law or business, additional economics, political science and professional ethics courses are useful. Students should consult their adviser(s).

Study Abroad The Cooper Union offers suitably qualified, approved students the opportunity to participate in research programs at various foreign universities during the summer. For example, students have attended universities in England, Ireland, Scotland, Australia, Hong Kong, Germany, China, Japan, Italy, Spain, Ghana and France. Cooper Union credit (up to six credits at the 300 level) is granted upon successful completion of the research work, presentation of a written report and its approval by the Office of the Dean. Applications are available in the dean's office in mid-January. (Students on probation are ineligible for this program). Credit is only allowable for exchange programs authorized by The Cooper Union School of Engineering.

Professional Development Mastering the technical aspects of an engineering field is only part of being a successful engineer. There are many other areas that go toward building and continuing a professional career.

The School of Engineering has established the Aba and Leja Lefkowitz Center for Professional Development to strengthen the non-technical attributes required of its engineering undergraduates. The program, which is mandatory for engineering freshmen and sophomores, provides a range of experiences and training through a zero-credit program of seminars, workshops events and activities under the course number ESC000.1-000.4 with a PASS/FAIL grade. Each workshop, seminar or activity is assigned a points score and successful completion of the course is based on accumulating a minimum number of points.

Because this is a zero-credit course, failure to accumulate enough points will not affect a student's GPA, his or her ability to graduate or inclusion on the Dean's List. However, successful completion will result in a note on the transcript stating: "ESC000.X Engineering Professional Development Seminars and Workshops—Successfully Completed."

The course is designed to introduce students to the profession of engineering, as well as aspects of their professional development. A wide range of topics are covered in ESC000 including ethics, environmental awareness, lifelong learning, career development, interpersonal skills, workplace issues, professional societies, professional licensure, teamwork skills, etc. These topics are dealt with using methods such as case studies, role-playing and interactive activities—"learning by doing" all provided by a diverse team of people ranging from students to alumni to professional experts. For example, extensive career development opportunities are provided by the Center for career Development, the Engineering Student Council moderates several seminars and Q and A sessions with alumni and upperclassmen and The Cooper Union's CONNECT Program provides intensive training in communication skills and awareness of the importance of effective communication in engineering.

These experiences help to make students aware of the importance of the non-technical skills needed for professional success. The course introduces engineering students to a number of the topics required for student outcomes (a–k) by ABET. Through this program students are given significant help in navigating their career at The Cooper Union as well as easing the transition into the workplace and ensuring professional success.

Engineering Advisory Council

The School of Engineering is advised in key engineering issues, such as leadership, ethics, communication skills, entrepreneurship and corporate responsibility, by its Advisory Council, which is comprised of company presidents, C.E.O.s, Nobel Laureates, engineers, physicians, attorneys and other business and professional experts. The council meets annually with faculty and students to discuss important issues in engineering education. In addition, the Technology Transfer Advisory Committee is made up of appropriate individuals to advise students and faculty about issues such as patents, commercialization of inventions, entrepreneurship, etc.

* Students may petition the dean/associate for reconsideration in the Dean's List after the Incomplete (I) has been made up.

ACADEMIC STANDARDS AND REGULATIONS

Academic Integrity

Faculty at Cooper Union are committed to preserving an environment that challenges every student to realize his or her potential. You are expected to provide your best effort and will be supported to produce original work of the highest caliber. Plagiarism is the presentation of another person's "work product" (ideas, words, equations, computer code, graphics, lab data, etc.) as one's own. Whether done intentionally or unintentionally, plagiarism will not be tolerated in the School of Engineering.

There are many types of plagiarism, some of which are listed below. (The list is not exhaustive. Speak with the appropriate faculty member or dean or associate dean of engineering if you are uncertain as to what constitutes ethical conduct in a particular situation.)

You are plagiarizing if:

• You present as your own work product a homework assignment, a take-home exam or a class project that includes the efforts of other individuals. The contributions of other individuals (if permitted by your instructor) must be acknowledged in writing on the submitted assignment, exam or project.

• You copy the work of other students on an in-class examination or communicate with other individuals in any fashion during an exam.

• You submit as part of a homework assignment, take-home exam or class project material that has been copied from any source (including, but not limited to, a reference book, periodical, the Internet) without properly citing the source, and/or without using quotation marks. It is also prohibited to submit such materials in a minimally altered form without proper attribution. Improperly copied material might include text, graphics (computer or otherwise), computer source code, etc.

Other prohibited acts of academic dishonesty include (but are not limited to):

• Attempting to obtain a copy of an examination before it is administered.

• Dishonesty in dealing with a faculty member or a dean, such as misrepresenting the statements of another faculty member.

• Bringing notes into an examination when forbidden to do so.

• Bringing any device into an examination (computer/ smartphone/ calculator), which permits the retrieval of examination-related materials unless expressly permitted by the instructor.

• Bringing any device into an examination that allows communication with other individuals or computers or computer databases unless expressly permitted by the instructor.

*A grade of B- cannot be transferred

Faculty members may not unilaterally resolve incidents of academic dishonesty. Each faculty member is required to report all cases of plagiarism or academic dishonesty to the engineering dean's office in a memorandum. If documentary evidence of the incident exists, it should be attached. The dean's office, in consultation with the faculty member and the student, will select from the following sanctions: a grade of **F** for the assignment,a grade of **F** for the course or dismissal of the student from the school. A record of all incidents will be kept in the dean's office and considered for second-time offenders. Students who are dismissed because of academic dishonesty should be aware that incident reports and any responsive actions by the dean's office or Academic Standards Committee become part of their permanent record.

Sexual or Racial Harassment

Such behavior will not be tolerated. Incidents should be reported immediately. Students should see the dean or associate dean, and also the dean of students as soon as possible.

Code of Conduct

Students are required to read and abide by *The Code of Conduct* published by the Office of Student Services.

GRADES OF RECORD

The definitions below deal with the student's attainment in the formal work of the subject. Nevertheless, it should be understood that such essential qualities as integrity, adherence to class regulations, enthusiasm, motivation, clarity in presentation of work and sense of obligation, together with ability to use the English language correctly and intelligibly, are reflected in the grade. The course grade is assigned by the instructor in conformity with definitions indicated in this section.

The grade **A** indicates a superior and comprehensive grasp of the principles of the subject. It denotes an ability to think quickly and with originality toward the solution of difficult problems.

The grade **B** indicates evidence of a good degree of familiarity with the principles involved in the subject. It implies less originality and a tendency to hold to patterns of thought presented in the formal subject matter.

The grade **C** indicates an average knowledge of the principles involved in the subject and a fair performance in solving problems involving these principles. This grade implies average ability to apply the principles to original problems.

The grade **D** indicates a minimum workable knowledge of the principles involved in the subject. This grade denotes low achievement and therefore the number of such grades permitted any student is limited in a manner prescribed by the section on Scholastic Standards.

The grade **F** indicates an unsatisfactory understanding of the subject matter involved. A grade of **F** may be made up only by repeating the subject in class; both the new grade and the new credits and the original grade and credits are included in the permanent record and in the grade point average. A student who receives an **F** grade in a repeated course is a candidate for dismissal by the school's Academic Standards Committee.

The Incomplete (I) Grade The designation of **I** indicates that the work of the course has not been completed and that assignment of a grade and credit has been postponed. This designation will be given only in cases of illness (confirmed by authorized physician's letter) or of other documented extraordinary circumstances beyond the student's control. The **I** designation will be given only with the approval of the dean or associate dean of engineering. At the time of submission of an **I** designation, the instructor will indicate whether the student's progress to that point has been satisfactory or unsatisfactory, offering an estimation of grades whenever possible as a means of assisting the Academic Standards Committee in their deliberations.

The deadline for removal of an **I** designation will be determined by the instructor, but will not be later than six weeks after the start of the spring semester for students who receive such a designation in the fall semester and not later than one week after the start of the fall semester for students who receive such a designation in the spring semester. If the **I** is not removed within the set time limit, either by completing the work in the subject or by passing a re-examination, the **I** will automatically and irrevocably become an **F** unless the dean or associate dean of engineering, in consultation with the instructor, extends the time or the student withdraws from the school.

Grade Point Average or Ratings To determine academic ratings, numerical equivalents are assigned to grades as follows: **A** is represented by 4, **B** by 3, **C** by 2, **D** by 1 and **F** by 0. The sum of the products of credits attempted and grade equivalents earned in a period at The Cooper Union, divided by the sum of credits for that period, is the rating for that period.

Only Cooper Union grades of **A**, **B**, **C**, **D** and **F** will be used in determining ratings. Grades from other colleges and other designations such as **I** and **W** are not used in Cooper Union ratings.

Grade Changes A change in an official grade of record, other than the designation **I**, cannot be made by the dean of Admissions and Records without the express consent of the dean or associate dean of engineering. Grade changes will not be accepted after one year has elapsed from the completion of the course.

Final Examinations Final examinations are held in most subjects, except in cases when content does not lend itself to formal examination, such as laboratory or project work. In certain other subjects, the class record may be ample for determining student standing. The decision on giving a final examination in a given subject is made by the instructor.

ACADEMIC PROBATION, WITHDRAWAL AND DISMISSAL

Probation is the consequence of unsatisfactory scholarship. It is a warning that may involve a compulsory reduction of academic load, interviews with an assigned adviser and additional academic counseling. A student on academic probation must fulfill conditions as prescribed by the Academic Standards Committee.

- The records of all students will be reviewed by the associate dean of engineering for recommendations to the Academic Standards Committee for appropriate action at any point in the student's career.
- Students may be required to withdraw or resign from The Cooper Union based on a single semester's academic performance, a cumulative GPA lower than 2.0, and/or infractions of the academic integrity policies.
- The Academic Standards Committee reserves the right to determine probation and/or dismissal at any point in the student's career for appropriate academic issues.
- A student whose semester grade point average is below 2.0 is on automatic probation and is a candidate for dismissal by the committee.
- Estimates of grades in subjects with **I** designations may be included in all committee deliberations.
- Students who fail to register will have their records annotated: "Dropped: Failure to Register."
- For information about leaves of absence, please refer to pages 24–25.
- Students who believe that a modification of their status should be made because of extenuating circumstances may petition, in writing, the Academic Standards Committee.

CHANGE OF PROGRAM

Adding a Course A student is permitted to add a course only during the first week of a semester, during the drop/add period, and only with the adviser's approval.

Adding a course after the drop/add period is not permitted even if the student has been attending the class.

Dropping a Course A student may drop a course during the first week of the semester, during the drop/add period, with the adviser's approval.

A course dropped during the first week of the semester will be deleted from the transcript.

Withdrawing from a Course A student anticipating inability to continue an assigned program should immediately see his or her adviser. A student's program may be adjusted at the discretion of and after conferring with the adviser and the dean or associate dean of engineering, but only in cases where scholastic performance is impaired by conditions beyond the control of the student, such as health or home conditions. After the drop/add period a student may withdraw from a course through the eighth week of the semester. A grade of **W** will appear on the transcript. A student who stops attending a course without permission of the instructor and the dean or associate dean will receive a grade of **WU**; however, the instructor is free to record a grade of **F** in such a case.

A student may lighten his or her academic load and receive a **W** grade after the eighth week of classes only with the approval of the course instructor, the adviser, and the dean or associate dean. It is the policy of the faculty and the Office of the Dean not to approve any withdrawal after the eighth week of classes except under extreme, extenuating circumstances.

A student is not permitted to drop or withdraw from a course if doing so would impede satisfactory progress towards the degree.

Repeating a Course When a course is repeated (due to failure or any other reason), the grade earned each time the course was repeated is calculated into the G.P.A.

COURSE DESIGNATION

Course Prefix

Biology	Bio
Chemical Engineering	ChE
Chemistry	Ch
Civil Engineering	CE
Computer Science	CS
Electrical Engineering	ECE
Engineering Sciences	ESC
Interdisciplinary Engineering	EID
Mathematics	Ma
Mechanical Engineering	ME
Physics	Ph

Students should consult official class schedules for courses offered in a given semester. There is no assurance that a course listed in this catalog will be given every year.

Be advised that each school at The Cooper Union offers certain electives that are open to all students; consult each school's course listing.

Unless otherwise indicated, credit listings are for single semesters.

Courses are not generally offered in the summer.

Definitions

• A *free elective* is any course (for which a student is qualified) given within The Cooper Union. Foreign language courses do not count as free electives.
• The status *advanced engineering elective* is to be determined by the adviser(s) and the Office of the Dean. Normally, such courses will require prerequisites and are usually taken by juniors and seniors.
• A *core elective* is defined as any course required in either the first, second or third year of the CE, ChE, EE or ME programs.
• A minimum of 12 credits of engineering electives must be at an advanced level.

DEPARTMENTS AND PROGRAMS

CHEMICAL ENGINEERING

FACULTY

Brazinsky (Chair), Davis, Lepek, Okorafor, Stock

Mission Statement

The Cooper Union's Department of Chemical Engineering is committed to the development and graduation of engineering professionals. The department will promote student learning and understanding of science and engineering fundamentals and guide and encourage the application of this knowledge to the ethical, professional practice of chemical engineering. This will be undertaken in an environment that is responsive to new technologies and that encourages lifelong learning and research.

Program Objectives

- Our graduates will attain professional careers where they apply their abilities to solve problems and meet challenges in engineering an non-engineering fields.
- Our graduates will join professional societies and/or attain professional licensure.
- Our graduates will grasp the concept of lifelong learning and appreciate the continuing development of new technologies and issues in the professional field.
- Our graduates will transition easily into their professional careers and demonstrate success in that role.
- Those graduates who pursue graduate studies and research at The Cooper Union and/or other institutions will have the necessary technical background, support and preparation to succeed.

The education of the chemical engineer requires a strong foundation in chemistry and physics, which must be applied through the medium of mathematics to the solution of design, modeling, scale-up and control problems. A thorough knowledge is required of chemical structures, together with the energetic and kinetic relationships predicted in chemical reactions and molecular transport. The chemical engineer deals with the application of these principles to processes carried out on a variety of scales from micro-reactors to an industrial scale, in which matter undergoes changes in physical state, chemical composition or energy content. Emphasis is placed on developing creative ability; facts and theories are presented primarily to stimulate further thought and study in all fields of chemical engineering.

Formal instruction is supplemented by visits to several plants and companies where the contribution of engineers can be observed and understood with respect to equipment, utilities, safety, costs, environmental impact, labor and supervision. The students get first-hand experience in the chemical engineering laboratory in applying engineering analysis to equipment performance, and in learning limitations of theoretical concepts. In the senior year, the student learns how to design chemical plants from fundamental data on new processes and to recognize areas of limited knowledge from the results of the design, and thus recommend pilot plant studies, if necessary.

Chemical engineering graduates find employment in a wide variety of areas. In addition to the chemical and petroleum industries, chemical engineers are involved heavily in the biomedical, materials and environmental fields. A chemical engineering education can also be easily applied to other interdisciplinary areas such as biochemical and biomedical engineering, energy resources, environmental engineering and materials science. As a result, chemical engineers are also finding employment in non-industrial institutions such as government, research think-tanks, policy study groups and even publishing companies.

The chemical engineering department does not make use of the 12-credit rule; see "Course Substitutions and Credits" under "Bachelor of Engineering Curriculum."

Minors

A minor can be obtained by a student in chemical engineering taking any four (4) courses in one of the fields below. The courses require permission of the student's adviser and the department chair. The courses listed are examples currently in The Cooper Union catalog. Note that some may require prerequisites or permission of the instructor. Additionally, note that it is not necessary to obtain a minor in any field in order to graduate with a bachelor of engineering in chemical engineering.

Upon completion of the minor a student should submit a list of courses that he or she wishes to be considered for certification to the department chair. Successful completion of the minor will be acknowledged by a certificate from the department accompanied by a letter listing the minor achieved and the courses taken.

Environmental Engineering

CE 141/Environmental Systems Engineering
CE 142/Water Resources Engineering (also EID 142)
CE 346/Hydraulic Engineering
EID 141/Air Pollution Control Systems
CE 414/Solid Waste Management
CE 435/Geo-Environmental Engineering (also EID 435)
CE 440/Industrial Waste Treatment Design
CE 441/Water and Wastewater Technology
CE 446/Pollution Prevention or Minimization
CE 447/Stream and Estuary Pollution
CE 449/Hazardous Waste Management
Che 447/Sustainability and Pollution Prevention

Biomedical Engineering

ECE 343/Bio-instrumentation and Sensing
EID 121/Biotransport Phenomena
EID 122/Biomaterials
EID 124/Bioengineering in Safety Design and Injury Analysis and Prevention
EID 125/Biomechanics
EID 320/ Special Topics in Bioengineering
EID 325/Science and Application of Bioengineering Technology
EID327/Tissue Engineering
Ch 340/Biochemistry (also Bio 102)
Bio 101/Molecular and Cellular Biology
EID 424/Bioengineering Applications in Sports Medicine
Ch 440/Biochemistry II

Energy Engineering

ME 130/Advanced Thermodynamics
ME 131/Energetics (also EID 131)
ME 330/Advanced Engine Concepts
ChE 421/Advanced Chemical Reaction Engineering
ChE 430/Thermodynamics of Special Systems
ChE 434/Special Topics in Combustion (also ME 434)

Graduate Program

In the Thesis M.E. degree graduate students in chemical engineering must complete a minimum of 30 credits beyond their baccalaureate degree. Of those 30 credits 9 credits must come from the following courses:

ChE 421 Advanced Chemical Reaction Engineering

ChE 430 Thermodynamics of Special Systems or ChE 431 Advanced Chemical Engineering Thermodynamics and Molecular Theory

ChE 441 Advanced Heat and Mass Transfer

Of the remaining 21 credits, 3 credits must be from Chemical Engineering graduate courses, 12 credits may be from graduate engineering or science electives, and 6 credits from a thesis project on an approved topic.

A thesis candidate must choose a full-time Cooper Union faculty member from either the chemistry or chemical engineering department as one of his or her thesis advisers. Before choosing a thesis topic, however, the student should explore various professors' research interests. Research interests of chemical engineering faculty members include non-Newtonian flow, crystal growth from high-temperature melts, polymer extrusion, heat and mass transfer with change of phase, drag coefficients in dense phase transport, construction of a database of engineering materials, mathematical modeling of bio-heat transfer in microcirculation, mathematical modeling of whole-body heat integrated gasification processes for the simultaneous disposal of sludge and garbage with concomitant production of steam and electricity, biochemical separation, protein purification, environmental engineering and mathematical modeling, evaluation of sustainability, batch process design and optimization, pollution prevention and mitigation, infinite linear programming, particle technology, multiphase flow and fluidization, pharmaceutical engineering and processes, nanomaterials and energy systems and processes.

Chemical Engineering Program

Freshman Year	Credits
Fall Semester:	
ESC000.1 Professional Development Seminar	0
Ma 110 Introduction to Linear Algebra	2
Ma 111 Calculus I	4
Ch 110 General Chemistry	3
EID 101 Engineering Design and Problem Solving	3
CS 102 Introduction to Computer Science	3
HSS 1 Literary Forms and Expressions	3
Total Credits Fall Semester	18
Spring Semester:	
ESC000.2 Professional Development Seminar	0
Ma 113 Calculus II	4
Ph 112 Physics I: Mechanics	4
Ch 111 General Chemistry Laboratory	1.5
Ch 160 Physical Principles of Chemistry	3
HSS 2 Texts and Contexts: Old Worlds and New	3
Total Credits Spring Semester	15.5

Sophomore Year	Credits
Fall Semester:	
ESC000.3 Professional Development Seminar	0
ChE 170 Material and Energy Balances	3
Ma 223 Vector Calculus	2
Ph 213 Physics II: Electromagnetic Phenomena	4
ESC 110.1 Materials Science for Chemical Engineers	3
Ph 291 Introductory Physics Laboratory	1.5
Ch 231 Organic Chemistry I	3
HSS 3 The Making of Modern Society	3
Total Credits Fall Semester	19.5
Spring Semester:	
ESC000.4 Professional Development Seminar	0
Ma 240 Ordinary and Partial Differential Equations	3
Ph 214 Physics III: Optics and Modern Physics	3
Ch 232 Organic Chemistry II	2
Ch 233 Organic Chemistry Laboratory	2
ChE 130 Chemical Engineering Thermodynamics I	3
HSS 4 The Modern Context: Figures and Topics	3
Total Credits Spring Semester	16

Junior Year	Credits
Fall Semester:	
Ma 224 Probability	2
ESC 121 Basic Principles of Electrical Engineering	2
Ch 251 Instrumental Analysis Laboratory	2
Ch 261 Physical Chemistry I	3
ChE 131 Chemical Engineering Thermodynamics II	3
ChE 140 Fluid Mechanics and Flow Systems	3
Engineering Elective	3
Total Credits Fall Semester	18
Spring Semester:	
Ch 262 Physical Chemistry II	2
ChE 121 Chemical Reaction Engineering	3
ChE 141 Heat and Mass Transfer	4
ChE 151 Process Simulation and Mathematical Techniques for Chemical Engineers	3
Engineering or Science Elective	3
Free Elective	3
Total Credits Spring Semester	18

Senior Year	Credits
Fall Semester:	
ChE 162.1 Chemical Engineering Laboratory I	1.5
ChE 161.1 Process Evaluation and Chemical Systems Design I	3
ChE 142 Separation Process Principles	3
ChE 152 Chemical Process Dynamics and Control	3
Engineering or Science Elective	3
Humanities/Social Sciences Elective	3
Total Credits Fall Semester	16.5
Spring Semester:	
ChE 162.2 Chemical Engineering Laboratory II	1.5
ChE 161.2 Process Evaluation and Chemical Systems Design II	3
Engineering or Science Elective	3
Free Elective	3
Humanities/Social Sciences Elective	3
Total Credits Spring Semester	13.5

Total credits required for degree	**135**

CIVIL ENGINEERING

FACULTY

J. Ahmad (Chair), Cataldo, Guido, Tzavelis, Yapijakis

Mission Statement

To prepare our students as civil engineering professionals who will have the depth and breadth of knowledge, sense of social and ethical responsibility, commitment to a safe environment and a desire to serve society in leadership positions.

Program Objectives

• Our civil engineering graduates will engage in lifelong learning to stay abreast of the latest body of knowledge and professional practices in civil engineering and allied disciplines throughout their careers.
• Our graduates will excel in teamwork, interdisciplinary concepts, organizational skills and problem-solving methodologies in their professional careers.
• Our graduates will attain positions of leadership as professional practitioners, government officials, academicians, inventors, researchers, etc., during their professional careers.
• Our graduates will have a strong sense of commitment to excellence, independent thinking, innovation and modern professional practices throughout their careers.
• Our graduates will have a strong commitment to professional and ethical responsibility during their careers.
• Our graduates who pursue careers in engineering will seek and successfully achieve professional licensure in their chosen fields.

Student Outcomes

The Civil Engineering Department has established the following set of outcomes that our undergraduate students are expected to achieve by the time of graduation:
1. An ability to apply knowledge of mathematics, science and engineering
2. An ability to design and conduct experiments, as well as to analyze and interpret data
3. An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability
4. An ability to function on multidisciplinary teams
5. An ability to identify, formulate, and solve engineering problems
6. An understanding of professional and ethical responsibility
7. An ability to communicate effectively
8. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
9. A recognition of the need for, and an ability to engage in life-long learning
10. A knowledge of contemporary issues
11. An ability to use the techniques, skills and modern engineering tools necessary for engineering practice
12. A broad fundamental knowledge to qualify for and pass the New York State FE Exam administered in April of the year of their graduation.

Program description

Civil engineering, earliest of the engineering professions, has evolved into a broad spectrum of specialities: structural, geotechnical, hydraulic, environmental, transportation, urban planning, construction management, sustainable design, urban security and infrastructure rehabilitation. Depending on his or her interests and abilities, the modern civil engineer also may become involved in research, design and development related to projects in alternative energy sources, space structures, protection against natural and man-made disasters, etc. The civil engineer also studies and develops new materials, new structural systems and new strategies for optimizing design. Basic research, especially in the areas of applied and experimental mechanics, often arises either as a preliminary or adjunct requisite to these studies.

The civil engineer who wishes to practice creatively in any of these fields must be thoroughly grounded in the basic sciences, mathematics and applied mechanics, structures and structural mechanics, engineering sciences and computer applications. Members of the civil engineering faculty are actively engaged in research in their specialities, which include modern advances in structural engineering and materials, geotechnical engineering, alternative energy sources, green design of buildings, water pollution control technologies, water resources engineering and urban security.

Within the civil engineering program, students may elect to pursue specialized study through an appropriate choice of electives in two areas:
• Structural and Geotechnical Engineering
• Water Resources and Environmental

Graduate level courses in these areas are available to seniors with superior academic records as indicated in the following lists:

Structures and Geotechnical Engineering: CE 422, CE 425, CE 426, CE 427, CE 428, CE 431, CE 432, CE 433, CE 434, CE 450, CE 470.

Water Resources and Environmental Engineering: CE 414, CE 440, CE 441, CE 442, CE 443, CE 444, CE 445, CE 446, CE 447, CE 448, CE 449.

Graduate Program

Completion of the master of engineering degree program in civil engineering is important for entry into the profession in any of the specialized areas discussed above. The civil engineering department offers many graduate level courses in the cited areas, such as structural engineering and environmental engineering.

Civil Engineering Program

Freshman Year	Credits
Fall Semester:	
ESC000.1 Professional Development Seminar	0
Ma 110 Introduction to Linear Algebra	2
Ma 111 Calculus I	4
Ch 110 General Chemistry	3
EID 101 Engineering Design and Problem Solving	3
CS 102 Introduction to Computer Science	3
HSS 1 Literary Forms and Expressions	3
Total credits fall semester	18
Spring Semester:	
ESC000.2 Professional Development Seminar	0
Ma 113 Calculus II	4
Ph 112 Physics I: Mechanics	4
Ch 111 General Chemistry Laboratory	1.5
Ch 160 Physical Principles of Chemistry	3
HSS 2 Texts and Contexts: Old Worlds and New	3
Total credits spring semester	15.5

Sophomore Year	Credits
Fall Semester:	
ESC000.3 Professional Development Seminar	0
Ma 223 Vector Calculus	2
Ma 224 Probability	2
Ph 213 Physics II: Electromagnetic Phenomena	4
Ph 291 Introductory Physics Laboratory	1.5
ESC 100 Engineering Mechanics	3
ESC 110 Materials Science	3
HSS 3 The Making of Modern Society	3
Total credits fall semester	18.5
Spring Semester:	
ESC000.4 Professional Development Seminar	0
ESC 120 Principles of Electrical Engineering	3
Ma 240 Ordinary and Partial Differential Equations	3
Ph 214 Physics III: Optics and Modern Physics	3
ESC 101 Solid Mechanics	3
CE 120 Fundamentals of Civil Engineering	3
HSS 4 The Modern Context: Figures and Topics	3
Total credits spring semester	18

Junior Year	Credits
Fall Semester:	
CE 121 Structural Engineering	4.5
CE 141 Environmental Systems Engineering	4.5
ESC 130 Engineering Thermodynamics	3
ESC 140 Fluid Mechanics and Flow Systems	3
Humanities/Social Sciences Elective	3
Total credits fall semester	18
Spring Semester:	
CE 122 Structural Engineering II	3
CE 131 Introduction to Geotechnical Engineering	4.5
CE 142 Water Resources Engineering	4.5
CE 341 Design of Steel Structures	3
Humanities/Social Sciences Elective	3
Total credits spring semester	18

Senior Year	Credits
Fall Semester:	
CE 342 Design of Reinforced Concrete Structures	3
CE 351 Urban Transportation Planning	3
CE 363 Civil Engineering Design I	3
Engineering or Science Electives	6
Total credits fall semester	15
Spring Semester:	
CE 361 Civil Engineering Experimental Projects	2
CE 364 Civil Engineering Design II	3
Engineering or Science Electives	9
Total credits spring semester	14

Total credits required for degree	**135**

ELECTRICAL ENGINEERING

FACULTY

Cumberbatch, Fontaine (Chair), Keene, Kirtman, Sable

Mission Statement

To develop a highly trained, consummate engineer: able to lead, to practice in a professional manner, to grow with technological advances, to express himself or herself in written and in oral form, to function as a project engineer immediately upon graduation and to pursue graduate studies in a variety of professional fields.

Program Objectives

- Our graduates will have positions where they function as first-class project engineers.
- Our graduates will have positions that require exceptional technical knowledge and professional design skills.
- Our graduates will engage in activities that involve professional-level written and oral expression.
- Our graduates will engage in activities that require demonstrating leadership skills.
- Our graduates will engage in activities that demonstrate a commitment to lifelong learning, research, independent thinking and innovation.

Program description

Basic courses in electronic circuits, signal processing and computer engineering, along with core mathematics, science and humanities courses, are taken in the freshman and sophomore years. Students may then elect to pursue study through an appropriate choice of courses in three areas:

- Electronic Systems and Materials
- Signal Processing and Communications
- Computer Engineering

There is overlap among the courses in the three tracks, and all students are exposed to a broad range of areas within electrical engineering, while being given the opportunity to study areas of interest in significant depth. The track designations are advisory in nature, and students may change their identified track as long as, by the time they graduate, they have fulfilled all the requirements in a selected track.

By the junior year, students are taking required advanced undergraduate courses (with a 300-level designation) that include material at the graduate level. The only required courses in the senior year are the capstone senior design project courses (ECE195/196). Undergraduate students with a strong background are encouraged, as part of the Integrated Master Program, to take graduate level electives once they have the proper prerequisites.

The curriculum interweaves strong theory, grounded in mathematics and science, with extensive use of CAD tools and practical projects. A broad education is supported by taking non-technical electives, including in humanities and social sciences. Team and individual projects begin in the freshman year and culminate with year-long senior projects. All laboratory courses, and many recitation courses, are project based. By the time students commence their senior projects, they perform open-ended system design, implementation and testing, cost analysis and prepare written and oral presentations. They act as project managers, under the guidance of a faculty adviser.

There are numerous research and independent study opportunities involving close work with faculty and practicing professionals on cutting edge problems.

Students plan their courses with the assistance of a faculty adviser. Through extensive experience working on team projects and proper selection of courses, students obtain a well-rounded, diverse and challenging educational experience.

Graduate Program

The candidate must choose a full-time Cooper Union faculty member from the electrical engineering department as one of his or her thesis advisers. In addition, that adviser, in consultation with the other faculty in the department, approves the set of courses used to fulfill the requirements for the Master's program. Possible areas of concentration or thesis topics are numerous and reflect the diverse interests of the faculty. Some examples are: digital signal processing (including speech, audio, image, video and biomedical signals); wireless communications and networks; big data, machine learning, NLP, reconfigurable and distributed computing; electronic materials and integrated circuit engineering; sustainable engineering.

Web Site

The Electrical Engineering department maintains a website at ee.cooper.edu.

Electronic Systems and Materials Track in Electrical Engineering

Freshman Year	Credits
Fall Semester:	
ESC000.1 Professional Development Seminar	0
Ma 110 Introduction to Linear Algebra	2
Ma 111 Calculus I	4
Ch 110 General Chemistry	3
EID 101 Engineering Design and Problem Solving	3
CS 102 Introduction to Computer Science	3
HSS 1 Literary Forms and Expressions	3
Total Credits Fall Semester	18
Spring Semester:	
ESC000.2 Professional Development Seminar	0
Ma 113 Calculus II	4
Ph 112 Physics I: Mechanics	4
ECE 150 Digital Logic Design	3
Ch 111 General Chemistry Laboratory	1.5
Ch 160 Physical Principles of Chemistry	3
HSS 2 Texts and Contexts: Old Worlds and New	3
Total Credits Spring Semester	18.5

Sophomore Year	Credits
Fall Semester:	
ESC000.3 Professional Development Seminar	0
ECE 140 Circuit Analysis	3
Ma 223 Vector Calculus	2
Ma 240 Ordinary and Partial Differential Equations	3
Ph 213 Physics II: Electromagnetic Phenomena	4
Ph 291 Introductory Physics Laboratory	1.5
HSS 3 The Making of Modern Society	3
Total Credits Fall Semester	16.5
Spring Semester:	
ESC000.4 Professional Development Seminar	0
ECE 110 MATLAB Seminar: Signals and Systems	0
ECE 111 Signal Processing & Systems Analysis	3
ECE 141 Electronics I	3
ECE 151 Computer Architecture	3
Ma 224 Probability	2
Ph 214 Physics III: Modern Physics	3
HSS 4 The Modern Context: Figures and Topics	3
Total Credits Spring Semester	17

Junior Year	Credits
Fall Semester:	
ECE 142 Electronics II	3
ECE 193 Electrical & Computer Engineering Projects I	1.5
ECE 300 Communication Theory[1]	3
ECE 310 Digital Signal Processing[2]	3
ECE 320 Control Systems[3]	3
Ma 326 Linear Algebra	3
Humanities/Social Sciences Elective	3
Total Credits Fall Semester	19.5
Spring Semester:	
ECE 194 Electrical & Computer Engineering Projects II	4
ECE 303 Communication Networks[4]	3
ECE 335 Engineering Electromagnetics[5]	4
ECE 341 Integrated Circuit Design	3
Humanities/Social Sciences Elective	3
Total Credits Spring Semester	17

Senior Year	Credits
Fall Semester:	
ECE 195 Electrical & Computer Engineering Projects III	4
Non-technical Elective	3
Engineering or Science Electives	7
Total Credits Fall Semester	13
Spring Semester:	
ECE 196 Electrical & Computer Engineering Projects IV	3
Non-technical Elective	3
Engineering or Science Electives	8.5
Total Credits Spring Semester	14.5

Total credits required for degree 135

Signal Processing and Communications Track in Electrical Engineering

Freshman Year	Credits
Fall Semester:	
ESC000.1 Professional Development Seminar	0
Ma 110 Introduction to Linear Algebra	2
Ma 111 Calculus I	4
Ch 110 General Chemistry	3
EID 101 Engineering Design and Problem Solving	3
CS 102 Introduction to Computer Science	3
HSS 1 Literary Forms and Expressions	3
Total Credits Fall Semester	18
Spring Semester:	
ESC000.2 Professional Development Seminar	0
Ma 113 Calculus II	4
Ph 112 Physics I: Mechanics	4
ECE 150 Digital Logic Design	3
Ch 111 General Chemistry Laboratory	1.5
Ch 160 Physical Principles of Chemistry	3
HSS 2 Texts and Contexts: Old Worlds and New	3
Total Credits Spring Semester	18.5

Sophomore Year	Credits
Fall Semester:	
ESC000.3 Professional Development Seminar	0
ECE 140 Circuit Analysis	3
Ma 223 Vector Calculus	2
Ma 240 Ordinary and Partial Differential Equations	3
Ph 213 Physics II: Electromagnetic Phenomena	4
Ph 291 Introductory Physics Laboratory	1.5
HSS 3 The Making of Modern Society	3
Total Credits Fall Semester	16.5
Spring Semester:	
ESC000.4 Professional Development Seminar	0
ECE 110 MATLAB Seminar: Signals and Systems	0
ECE 111 Signal Processing & Systems Analysis	3
ECE 141 Electronics I	3
ECE 151 Computer Architecture	3
Ma 224 Probability	2
Ph 214 Physics III: Modern Physics	3
HSS 4 The Modern Context: Figures and Topics	3
Total Credits Spring Semester	17

Junior Year	Credits
Fall Semester:	
ECE 142 Electronics II	3
ECE 193 Electrical & Computer Engineering Projects I	1.5
ECE 300 Communication Theory[1]	3
ECE 310 Digital Signal Processing[2]	3
ECE 320 Control Systems[3]	3
Ma 326 Linear Algebra	3
Humanities/Social Sciences Elective	3
Total Credits Fall Semester	19.5
Spring Semester:	
ECE 194 Electrical & Computer Engineering Projects II	4
ECE 302 Probability Models & Stochastic Processes	3
ECE 303 Communication Networks[4]	3
ECE 335 Engineering Electromagnetics[5]	4
Humanities/Social Sciences Elective	3
Total Credits Spring Semester	17

Senior Year	Credits
Fall Semester:	
ECE 195 Electrical & Computer Engineering Projects III	4
Non-technical Elective	3
Engineering or Science Electives	7
Total Credits Fall Semester	14
Spring Semester:	
ECE 196 Electrical & Computer Engineering Projects IV	3
Non-technical Elective	3
Engineering or Science Electives	8.5
Total Credits Spring Semester	14.5

Total credits required for degree	**135**

[1] Formerly ECE 101
[2] Formerly ECE 114
[3] Formerly ECE 121
[4] Formerly ECE 103
[5] Formerly ECE 135

Computer Engineering Track in Electrical Engineering

First Year	Credits
Fall Semester:	
ESC000.1 Professional Development Seminar	0
Ma 110 Introduction to Linear Algebra	2
Ma 111 Calculus I	4
Ch 110 General Chemistry	3
EID 101 Engineering Design and Problem Solving	3
CS 102 Introduction to Computer Science	3
HSS 1 Literary Forms and Experessions	3
Total Credits Fall Semester	18
Spring Semester:	
ESC000.2 Professional Development Seminar	0
Ma 113 Calculus II	4
Ph 112 Physics I: Mechanics	4
ECE 150 Digital Logic Design	3
Ch 111 General Chemistry Laboratory	1.5
Ch 160 Physical Principles of Chemistry	3
HSS 2 Texts and Contexts: Old Worlds and New	3
Total Credits Spring Semester	18.5

Sophomore Year	Credits
Fall Semester:	
ESC000.3 Professional Development Seminar	0
ECE 140 Circuit Analysis	3
ECE 161 Programming Languages	3
Ma 223 Vector Calculus	2
Ma 240 Ordinary and Partial Differential Equations	3
Ph 213 Physics II: Electromagnetic Phenomena	4
Ph 291 Introductory Physics Laboratory	1.5
HSS 3 The Making of Modern Society	3
Total Credits Fall Semester	19.5
Spring Semester:	
ESC000.4 Professional Development Seminar	0
ECE 110 MATLAB Seminar: Signals and Systems	0
ECE 111 Signal Processing & Systems Analysis	3
ECE 141 Electronics I	3
ECE 151 Computer Architecture	3
ECE 164 Data Structures and Algorithms I	2
Ma 224 Probability	2
Ph 214 Physics III: Modern Physics	3
HSS 4 The Modern Context: Figures and Topics	3
Total Credits Spring Semester	19

Junior Year	Credits
Fall Semester:	
ECE 142 Electronics II	3
ECE 165 Data Structures and Algorithms II	2
ECE 193 Electrical & Computer Engineering Projects I	1.5
ECE 300 Communication Theory[1]	3
ECE 310 Digital Signal Processing[2]	3
Ma 352 Discrete Mathematics	3
Humanities/Social Sciences Elective	3
Total Credits Fall Semester	18.5
Spring Semester:	
ECE 194 Electrical & Computer Engineering Projects II	4
ECE 302 Probability Models & Stochastic Processes	3
ECE 303 Communication Networks[3]	3
ECE 361 Software Engineering & Large System Design	3
Humanities/Social Sciences Elective	3
Total Credits Spring Semester	16

Senior Year	Credits
Fall Semester:	
ECE 195 Electrical & Computer Engineering Projects III	4
Non-technical Elective	3
Engineering or Science Electives	6
Total Credits Fall Semester	13
Spring Semester:	
ECE 196 Electrical & Computer Engineering Projects IV	3
Non-technical Elective	3
Engineering or Science Electives	6.5
Total Credits Spring Semester	12.5

Total credits required for degree **135**

[1] Formerly ECE 101
[2] Formerly ECE 114
[3] Formerly ECE 103

MECHANICAL ENGINEERING

FACULTY

Baglione, Delagrammatikas, Lima, Luchtenburg, Sidebotham, Wei (Chair), Wootton

Mission Statement

The Cooper Union's Department of Mechanical Engineering will produce broadly- and rigorously-educated graduates, able to practice professionally, pursue advanced studies and innovate in a wide range of fields. Together with our faculty and staff, our students will develop a commitment toward lifelong interdisciplinary learning, fulfill their potential for responsible leadership and inspire others to continuously pursue excellence by example.

Program Objectives

Our graduates will

- apply their broad and rigorous education to responsible, interdisciplinary problem solving,
- communicate clearly and effectively in their chosen professions and
- continue to learn and educate themselves in their fields of pursuit.

Program description

Mechanical engineering is concerned with the devices and phenomena related to the generation, transmission, application and control of power. Mechanical engineering grew up with the Industrial Revolution and is today the broadest of the engineering disciplines, encompassing many activities and fields of interest. Mechanical engineers may be involved with research and development, design, manufacturing, sales, application and service, administration and management, as well as teaching and consulting. Fields of interest include solid mechanics, materials, fluid mechanics, vibrations and acoustics, heat transfer and thermodynamics, combustion, control systems, manufacturing, CAD/CAM and robotics or combinations of these as is often the case in the design and development work of complex projects. (Examples: the space shuttle, the investigation of alternate energy from renewable resources, the development of completely automated factories, robotics and biomedical engineering systems.) At the Albert Nerken School of Engineering, the mechanical engineering faculty and students have been, and continue to be, involved in these and other exciting new developments through their project work, research work or consulting.

Mechanical engineering is an ideal foundation for careers in the aerospace industry, ocean engineering, marine engineering, biomedical engineering, the automobile industry, the power and utility industries and virtually any area of activity that requires analytical abilities combined with a strong background in design practice.

The sequences of courses shown in the undergraduate curriculum table emphasize the fundamental engineering sciences as well as their applications in a computer environment and professional design practice. By the selection of electives and of their design and research projects, students have a large degree of flexibility in exploring their own interests.

Graduate Program

Areas of research include computer-aided design and engineering, robotics, biomedical engineering, automotive systems, mechatronics, thermoelectric power generation, vibrations and acoustics, combustion and other interdisciplinary areas of engineering.

Mechanical Engineering Program

Freshman Year	Credits
Fall Semester:	
ESC000.1 Professional Development Seminar	0
Ma 110 Introduction to Linear Algebra	2
Ma 111 Calculus I	4
Ch 110 General Chemistry	3
EID 101 Engineering Design and Problem Solving	3
CS 102 Introduction to Computer Science	3
HSS 1 Literary Forms and Expressions	3
Total Credits Fall Semester	18
Spring Semester:	
ESC000.2 Professional Development Seminar	0
Ma 113 Calculus II	4
Ph 112 Physics I: Mechanics	4
EID 103 Principles of Design	3
Ch 111 General Chemistry Laboratory	1.5
Ch 160 Physical Principles of Chemistry	3
HSS 2 Texts and Contexts: Old Worlds and New	3
Total Credits Spring Semester	18.5

Sophomore Year	Credits
Fall Semester:	
ESC000.3 Professional Development Seminar	0
Ma 223 Vector Calculus	2
Ma 240 Ordinary and Partial Differential Equation	3
Ph 213 Physics II: Electromagnetic Phenomena	4
Ph 291 Introductory Physics Laboratory	1.5
ESC 100 Engineering Mechanics	3
ESC 110 Materials Science	3
HSS 3 The Making of Modern Society	3
Total Credits Fall Semester	19.5
Spring Semester:	
ESC000.4 Professional Development Seminar	0
ESC 121 Basic Principles of Electrical Engineering	2
Ma 224 Probability	2
Ph 214 Physics III: Optics and Modern Physics	3
ESC 101 Mechanics of Materials	3
ESC 161 Systems Engineering	3
ME 155 Design and Prototyping	2
HSS 4 The Modern Context: Figures and Topics	3
Total Credits Spring Semester	18

Junior Year	Credits
Fall Semester:	
ESC 130 Engineering Thermodynamics	3
ESC 140 Fluid Mechanics & Flow Systems	3
ME 100 Stress and Applied Elasticity	3
ME 151 Feedback Control Systems	3
Engineering or Science Elective[1]	3
Humanities/Social Sciences Elective	3
Total Credits Fall Semester	18
Spring Semester:	
ME 101 Mechanical Vibrations	3
ME 130 Advanced Thermodynamics	3
ME 142 Heat Transfer	3
ME 160 Engineering Experimentation	3
Engineering or Science Elective[1]	3
Humanities/Social Sciences Elective	3
Total Credits Spring Semester	18

Senior Year	Credits
Fall Semester:	
ME 163 Mechanical Engineering Projects	3
ME 312 Manufacturing Engineering	3
Electives:	
ME 300- or 400-level Lecture Course	3
Free Electives[2]	4
Total Credits Fall Semester	13
Spring Semester:	
ME 164 Capstone Senior Mechanical Engineering Design	3
Electives:	
ME 300- or 400-level Lecture Course	3
Free Electives[2]	6
Total Credits Spring Semester	12

Total credits required for degree **135**

[1] Courses with prefix BIO, Ch, ChE, CE, CS, ECE, EID, ESC, Ma, ME, Ph
[2] Any course, except foreign languages, offered at The Cooper Union

BACHELOR OF SCIENCE IN ENGINEERING CURRICULUM

General Engineering

The School of Engineering offers a bachelors of science degree in General Engineering. It is intended for students who have a clear idea of their educational objectives. These may require a more flexible inter-disciplinary course of study. This program is also suitable for students who desire a strong, broad-based, rigorous engineering background as preparation for graduate study in mathematics, science or other disciplines.

Curriculum

While details of programs will vary according to educational goals and adviser's requirements, the core is as follows:

	Credits
Core Courses	55
Humanities and Social Sciences (over and above the core courses)	minimum 6
Engineering and Engineering Science and Computer Science (over and above the core courses)	minimum 44
Free Electives	30
Total credits	**135**

The program is administered by an interdepartmental committee. Each student is assigned an adviser from the committee: other faculty may also act as co-advisers. Choice of electives is closely monitored for academic rigor and coherence by the interdepartmental committee.

Students who are considering applying to medical or dental school after completing the program are advised to take one year of biology. Law schools may require additional courses in the social sciences.

The program is not suitable for students who wish professional licensure.

Core Curriculum of the Bachelor of Science Program

Freshman Year	Credits
Fall Semester:	
ESC 000.1 Professional Development Seminar	0
Ma 110 Introduction to Linear Algebra	2
Ma 111 Calculus I	4
Ch 110 General Chemistry	3
EID 101 Engineering Design and Problem Solving	3
CS 102 Computer Programming for Engineers	3
HSS 1 Literary Forms and Expressions	3
Total credits fall semester	18
Spring Semester:	
ESC 000.2 Professional Development Seminar	0
Ma 113 Calculus II	4
Ch 111 General Chemistry Laboratory	1.5
Ch 160 Physical Principles of Chemistry	3
Ph 112 Physics I: Mechanics	4
HSS 2 Texts and Contexts: Old Worlds and New	3
Total credits spring semester	15.5

Sophomore Year	Credits
Fall Semester:	
ESC 000.3 Professional Development Seminar	0
Ma 223 Vector Calculus	2
Ma 224 Probability	2
Ph 213 Physics II: Electromagnetic Phenomena	4
Ph 291 Introductory Physics Lab	1.5
HSS 3 The Making of Modern Society	3
Electives	6
Total credits fall semester	18.5
Spring Semester:	
ESC 000.4 Professional Development Seminar	0
Ma 240 Ordinary and Partial Differential Equations	3
Ph 214 Physics III: Optics and Modern Physics	3
HSS 4 The Modern Context: Figures and Topics	3
Electives	10
Total credits spring semester	19

NON-DEGREE DEPARTMENTS

Chemistry

Faculty: Lay, Newmark (Chair), Savizky, Topper

The Department of Chemistry offers a wide range of courses that are necessary for the understanding of the various engineering disciplines. All first-year engineering students enroll in General Chemistry (a general quantitative and descriptive overview of chemistry), Physical Principles of Chemistry (a quantitative discussion of chemical thermodynamics, electrochemistry and kinetics) and General Chemistry Laboratory (chemical preparation and analysis, data recording, report writing and safety).

Sophomore and junior level courses required for chemical engineering majors can also be taken as electives by those wishing to further their knowledge in the areas of analytical chemistry, biochemistry, organic chemistry and physical chemistry.

In addition, advanced elective courses in biochemistry, inorganic chemistry, theoretical chemistry and nanoscience are available, and are suitable for students interested in bioengineering, chemistry, materials engineering, nanotechnology, or pre-medical studies. Research at the undergraduate and master's levels can be conducted under the supervision of the chemistry faculty. Interested students should meet with the department faculty to discuss possible research areas.

The Department operates laboratories in general chemistry, organic chemistry, instrumental analysis, bioorganic chemistry, computational chemistry and nanochemistry for instruction and research projects.

Mathematics

Faculty: Agrawal (Chair), Bailyn, Hopkins, Mintchev, Smyth, Vulakh

The primary responsibility of the Department of Mathematics is the maintenance and delivery of the core mathematics curriculum for the School of Engineering. This consists of a sequence of required courses given in the first two years covering calculus, linear algebra, probability, vector calculus and differential equations. In addition to the core courses, there are a variety of elective mathematics courses, some of which are computer-related. The mathematics curriculum will more than adequately prepare the student for professional work as well as graduate study in engineering and applied mathematics.

The faculty of mathematics strives to develop in the student a firm foundation in, and an appreciation of, the structure and methods of mathematics. Students interested in mathematics research should consult the chair for specific areas of expertise.

The department of mathematics offers a minor in mathematics. Students seeking a minor in mathematics must complete at least 15 credits of mathematics coursework in addition to the 17 credits required by every engineering department. These additional credits must include Mathematical Analysis I and II (Ma 350, 351), Linear Algebra (Ma 326), Modern Algebra (Ma 347) and an elective course in mathematics at or above the 300 level. An overall G.P.A., at graduation, of at least 3.0 among the mathematics portion (32 credits) of the program is required to obtain a minor in mathematics.

Physics

Faculty: A. Wolf (Chair), Yecko

The physics program at The Cooper Union provides a sequence of introductory courses devised to introduce students in engineering to fundamental physical concepts that underlie all the engineering disciplines. Additionally, the Physics Department offers elective courses that are crafted to provide an enhanced understanding of specially selected fields of interest in engineering science.

COURSES

Students should consult official schedules for courses offered in a given semester. There is no assurance that a course listed in this catalog will be given every year.

Each school offers a range of elective courses that are open to all students; consult each school's course listing.

Prefix Key
Course designations use an alphabetical prefix and a three-digit numbering system.

The first digit usually denotes:

(1, 2)	Lower level undergraduate
(3)	Advanced undergraduate
(4)	Graduate courses

Bio	Biology
ChE	Chemical Engineering
Ch	Chemistry
CE	Civil Engineering
CS	Computer Science
ECE	Electrical Engineering
ESC	Engineering Sciences
EID	Interdisciplinary Engineering
Ma	Mathematics
ME	Mechanical Engineering
Ph	Physics

Chemical Engineering

UNDERGRADUATE

ChE 121 Chemical Reaction Engineering
After consideration of chemical reaction kinetics and thermodynamics, the course focuses on the design relationships for batch, semi-batch, plug-flow and mixed reactors. The application of these design relationships is explored in ideal, isothermal, non-isothermal, adiabatic reactors. Homogeneous, heterogeneous and biological systems are discussed including the effect of transport phenomena on reaction rates and reactor design.
3 credits. Prerequisites: ChE 170 and ChE 140

ChE 130 Chemical Engineering Thermodynamics I
First law of thermodynamics for closed systems; perfect gasses, 2- and 3-phase systems of one component; transient and steady state analyses using the first law of thermodynamics for open systems; second law of thermo-dynamics; introduction to concepts of entropy. Gibbs free energy and Helmholtz free energy; derivation and application of equations describing the auxiliiary thermodynamic functions and conditions of equilibrium in imperfect gasses.
3 credits. Prerequisites: Ch 160 or ChE 170

ChE 131 Chemical Engineering Thermodynamics II
Concept of fugacity in imperfect gases; chemical potential and partial molal properties in mixtures; Gibbs-Duhem Equation; ideal solutions of imperfect gas mixtures; the Lewis and Randall Rule; methods of calculating activity coefficients in non-ideal mixtures; vapor-liquid equilibria; checking thermodynamic consistency of vapor-liquid equilibrium data; equilibrium constant, enthalpy change and Gibbs free energy of formation in chemical reactions.
3 credits. Prerequisite: ChE 130

ChE 140 Fluid Mechanics and Flow Systems
Introductory concepts of fluid mechanics and fluid statics. Development and applications of differential forms of basic equations. Dynamics of inviscid and viscous fluids, flow measurement and dimensional analysis with applications in fluid dynamics. Friction loss and friction factor correlation; design of piping systems.
3 credits. Prerequisites: none

ChE 141 Heat and Mass Transfer
Introduction to heat and mass transfer. Steady-state and unsteady-state heat transfer. Steady-state and unsteady-state mass transfer. Interphase transport and transfer coefficients. Convective heat and mass transfer. Internal and external forced convection. Heat transfer equipment. Natural convection. Boiling and condensation. Radiation heat transfer.
4 credits. Prerequisite: ESC 140.

ChE 142 Separation Process Principles
Application of thermodynamic and transport concepts to the design of continuous-contact and staged mass transfer processes common in the chemical process industries. Separation by phase addition, phase creation, by barrier, by solid agent and by external field or gradient. Examination of the limitations of theory and empiricism in design practice.
3 credits. Prerequisites: ChE 131 and ChE 141

ChE 151 Process Simulation and Mathematical Techniques for Chemical Engineers
In this course, numerical methods will be applied to chemical engineering problems in mass and energy balances, thermodynamics, fluid flow, heat transfer, separations, and chemical reactor analysis. Topics include: computer calculations and round-off error, algorithms and convergence, finding roots by bisection or Newton's method, curve fitting and interpolation/extrapolation, numerical integration and differentiation, numerical solution of initial value problems, stiffness, matrices and determinants, matrix properties, special matrices, methods of solution for systems of linear equations by matrices, eigenvalues, eigenvectors, solving systems of non-linear equations, and applications to unit operations. We will use series methods and numerical methods applied to various chemical engineering models, including the following specific methods: Euler's method, Runge-Kutta methods, the Finite difference method, and Newton-Raphson for vector systems.
3 credits. Prerequisite: ChE 140

ChE 152 Chemical Process Dynamics and Control
Introduction to logic of process dynamics and principles of control in chemical engineering applications; block diagram notation, input disturbance, frequency response and stability criteria for chemical equipment and chemical reaction systems; single- and multiple-loop systems; phase plane analysis of reaction systems; application of analog computer in solution of problems.
3 credits. Prerequisite: ChE 151

ChE 161.1 Process Evaluation and Design I
The course uses design projects to explore process flow diagrams and initial equipment design estimates based on process and unit operation material and heat balances. Studies include equipment cost estimation methods that are developed into process economic evaluations and profitability analysis. The course concludes with process and equipment design using Simulation Science's PRO-vision/PRO-II and an examination of optimization techniques.
3 credits each. Prerequisites: ChE 141 and ChE 121

ChE 161.2 Process Evaluation and Design II
This is a continuation of ChE 161.1, and is the "capstone design course" in chemical engineering. All aspects of chemical engineering are integrated in the design of a chemical process plant. The design process consists of flow-sheet development, equipment selection and sizing, utility requirements, instrumentation and control, economic analysis and formulation of safety procedures. The plant design is carried out in class and includes the use of professional simulation packages. The AIChE project is included in this course.
3 credits. Prerequisite: ChE 161.1

ChE 162.1-162.2 Chemical Engineering Laboratory I & II
This laboratory course emphasizes the application of fundamentals and engineering to processing and unit operations. The experiments range from traditional engineering applications to new technologies and are designed to provide hands-on experiences that complement the theories and principles discussed in the classroom. Preparation of detailed project reports and oral presentations are important components of this course.
1.5 credits each. Prerequisite: ChE 121, ChE 141; corequisite: ChE 142

ChE 170 Material and Energy Balances Introduction to the analysis of chemical process systems, using material and energy conservation equations. Estimation of thermodynamics and thermochemical properties of real fluids for engineering calculations. Numerical methods and their implementation on the digital computer for solution of chemical engineering problems.
3 credits. Prerequisite: Ch 160

ChE 391 Research Problem I
An elective course available to qualified and interested students recommended by the faculty. Students may select problems of particular interest in some aspect of theoretical or applied chemical engineering. Topics range from highly theoretical to completely practical, and each student is encouraged to do creative work on his or her own with faculty guidance.
3 credits. Prerequisite: senior standing

ChE 392 Research Problem II Continuation of ChE 391.
3 credits. Prerequisite: ChE 391

ChE 393 Research Problem 111 Continuation of ChE 392.
3 credits. Prerequisite: ChE 392

ChE 394 Research Problem IV Continuation of ChE 393.
3 credits. Prerequisite: ChE 393

GRADUATE

ChE 421 Advanced Chemical Reaction Engineering
Principles and practices of chemical reaction systems emphasizing heterogeneous chemical kinetics, coupled heat and mass transfer in reacting systems and reactor dynamics. Modeling and simulation of systems are extensively applied.
3 credits. Prerequisite: ChE 121

ChE 430 Thermodynamics of Special Systems (same as EID 430 and ME 430)
3 credits. Prerequisite: ChE 131

ChE 431 Advanced Chemical Engineering Thermodynamics and Molecular Theory
Modern methods of applying thermodynamics and molecular physics to phase behavior of fluid mixtures, intermolecular forces and thermodynamic properties, molecular dynamic properties, molecular theory of gases and liquids, theories of liquid solutions and fluid mixtures at high pressures.
3 credits. Prerequisite: ChE 131

ChE 433 Rocket Science (same as ME 433)
3 credits. Prerequisites: ChE 130 and ChE 140

ChE 434 Special Topics in Combustion (same as ME 434)
3 credits. Prerequisite: ESC 130/ChE 130

ChE 440 Advanced Fluid Mechanics (same as EID 440 and ME 440)
Introduction to the energy equation. Steady and transient heat transfer by conduction. Convective heat transfer. Energy transport in flowing media. Free convection. Conservation of species equation. Fisk's law of binary diffusion. Mass transfer with simultaneous homogeneous or heterogeneous reaction. Multicomponent heat and mass transfer. Stefan-Maxwell equations for multicomponent diffusion. Simultaneous heat and mass transfer. Transport in electrolyte solutions. Special topics may include: membrane separation processes, drug delivery and controlled release, turbulent heat and mass transfer, boundary layer heat and mass transfer, and chemically reacting flows.
3 credits. Prerequisite: ESC 140

ChE 441 Advanced Heat and Mass Transfer (same as EID 441)
Introduction to the energy equation. Steady and transient heat transfer by conduction. Convective heat transfer. Energy transport in flowing media. Free convection. Conservation of species equation. Fick's law of binary diffusion. Mass transfer with simultaneous homogeneous or heterogeneous reaction. Multicomponent heat and mass transfer. Stefan-Maxwell equations for multicomponent diffusion. Simultaneous heat and mass transfer. Transport in electrolyte solutions. Special topics may include: membrane separation processes, drug delivery and controlled release, turbulent heat and mass transfer, boundary layer heat and mass transfer, and chemically reacting flows.
3 credits. Prerequisite: ChE 440 or ME 440 or EID 440

ChE 445 Particle Technology
Introduction to particle technology and multiphase flow. Particle properties and characterization. Granular materials and flow. Gas-solid flows. Flow through packed beds. Fluidization. Gas-solid separations. Slurry transport. Pneumatic transport. Powders and bulk solids. Mixing and segregation. Particle size reduction and enlargement. Aerosol dynamics. Industrial petrochemical and pharmaceutical processes: fluid catalytic cracking, gas cyclones, hoppers, granulation, coating.
3 credits. Prerequisite: ESC 140

ChE 447 Sustainability and Pollution Prevention (same as EID 447)
The first part of this course discusses in detail a methodology for defining and assessing the sustainability of an entity. The course then proceeds with more traditional topics in pollution prevention for chemical processes, outlining concepts on the macroscale, (life-cycle assessment) and mesoscale (pollution prevention for unit operations). By the end of this course, you should be able to use a fuzzy-logic-based methodology to define and assess sustainability, perform a sensitivity analysis which identifies the most critical components of sustainability for a given corporation, perform a life-cycle assessment on a product or process, identify and apply chemical process design methods for waste minimization, energy efficiency, and minimal environmental impact and design, size, and cost a simple waste-treatment process.
3 credits. Prerequisite: permission of instructor

ChE 460 Process Heat Transfer Equipment
The chemical engineer must develop, design and engineer both the complete process and the equipment used; choose the proper raw materials; operate the plant efficiently, safely and economically; and see to it that products meet the requirements set by the customer. Chemical engineering is both an art and a science. Whenever science helps the engineer to solve a problem, science should be used. When, as is usually the case, science does not give a complete answer, it is necessary to use experience and judgment. The professional stature of an engineer depends on skill in utilizing all sources of information to reach practical solutions to processing problems. This course will concentrate specifically on the theoretical and practical principles of detailed equipment design for process heat transfer operations. Attempts will be made to emphasize modern technologies used in these operations.
3 credits. Prerequisite: permission of instructor

ChE 461 Principles of Design and Analysis of Reactors
The chemical engineer must develop, design and engineer both the complete process and the equipment used; choose the proper raw materials; operate the plant efficiently, safely and economically; and see to it that products meet the requirements set by the customer. Chemical engineering is both an art and a science. Whenever science helps the engineer to solve a problem, science should be used. When, as is usually the case, science does not give a complete answer, it is necessary to use experience and judgment. The professional stature of an engineer depends on skill in utilizing all sources of information to reach practical solutions to processing problems. This course will concentrate specifically on the theoretical and practical principles of detailed equipment design for process reaction operations. Attempts will be made to emphasize modern technologies used in these operations.
3 credits. Prerequisite: permission of instructor

ChE 462 Design and Operation of Distillation Systems
The chemical engineer must develop, design and engineer both the complete process and the equipment used; choose the proper raw materials; operate the plant efficiently, safely and economically; and see to it that products meet the requirements set by the customer. Chemical engineering is both an art and a science. Whenever science helps the engineer to solve a problem, science should be used. When, as is usually the case, science does not give a complete answer, it is necessary to use experience and judgment. The professional stature of an engineer depends on skill in utilizing all sources of information to reach practical solutions to processing problems. This course will concentrate specifically on the theoretical and practical principles of detailed equipment design for process distillation operations. Attempts will be made to emphasize modern technologies used in these operations.
3 credits. Prerequisite: permission of instructor

ChE 475 Pharmaceutical Engineering
Introduction to pharmaceutical engineering. Overview of the pharmaceutical industry and drug discovery and development. Clinical trials, regulation, and validation. Scientific principles of dosage forms including solutions, disperse systems, dissolution, stability, and surface phenomena. Biopharmaceutical principles of drug delivery. Pharmacodynamics, pharmacokinetics, and biopharmaceuticals. Unit operations for solid and liquid dosage forms. Pharmaceutical plant design.
3 credits. Prerequisites: ChE 121, ChE 142, and ChE 262, or permission of instructor

ChE 488 Convex Optimization Techniques (same as EID 488)
This course discusses in detail different methods for the optimization of systems of engineering and economic interest using the techniques of linear and nonlinear programming. The focus is on convex optimization, which is the solution of problems with only one best cost, design, size etc. We will consider problems such as least squares, supply chain management, batch process networks, network flow, dynamic programming, portfolio optimization and other examples across all engineering disciplines. Students will learn about optimization theory and problem formulation, with some computational component. By the end of the course, students should be able to: create optimization problems from a physical situation, identify whether a problem can be solved or not, transform problems into equivalent forms, list optimality conditions for problems, find the dual of a problem and identify its relation to the primal, and use at least one method to solve a convex programming problem using a computer.
3 credits. Prerequisites: ChE 151 or ESC 161, Ma 326 (co-enrollment is fine)

ChE 490 Process Synthesis
This course provides a new basis for the design of integrated chemical processes. The ability to predict, at the outset, achievable design targets that have a sound scientific basis is fundamental to the approach. These targets relate to energy, capital and raw materials, costs and flexibility. Topics will include review of basic thermodynamic concepts, capital/energy trade-off, process integration–multiple utilities, process/utility interface, reactors and separators in the context of overall process–power optimization, design for flexibility, total sites layout, batch processes and process plant retrofit.
3 credits. Prerequisites: ChE 161.1 and ChE 161.2 or permission of instructor

ChE 499 Thesis/Project
Master's candidates are required to conduct, under the guidance of a faculty adviser, an original investigation of a problem in chemical engineering, individually or in a group, and to submit a written thesis describing the results of the work.
6 credits for full year.

Civil Engineering

UNDERGRADUATE

CE 120 Civil Engineering Fundamentals
Planning, execution and interpretation of drawings and specifications for civil engineering projects. Sample drawings and specifications. Contractual requirements. Sample contracts. Permitting, scheduling and cost estimation. Basic operations of design and construction firms. Interface with other disciplines on civil engineering projects.
3 credits. Prerequisite: EID 101

CE 121 Structural Engineering I
Discussion of materials, loads and forms of structures. Analysis of determinate structures. Displacements of structures and their importance in applications. Experimental aspects of materials behavior in structural applications. Emphasis is placed on basic experimental techniques, design of experiments, selection and use of appropriate instrumentation and interpretation of results.
4.5 credits (3 hours of lecture, 3 hours of laboratory). Prerequisite: ESC 101

CE 122 Structural Engineering II
Modern methods of structural analysis of indeterminate structures. Discussion of energy methods, force methods and displacement methods. Formulation of elementary matrix stiffness and flexibility methods. Computer applications in structural analysis.
3 credits. Prerequisite: CE 121

CE 131 Introduction to Geotechnical Engineering
Introduction to various indexing tests of soils, clay mineralogy, permeability, seepage and flow nets, stress distribution in soil masses, one-dimensional consolidation theory, strength characteristics of soils, application of Mohr's Circle to soil mechanics, stability of slopes.
4.5 credits (3 hours of lecture, 3 hours of laboratory). Prerequisite: ESC 101; prerequisite or corequisite: ESC 140

CE 141 Environmental Systems Engineering (same as EID 141)
Qualitative and quantitative treatment of water and wastewater systems as related to domestic and industrial needs and their effect on the environment. Introduction to air pollution sources and control and solid/hazardous waste engineering. Design of water and wastewater treatment plants. Field and laboratory techniques for measurement of water quality parameters. Laboratory analysis of representative waters and wastewaters for commonly determined parameters as related to applications in water environment.
4.5 credits (3 hours of lecture, 3 hours of laboratory). Prerequisite: ESC 140

CE 142 Water Resources Engineering (same as EID 142)
Problems in conservation and utilization of water. Hydrologic techniques. Surface water and ground water supplies. Water transmission and distribution. Flood control, navigation and irrigation. Introduction to open channel flow and pipe networks. Design of hydraulic structures. Experimental aspects of hydraulic phenomenon. Emphasis is placed on basic experimental techniques, design of experiments, selection and use of appropriate instrumentation and interpretation of results.
4.5 credits (3 hours of lecture, 3 hours of laboratory). Prerequisite: ESC 140

CE 331 Foundation Engineering
Layout of subsurface investigation program, SPT (Standard Penetration Test), Dutch-cone penetrometer. Analysis and design of spread footings on cohesive and cohesionless soil by stability and settlement procedures, combined footings, strap footings, floating foundations and pile foundations. Settlement analysis due to deep-seated consolidation.
3 credits. Prerequisite: CE 131

CE 332 Lateral Earth Pressures and Retaining Structures
Introduction to classical lateral earth pressure theories (Rankine and Coulomb). Analysis and design of cantilever and gravity retaining walls, cantilevered and anchored sheetpile bulkheads, anchorage systems (individual and continuous deadmen, grouted tiebacks) and braced cofferdams. Gravity Wall Systems (Gabion Walls, Criblock Walls and Double Wall).
3 credits. Prerequisite: CE 131

CE 341 Design of Steel Structures
Study of behavior and design of structural steel components and their connections. Understanding and development of design requirements for safety and serviceability, as related to latest structural steel specifications by the American Institute of Steel Construction (A.I.S.C.). Current design emphasizing LRFD, fabrication and construction practices. Composite design.
3 credits. Prerequisite: CE 121; corequisite: CE 122

CE 342 Design of Reinforced Concrete Structures
Study of the behavior and design of structural concrete components and their connections. Understanding and development of design requirements for safety and serviceability, as related to latest specifications by the American Concrete Institute (A.C.I.). Current design, fabrication and construction practices. Introduction to prestressed concrete.
3 credits. Prerequisite: CE 122

CE 346 Hydraulic Engineering
An integration and application of the principles of fluid mechanics to problems concerned with water supply and distribution. Open channel flow and design of hydraulic structures.
3 credits. Prerequisite: CE 142

CE 351 Urban Transportation Planning
Historical background and evolution of current procedures used in the "urban transportation planning process." Covered are the historical framework, urban development theories, land use, trip generation, trip distribution models, traffic assignment techniques, modal split and introduction to urban transportation systems.
3 credits. Prerequisite: permission of instructor

CE 352 Elements of Transportation Design
Review of urban transportation planning process. Specific design elements of various highway and public transportation systems. Included are locational design, traffic service, environmental impact analyses, alternatives evaluation, geometric design elements, operations and capacity and level-of-service analysis. Also, selected topics in urban transportation systems.
3 credits. Prerequisite: permission of instructor

CE 361 Civil Engineering Experimental Projects
Exploratory experimental projects in materials, hydraulics, soils, environmental or other civil engineering specialties. Projects are conceived, designed and executed by groups of students under faculty supervision.
2 credits. Prerequisite: permission of instructor. (Students are required to have taken introductory civil engineering subject(s) related to project)

CE 363 Civil Engineering Design I
Individual or group design projects based upon the interests of the students and with the approval of the instructor. Final engineering reports and formal oral presentations are required for all projects. Lectures by faculty and professional practitioners cover the following topics: engineering, environmental and economic feasibility assessment issues; preparation of plans and specifications; cost estimates; progress chart and critical path; interfacing with community, etc. Field visits to major New York City projects under construction.
3 credits. Prerequisite: permission of instructor. (Students are required to have taken introductory CE subject(s)) related to project)

CE 364 Civil Engineering Design II
Continuation of CE 363.
3 credits. Prerequisite: CE 363

CE 369 Civil Engineering Project
Individual design, research or experimental projects. Open only to well-qualified students.
3 credits. Prerequisite: permission of instructor

CE/EID 390 Introduction to Sustainable Design Sustainable design minimizes the impact on the environment by site planning and design, energy and water conservation and interior environmental quality. This course will focus on the design of a prototype structure using sun, light, air, renewable materials, geological systems, hydrological systems and green roofing. Each student will develop a project outlined by the U.S. Green Building Council rating system known as LEED. The six areas that will be developed to design the project are: sustainable sites, water efficiency, energy and atmosphere, material and resources, indoor environmental quality and innovative design process. Class time is separated into a series of lectures, private consultations and student presentations.
3 credits. Prerequisite: ESC 140, CE 122 or ME 100 and permission of instructor

CE 391 Laboratory Testing of Building Materials
Laboratory testing of common building materials such as concrete, steel, and laminated glazing. Concrete mix design. Casting, curing and strength testing of concrete cylinders at 7, 21 and 28 days. Casting, curing and testing of a reinforced concrete beam for stress, strain and deflection. Casting, curing and strength testing of a reinforced concrete column. Deflection testing of a steel beam. Buckling of slender steel columns. Vibrations of a steel beam and a steel frame. Control of deflections through bracing and stiffeners. Impact testing of laminated glazing panels.The course will consist of 3-hr. weekly laboratory sessions for 15 weeks.
3 credits. Prerequisite: This course is open to third-year architecture and third-year civil engineering students. Art students and engineering students of majors other than civil engineering require permission of instructor.

GRADUATE

CE 414 Solid Waste Management (same as EID 414)
Engineering aspects of solid waste collection, transport and disposal, including sanitary landfill design, incineration, composting, recovery and re-utilization of resources. Optimization techniques of facility-siting and collection route selection and economic evaluation of factors affecting selection of disposal methods.
3 credits. Prerequisite: permission of instructor

CE 422 Finite Element Methods (same as EID 422)
Shape functions and generalized displacements. Assemblage of elements. Convergence criteria. Triangular, rectangular and quadrilateral elements in plane stress and plane strain. Isoparametric formulations. General solids. Hexahedral and tetrahedral elements. Flexure in plates. General shells. Natural coordinates. Computer programs.
3 credits. Prerequisite: CE 122 or ME 100

CE 424 Plates and Shells
Discretized grid-work and grillage analysis by matrix techniques. Development of the classical thin plate theory. Mathematical and numerical solutions of the plate equation. Introduction to thin shell theory. Practical applications such as cylindrical shell roofs, spherical shell with an edge ring and various cases of shells of revolution.
3 credits. Prerequisite: CE 122

CE 425 Structural Dynamics (same as EID 425)
Dynamic behavior and design of structures subjected to time-dependent loads. Included in the load systems are earthquakes, blasts, wind and vehicles. Shock spectra and pressure impulse curves. Special applications in blast mitigation design.
3 credits. Prerequisite: CE 122

CE 426 Advanced Structural Design
Discussion of principal design codes (AISC, ACI and AASHTO) as they relate to ASCE Standards, the International Building Code (IAC) and NYC Building codes Advanced materials behavior. Strength and serviceability requirements. Design of composite girders and slabs. Limit state response and formation of plastic hinges in steel and concrete structures. Structural upgrade and retro-fit of existing structures.
3 credits. Prerequisite or corequisite: CE 341

CE 427 Behavior and Design of Prestressed Concrete Structures
Behavior and design of prestressed members in flexure, shear, bond and torsion; continuous beams; columns; prestressed systems; loss of prestress. Emphasis is placed on ultimate strength design and the background of latest ACI code.
3 credits. Prerequisite: CE 341

CE 431 Advanced Foundation Engineering
Analysis and design of foundations subjected to vibratory loading, beams on elastic foundation (vertical subgrade modulus), laterally loaded piles (with software applications), Wave Equation Analysis of Piles (with software application of WEAP).
3 credits. Prerequisites: CE 131 and permission of instructor

CE 432 Special Topics in Lateral Earth Pressure and Retaining Structures
Analysis and design of cellular cofferdams, reinforced earth-retaining structures, slurry walls and retaining structures subjected to earthquake loading, soil nailing.
3 credits. Prerequisites: CE 131 and permission of instructor

CE 433 Advanced Topics in Geotechnical Engineering I
Analysis of slopes using translatory slides and available software packages (PCSTABL). Ground improvement technologies: including dynamic compaction, grouting, ground freezing and reinforced earth technologies.
3 credits. Prerequisite: permission of instructor

CE 434 Advanced Topics in Geotechnical Engineering II
Stresses in homogeneous and layered systems due to surface and buried loads. Development of flow network concepts and the Terzaghi one-dimensional consolidation theory, secondary consolidation, site pre-loading, sand drains and prefabricated vertical drains.
3 credits. Prerequisite: permission of instructor

CE 435 Geo-Environmental Engineering
Discussion of pertinent regulations and regulatory programs relevant to contaminated soil. Identification and characterization of contaminated soils, discussion of current treatment technologies both ex-situ and in-situ. Geotechnical design of waste facilities, closure and improvement of waste facilities. Utilization of waste for engineering purposes. Reuse and recycling of contaminated soil.
3 credits. Prerequisites: ESC 140, CE 131, CE 141 and permission of *instructor*.

CE 436 Forensic Geotechnical Engineering
Types of damage—architectural, functional and structural. Investigate problems the forensic geotechnical engineer encounters: settlement of structures, damage to soil expansion, lateral movement of buildings, damage due to seismic energy of earthquakes, slope erosion, deterioration due to sulfate attack and frost, seepage. Development of repair recommendations and presentations of case studies.
3 credits. Prerequisite CE131 or permission of instructor

CE 440 Industrial Waste Treatment Design (same as EID 438)
Integrated lecture and design periods that cover the sources of industrial wastewaters, their quantities and characteristics, and their treatability by physical, chemical and biological processes. Status of regulations involving categorical standards, local and state industrial pretreatment programs, NPDES permits, etc. Problems and solutions involved in combining municipal and industrial waste treatment. Case studies.
3 credits. Prerequisite: permission of instructor

CE 441 Water and Wastewater Technology (same as EID 439)
Wastewater sources and estimates of domestic, commercial and industrial flows. Integrated lecture and design periods that cover unit processes for water and wastewater treatment. Design projects include hydraulic and process design of oxidation ponds, screening, grit removal, sedimentation tanks, secondary biological treatment, other physicochemical processes and outfall design.
3 credits. Prerequisite: permission of instructor

CE 442 Open Channel Hydraulics
Derivation of the general one-dimensional equations of continuity, momentum and energy used in open channel flow analysis. Steady uniform flow and boundary resistance. Steady nonuniform flows, channel transitions and controls, hydraulic jumps, surges, surface curves for gradually varied flow including the effects of lateral inflow. Unsteady flow in open channels. Dynamic waves, method of characteristics, surge formation. Kinematic waves, flood routing and overland flow. Design of channels and other hydraulic structures.
3 credits. Prerequisite: CE 142

CE 444 Hydrology
Hydrology of the water cycle related to air mass movement, precipitations, evaporation, stream flow, floods, infiltration and groundwater including statistical hydrology. Design of irrigation systems.
3 credits. Prerequisite: CE 142

CE 446 Pollution Prevention or Minimization (same as EID 446)
Introduction to the new concept and regulations in the U.S. and Canada of Pollution Prevention or Waste Minimization for managing hazardous pollution and protecting the environment and public health. Methodology of conducting environmental audits and lessons learned from successful pollution prevention programs. Case studies of various programs in industry, etc.
3 credits. Prerequisite: permission of instructor

CE 447 Stream and Estuary Pollution
Application of basic concepts of fluid kinetics and dynamics to the analysis of dispersal and decay of contaminants introduced into lakes, streams, estuaries and oceans. Analysis and modeling of leachate and other contaminants into groundwater.
3 credits. Prerequisite: CE 142

CE 448 Environmental and Sanitary Engineering (same as EID 448)
Topics include types of environmental pollution and their effects; water quality standards and introduction to laboratory analyses of water quality parameters; sources and estimates of water and wastewater flows; physicochemical unit treatment processes. Integrated lecture and design periods cover water supply network, wastewater collection system and water treatment design projects.
3 credits. Prerequisite: permission of instructor

CE 449 Hazardous Waste Management (same as EID 449)
Definition and characteristics of hazardous wastes. Generation, transport, treatment, storage and disposal of hazardous wastes. Leachate characteristics and management. Treatment technologies. Monitoring and safety considerations. Obligations under Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Field trips.
3 credits. Prerequisite: permission of instructor

CE 450 Civil Engineering Construction
Preparation of plans and specifications. The bidding and award process. Contractual relations between the owner and the contractor. Preparation of cost estimate for a competitively bid project. Preparation of a progress chart and critical path. Sequencing various job elements. Engineering the actual construction. Management of labor. Interlacing with the community. Environmental requirements. Job safety. Changes and unanticipated conditions. Contract disputes and their resolutions.
3 credits. Prerequisite: CE 341

CE 460 Innovations in Urban Infrastructure Design
Innovations in the design, delivery, monitoring and rehabilitation of urban infrastructure. Recent advances in methods and technologies such as remote sensing, visualization, data acquisition systems, non-destructive testing, data mining, geographical information systems (GIS), and building information modeling (BIM). Emphasis will be placed on applications relating to real-world projects in large urban centers in the United States and the world.
3 credits. Prerequisite: CE 121 or ME 101

CE 470 Urban Security (same as EID 470)
Design of urban systems to protect against terrorism. Analysis of blast loads. Blast mitigation design considerations. Technology transfer: military/defense to civilian sector. Response spectra. Pressure-Impulse Curves. Stand off distances. Blast mitigation measures for buildings, bridges and tunnels. Prevention of progressive collapse in tall buildings. Design of glazing. Retrofit upgrade of existing urban infrastructure. Proposed changes in New York City Building Code to protect against terrorism. Insurance issues for commercial buildings.
3 credits. Prerequisites: CE 122 or ME 101 and permission of instructor

CE 481 Bridge Engineering
Codes and Applicability. General forms and components—trusses, segmental, cable-stayed and suspension. Primary loads and load combinations. Serviceability vs. strength. Consideration of extreme events. Design of super-structures—deck design, girder design, floor-beam design. Design of substructures-piers, abutments, frames and foundations. Scour and other adverse considerations. Wind, seismic and pushover analyses. Bearings, expansion joints and barriers.
3 credits. Prerequisite CE 122 or permission of instructor.

CE 482 Resilient Civil Infrastructure
Hazard mitigation including quantification of resilience. Multi-scale and/or multi-hazard risk assessement. Smart/adaptive systems to protect against natural and human-created hazards. Predictive science toward forecasting infrastructure response to climate change or extreme events. Development of frameworks for optimization of infrastructure networks. Complex systems approaches to the analysis of the interconnected nature of civil infrastructure and its interdependencies.
3 Credits. Prerequisite: permission of instructor

CE 483 Building Information Modeling
Introduction to Building Information Modeling (BIM). Generation and management of digital representations of physical and functional characteristics of a facility. Extensive use and programming of BIM as a shared knowledge resource among the various stakeholders to support decision-making about a facility from earliest conceptual stages, through design and construction, and through its operational life and eventual demolition.
3 credits. Prerequisite: permission of instructor

CE 484 Civil Engineering Project Management
This course provides an overview of the guiding principles of civil engineering project management. Five groups of project management processes will be considered: initiating, planning, executing, monitoring and controlling, and closing. The focus will be on developing the core competencies and skill sets required for planning and controlling civil engineering projects and understanding interpersonal issues that drive successful project outcomes.
3 credits. Prerequisite: Permission of instructor

CE 485 Green Sustainable Cities
Design and modeling of green streets green walls, green roofs, blue roofs, and green parking lots; concepts and practical considerations. Study of evapotranspiration, radiation, and drainage of vegetative systems. Sustainable management and reuse considerations of urban storm water; sustainable and positive environmental impact design concepts. Management and reuse/recycle considerations for urban gray water. Examples of international projects and case studies. Team design projects with class powerpoint presentations.
3 Credits. Prerequisite: permission of instructor

CE 486 Urban Megaprojects and Environmental Impacts
The political embrace of city competition internationally has combined with the globalization of banking, real estate development, and architecture to make Urban Megaprojects seemingly inevitable. With the world economy slowed, it is time to delve into the motivation for and consequences (including environmental impacts) of the now-ubiquitous and globally-entrenched Urban Megaprojects. The aim of this course is to understand the causes and consequences of new scales and forms of territorial restructuring in a steadily globalizing world by focusing on Urban Megaproject development. Case studies from cities such as Bilbao, Budapest, Abu Dhabi, New York, Paris, Sao Paulo, Shanghai, Detroit, Philadelphia, and Mexico City will be presented in an interdisciplinary approach including sociology, planning, architecture, and environmental impacts. Individual term papers on case studies will be presented to class with powerpoint.
3 credits. Prerequisite: instructor's approval

CE 487 Alternative Energy Projects
The design parameters and pros and cons of all types of alternative energy production systems currently in use around the world will be presented. Concepts, practical considerations, environmental impacts, and economics will be evaluated. Alternative energy production systems such as solar, wind power, geothermal, hydropower, pumped storage, industrial growth of algae for biodiesel, will be examined and cade studies from around the world will be presented. Individual term papers on case studies will be presented to class by powerpoint.
3 credits. Prerequisite: instructor's approval

CE 499 Thesis/Project
Master's candidates are required to conduct, under the guidance of a faculty adviser, an original investigation of a problem in civil engineering, individually or in a group, and to submit a written thesis describing the results of the work.
6 credits for full year.

Electrical Engineering

UNDERGRADUATE

ECE 110 MATLAB Seminar: Signals & Systems
A weekly hands-on, interactive seminar that introduces students to MATLAB, in general, and the Signal Processing Toolbox in particular. Students explore scientific computation and scientific visualization with MATLAB. Concepts of signal processing and system analysis that are presented in ECE 111 or other introductory courses on the subject are reinforced through a variety of demonstrations and exercises. It is strongly encouraged for students taking a first course in signals and systems, or for students expecting to use MATLAB in projects or courses.
0 credits.

ECE 111 Signal Processing & Systems Analysis
A presentation of signals and systems that does not rely on prior knowledge of electrical circuits or differential equations. Sine waves, phasors, continuous-time and discrete-time signals, sampling. Starting from elementary discrete-time systems (FIR filters), and moving on to more complex systems (IIR digital filters and analog filters), concepts such as impulse response, convolution, frequency response, transfer functions (z-transform and Laplace transform) are presented. Block and signal-flow diagrams. Linearity, causality, time-invariance, stability. Feedback: open-loop and closed-loop gain. Transient response, poles and zeros. Vector spaces of signals, Fourier analysis, modulated signals, random signals. Examples include speech and audio signals, communication and control systems. Extensive use of MATLAB.
3 credits. Prerequisite: Ma 113; corequisite: ECE 110

ECE 140 Circuit Analysis
Circuit components, dependent and independent sources, Kirchhoff's laws, loop and nodal analysis. Superposition, Thevenin and Norton equivalent circuits, and other techniques for circuit simplification. Time-domain analysis of RLC circuits, initial conditions, transient response and steady-state. Phasor analysis, complex power. Ideal op-amps.
3 credits. Prerequisite: Ma 113. Ma 240 is a suggested corequisite

ECE 141 Electronics I
Semiconductor physics: band theory, carrier distributions and transport mechanisms. PN-junctions, PN junction devices. Diode circuits. BJTs: current relationships, operating region. Biasing circuits, DC Analysis; small-signal models, AC analysis. BJT amplifier configurations.
3 credits. Prerequisite: ECE 140

ECE 142 Electronics II
MOS circuits: DC operation and analysis. Single stage MOS amplifiers, circuit design, DC and small signal analysis. Cascode amplifier. Current mirrors, active loads. BJT and MOS differential amplifiers. Monolithic operational amplifiers. Output stages. Frequency response. Introduction to feedback theory, amplifier topologies. Circuit design and analysis are supplemented with industry standard CAD software.
3 credits. Prerequisites: ECE 141 and ECE 111

ECE 150 Digital Logic Design
Theoretical and practical issues concerning design with combinational and sequential logic circuits, and programmable logic devices.
Number systems, Boolean algebra, representation and simplification of Boolean functions, universal logic families. Finite-state machines, state tables and state diagrams, flip-flops, counters, registers. Adders, decoders, comparators, multiplexers, memories and applications. Programmable devices: PLA, PLD, etc. Principles of analog circuits are presented in the context of real world problems, such as "glitches," power and ground bounce, contact bounce, tri-state logic and bus interfacing, timing circuits, asynchronous versus synchronous circuit components. Characterization of electronic and logical properties of digital circuits. Course work involves individual and team projects in which: digital circuits are designed and prototypes are constructed and tested on breadboards; designs involving programmable logic devices are developed using CAD tools. The projects, approximately 50 percent of the course grade, are used to assess technical writing, oral presentation, teamwork and project management skills.
3 credits. Prerequisites: none. Non-refundable materials fee: $40

ECE 151 Computer Architecture
Introduction to the design of computers and computer systems. Topics include: integer and floating-point representations and operations: ALU design; von Neumann and Harvard architectures; accumulator, general purpose register and stack-based processor design; RISC and CISC architectures; addressing modes; vector operations; microprogrammed and hard-wired controllers; machine language and assembly language programming; static and dynamics memory operation, timing and interfacing; cache; virtual memory; I/O systems: bus design and data transfer, DMA; interrupts and interrupt handling, polling; disk operation and organization; pipelined processor design. The course has a substantial project component that includes assembly language programming and the design and construction of systems that contain microcontrollers, programmable logic, and a variety of I/O devices.
3 credits. Prerequisite: ECE 150.

ECE 161 Programming Languages
Examination of the fundamental concepts of practical programming languages, focusing on C and C++ but including additional languages. Topics include binary representations of numbers, operators, static and dynamic memory allocation, arrays, strings, structures, flow control, file I/O, stacks, queues, lists, activation records and recursion. Object oriented programming concepts covered include classes, encapsulation, information hiding, operator and function overloading, constructors, destructors, inheritance and polymorphism.
3 credits. Prerequisite: CS 102

ECE 164 Data Structures & Algorithms I
An introduction to fundamental data structures and algorithms, with an emphasis on practical implementation issues and good programming methodology. Topics include lists, stacks, queues, trees, hash tables and sorting algorithms. Also an introduction to analysis of algorithms with big-O notation. Assignments include programming projects and problem sets.
2 credits. Prerequisite: ECE 161 or permission of the instructor

ECE 165 Data Structures & Algorithms II
A continuation of ECE 164, also with an emphasis on practical implementation issues and good programming methodology. Topics include graphs, graph-related algorithms and dynamic programming techniques. Also an introduction to some advanced topics such as Turing machines, computability and NP-complete systems. Assignments include programming projects and problem sets.
2 credits. Prerequisite: ECE 164

ECE 193 Electrical & Computer Engineering Projects I
An introduction to laboratory techniques for electrical and computer engineering. Topics include the use of electronic test equipment (e.g., DVM, oscilloscope, curve tracer, spectrum analyzer); circuit analysis, design and simulation; and the use of discrete and integrated electronic components and circuits. Several projects/experiments of limited scope reinforce concepts learned in previous courses and provide an understanding of the fundamental building blocks employed in the more advanced designs in successive projects courses. Students regularly give oral presentations and demonstrate laboratory proficiency through in-class demonstrations and concise, formal technical reports.
1.5 credits. Prerequisites: ECE 111, ECE 141, ECE 150. Co-requisite: ECE142.

ECE 194 Electrical & Computer Engineering Projects IV
Principles learned in ECE 193 are applied to the design, construction and characterization of electrical and computer engineering projects of significant complexity. Assignments may involve both analog and digital design, and students are free to pursue any solution that satisfies the engineering requirements and meets with the instructor's approval. Formal and informal lectures are given on safety, circuit operation and design, and construction techniques; students participate in design reviews and write technical reports.
4 credits. Prerequisite: ECE 193.

ECE 195 Electrical & Computer Engineering Projects III
ECE 195 and ECE 196 constitute the year-long senior design project. Students work in small groups on projects chosen with the advice and consent of the faculty adviser. Projects may be oriented towards research or product development, and may be in any area of electrical and computer engineering, such as in: computer engineering, signal processing (imaging, sensor arrays, multimedia), telecommunications, computer networks, microwaves, optics, advanced electronics, VLSI chip design, or an interdisciplinary area such as robotics or bioengineering. Students perform all aspects of project management, such as scheduling, budgeting, system design and developing milestones, as well as technical work including hardware and software implementation, testing and performance evaluation. Students also give several spontaneous and rehearsed oral presentations and prepare written reports. Students attend weekly lectures covering: social, economic, legal and ethical issues; safety and laboratory practice; design methodologies; technical writing; preparation of multimedia presentations and tailoring presentations to target audiences.
4 credits. Prerequisite: ECE 194.

ECE 196 Electrical & Computer Engineering Projects IV
This course concludes the senior project begun in ECE 195. Students submit two complete theses, one in short form and the other in long form, and give at least two presentations, one short and one long. The initial goal is to a achieve a functioning system. Afterwards, students undertake the completion of the prototyping cycle, which may involve improving the circuit implementation (such as by employing PCBs populated with surface mount chips), adding a user-friendly interface, obtaining precise performance evaluations, or developing demonstrations and a user's manual. Advanced students are strongly encouraged to complete their project early and commence a master's thesis.
3 credits. Prerequisite: ECE 195.

ECE 300 Communication Theory
Information theory: entropy, information, channel capacity, rate-distortion functions, theoretical limits to data transmission and compression. Error control coding: block, cyclic and convolutional codes, Viterbi algorithm. Baseband and bandpass signals, signal constellations, noise and channel models. Analog and digital modulation formats (amplitude, phase and frequency), MAP and ML receivers, ISI and equalization. Coherent and non-coherent detection, carrier recovery and synchronization. Performance: computation of SNR, BER, power and bandwidth requirements. TDMA, FDMA, CDMA.
3 credits. Prerequisites: Ma 224 and ECE 111

ECE 302 Probability Models & Stochastic Processes
Topics in probability, random variables and stochastic processes applied to the fields of electrical and computer engineering. Probability, events, random variables, expectation, moments, characteristic functions, conditional probability and expectation. Functions of random variables, random vectors, Gausian random vectors, Poisson points. Bounding and limit theorems. Relations among important distributions and probability models. Stochastic processes: stationarity, ergodicity, Brownian motion, Markov processes. Deterministic systems with stochastic inputs, correlation and power spectral density, ARMA models. Hilbert space and applications: orthogonality principle, discrete Wiener and Kalman filters, linear prediction, lattice filters.
3 credits. Prerequisites: Ma 224 and ECE 300 or ECE 310 or permission of instructor

ECE 303 Communication Networks
Analysis and design of communication networks. Network protocols, architecture, security, privacy, routing and congestion control, Internet, local area networks, wireless networks, multimedia services. Physical layer, multiple access techniques, transport layer. Introduction to probabilistic and stochastic analytic techniques for communication networks.
3 credits. Prerequisites: ECE 150 and Ma 224

ECE 305 Computer Security
This course covers attack and defense perspectives of applied information security. Topics will include networked and embedded applications, access controls systems and their failure modes, privilege escalation, case studies and some applied cryptography. Safe practices and OS flaw mitigation will be reinforced through security-sensitive programming projects. Course work will include penetration testing, code auditing and independent programming projects using professional auditing frameworks.
3 credits. Prerequisite: CS 102

ECE 310 Digital Signal Processing
Review of Laplace and z-transforms. Minimum-phase and all-pass functions. Multidimensional signals, systems and Fourier analysis. Analog filter design, digital IIR and FIR filter design. Sampling, multirate systems and filter banks, A/D and D/A converter models. Discrete-time state-space. Filter structures, quantization effects and design to mitigate quantization effects. DFT and FFT. Spectral analysis of deterministic and random signals. Introduction to adaptive filters. Differential coding, transform coding. Speech, audio and video signals. Extensive use of MATLAB.
3 credits. Prerequisites: Ma 240 and ECE 111

ECE 311 Modern DSP Hardware
Advanced modern digital signal processors—algorithm design and implementation for parallel and reconfigurable hardware platforms. Systems to be studied include FPGAs, multi-core processors, GPUs. HDL, validation and performance evaluation. A wide variety of target applications will be considered, selected according to student and instructor interest.
3 credits. Prerequisites: ECE 310 and ECE 151

ECE 313 Music & Engineering
Spectral representation and analysis of music. Analog and digital music signals, instruments and synthesizers, analog circuits and digital processing. Description of musical quality and perception, introduction to acoustics, stereo and special effects. Computer interfacing with MIDI and laboratory experiments.
3 credits. Prerequisites: ECE 111 and ECE 150

ECE 314 Audio Engineering Projects
An introduction to design, implementation, fabrication and modification of musical and audio electronics and hardware in a laboratory environment. Projects will include analog and digital signal processing for audio signals, with focus on implementation of real-time algorithms in hardware. Additional projects will include design and implementation of electro-mechanical systems and transducers for audio input / output / display. Formal and informal lectures will include examples drawn from standard implementations, safety concerns, audio specific design and construction techniques; participation in oral presentations and technical reports will be required.
3 credits. Prerequisites: ECE 141 and ECE 150, or permission of the instructor

ECE 320 Control Systems
Block and signal-flow diagrams, Mason's theorem. Laplace transform, frequency response, Bode plots, root locus, Routh-Hurwitz array. Analysis of feedback control systems: open-loop and closed-loop gain, Nichols chart, Nyquist diagram, gain and phase margin. Continuous-time state-space analysis, state-variable feedback, canonical forms, observability and controllability. Second-order models, transient and steady-state performance. Emphasis on analog systems, although digital control systems will be discussed as time allows. Extensive use of MATLAB.
3 credits. Prerequisites: Ma 240 and ECE 111

ECE 321 Control Systems Design
Control system design using Bode plots, Nichols chart, root locus. Design by pole placement, Ackermann's formula, state-variable feedback. Cascade compensation, minor-loop feedback. Controller and estimator design, regulator systems, systems with a reference input. Introduction to digital control: hybrid analog-digital control systems, sampled-data systems, digital extensions of Bode plots and root locus, Ragazzini's method. Extensive use of MATLAB.
3 credits. Prerequisite: ECE 320

ECE 323 Embedded System Design
Hardware and software design for embedded systems. SBC and microcontroller architectures, A/D and D/A conversion, signal conditioning, interfacing and controlling electronic and electro-mechanical systems. Assembly language and high-level language programming, efficient use of computational and physical resources, considerations for speed and robustness, debugging methods, use of simulators and in-circuit emulators. The course is project-based, and students are required to design and construct an embedded system.
3 credits. Prerequisites: ECE 320 and ECE 151

ECE 332 Electro-Mechanical Energy Conversion
Analysis of energy sources and energy converters. Principles of electro-mechanical energy conversion; singly and multiply excited systems; rotating and linear machines; three-phase circuits; magnetic circuits and transformers; torque and induced voltage from field considerations; synchronous machines; induction motors; DC machines. Introduction to power electronics. Applications including high-speed transportation, energy storage and interconnection of distant generating stations.
3 credits. Prerequisites: ESC 120 or ECE 140 and Ph 213

ECE 335 Engineering Electromagnetics
This course emphasizes time-varying fields, with topics presented from electrostatics and magnetostatics as necessary. Maxwell's equations, constitutive relations, phasor vector fields, wave and Helmholtz equations, potentials, boundary conditions. Plane waves in lossless and lossy materials, polarization, incidence. Transmission lines: transient analysis, TDR, phasor analysis, standing wave diagrams, Smith chart, impedance matching. Guided waves: TEM, TE and TM modes, dispersion, evanescence, cavity resonators. Microwave network analysis and device characterization with scattering parameters. Antennas, antenna arrays and Fourier optics. Additional topics from microwaves and optics will be covered as time allows. Students use a vector network analyzer to perform measurements at high frequencies.
4 credits. Prerequisites: Ma 223, Ph 213, ECE 140 and ECE 111

ECE 341 Integrated Circuit Engineering
Feedback theory, frequency compensation. Integrated circuit fabrication and technology. Device modeling, thermal effects. VLSI CAD design tools. Circuit layout, extraction and simulation. Design and analysis of multistage MOS operational amplifiers, OTA architectures. Nonlinear circuits, comparators. Analog switches. Digital phase-locked loops. Sample and hold circuits. Data converter architectures. Switched capacitor circuits. Bandgap reference circuits. MOST digital circuit design and layout, hierarchical approaches. Final design project is a mixed analog/digital circuit (e.g., Flash A/D converter, phase-locked loop), which is sent for fabrication.
3 credits. Prerequisite: ECE 142

ECE 343 Bio-instrumentation and Sensing
The basic human vital signs and some related elementary physiology viewed from an engineering standpoint with special emphasis placed upon current electronic measurement methods. Electrocardiographic and electromyographic signals. Safety problems related to electrical isolation. Guarded, fully isolated, modulated carrier operational amplifiers and microvolt-level amplification. Solid-state "grain of wheat" pressure sensors, microelectrodes, thermal probes, ultrasonic transducers and other biosignal sensors. Course work includes instrumentation and sensing projects.
3 credits. Prerequisites: ECE 111 and ECE 142

ECE 357 Computer Operating Systems
Theory and implementation of modern computer operating systems. Message-based and multiprocessor kernels. Networking and interprocess communication. Security, auditing and authentication. Device drivers, interrupt handling, task switching, virtual memory, memory management, scheduling, synchronization and locking. File systems, resource allocation and management. Real-time, fault-tolerant and high security operating systems. User environment and interface issues. Projects in operating system design and programming, case studies.
3 credits. Prerequisites: ECE 151 and ECE 161 or ECE 164

ECE 361 Software Engineering & Large Systems Design
This course teaches about the development stages of large, robust, expandable software systems developed as part of a team. Topics include project management, capturing requirements, system design, UML, program design, testing, delivery and maintenance. The class will develop a large project as a team using Java throughout the semester. Tools, libraries and techniques necessary for the project will be covered in class, e.g., Eclipse, Javadoc, XML, SOAP, servlets, threads and processes, Swing, JUnit, mySQL, JDBC, etc. The specific resources might change from semester to semester.
3 credits. Prerequisite: ECE 165

ECE 391 Research Problem
An elective course open to qualified upper division students. Students may approach an EE faculty member and apply to carry out research on problems of mutual interest in theoretical or applied electrical and computer engineering. Student performs creative work with faculty guidance.
3 credits. Prerequisite: Instructor approval

ECE 392 Research Problem II (continuation of ECE 391)
3 credits. Prerequisite: instructor approval

ECE 399 Selected Topics in Electrical & Computer Engineering
Subjects may include seminars on topics related to advances in technology, current research areas. Also individual research, design and development or study of subjects in electrical and computer engineering.
1-3 credits. Prerequisite: permission of instructor

GRADUATE

ECE 401 Selected Topics in Communication Theory
Advanced topics in communications engineering, selected according to student and instructor interest.
3 credits. Prerequisites: ECE 300 and permission of instructor

ECE 402 Selected Topics in Probability & Stochastic Processes
Advanced topics in applied probability or stochastic processes. Possible areas of study include: Markov processes, queuing theory, information theory, stochastic systems, financial engineering.
1-3 credits. Prerequisite: ECE 302 or permission of instructor

ECE 405 Advanced Digital Communications
Advanced digital modulation including formats with memory, continuous-phase and constant-envelope schemes. Performance analysis for AWGN and other channels. Multitone and multicarrier communications. Spread spectrum with applications to multiple access schemes and secure communications. CDMA: PN sequence generation and properties, multi-user detection. Additional topics as time permits.
3 credits. Prerequisites: ECE 300 and ECE 302

ECE 407 Wireless System Design
Hands-on exposure to the design and implementation of modern digital communication systems using software-defined radio (SDR) technology. The prototyping and real-time experimentation of these systems via SDR will enable greater flexibility in the assessment of design trade-offs as well as the illustration of "real world" operational behavior. Laboratory modules for performance comparisons with quantitative analytical techniques will be conducted in order to reinforce digital communication system design concepts. A large course project consisting of original research will be required. Course topics include SDR architectures and implementations, digital signaling and data transmission analysis in noise, digital receiver structures (matched filtering, correlation), multicarrier communication techniques, radio frequency spectrum sensing and identification (energy detection, matched filtering), and fundamentals of radio resource management.
3 credits. Prerequisites: ECE 300 and ECE 310

ECE 408 Wireless Communications
Survey of cellular mobile radio systems and formats, including market trends and technological advances. The emphasis is on CDMA and 3G systems, and emerging schemes such as WiFi networks, although TDMA systems will be discussed as well. Propagation and multipath fading channel models and simulation. Cellular system capacity, traffic models, multiple-access techniques, handoff and power control algorithms. Modulation formats, detection schemes and performance. Mitigating fading: pulse shaping, DFE, MLSE (Viterbi). DSP algorithms for baseband processing.
3 credits. Prerequisite: ECE 300

ECE 410 Radar & Sensor Array Processing
Terminology and system overview for modern radar and sensor array systems; antenna parameters; radar signals and waveforms; Doppler processing; detection; synthetic aperture imaging (SAR); beamforming and space-time array processing (STAP); adaptive methods; additional topics may be covered according to student and instructor interest. Computer simulations and readings in the technical literature.
3 credits. Prerequisites: ECE 300 and ECE 310

ECE 411 Selected Topics in Signal Processing
Advanced topics in signal processing selected according to student and instructor interest.
3 credits. Prerequisites: ECE 310 and permission of instructor

ECE 412 Speech & Audio Processing
Selected topics in digital speech and audio processing. Speech analysis, synthesis and recognition. Acoustics and acoustic modeling. Auditory perception. Audio feature extraction including complex cepstrum and LPC coefficients. Hidden Markov models and other speech recognition approaches. Speech and audio coding such as MP3 and CELP. Text to speech. Music synthesis, analysis and retrieval.
3 credits. Prerequisites: MA224 and ECE111. Co-requisite: ECE302.

ECE 414 Machine Learning
Machine learning of structural relationships among variables from empirical data. Decision theory, Bayesian methods. Classification: naïve Bayes, linear discriminant analysis, support vector machines (SVM), boosting. Regression: least-squares, regularization methods, logistic regression. Clustering using k-means and EM algorithms. Model selection: bias-variance tradeoff, cross-validation, over-fitting. Feature selection and dimensionality reduction methods including PCA, ICA, MDS. Kernel methods. Other topics may be covered as time permits.
3 credits. Prerequisities: Ma 223, Ma224; either ECE 111, ChE 151 or ESC 161

ECE 415 Wavelets and Multiresolution Imaging (same as MA 415)
Wavelets and multiresolution signal processing with an emphasis on 2D and 3D cases. STFT, wavelet analysis, wavelet packets, DWT. Multirate filter banks, PR and paraunitary conditions, multidimensional filters, multidimensional sampling lattices. Bases, frames and sparse representations. Image and video applications such as: compression, noise reduction, tomography and other inverse problems, hyperspectral imaging, compressive sensing. Course work includes MATLAB projects and readings in the technical literature.
3 credits. Prerequisites: ECE 310 and MA 326 or permission of instructor

ECE 416 Adaptive Filters
Statistical signal processing theory: discrete-time Wiener and Kalman filters, linear prediction, steepest descent and stochastic gradient. LMS, normalized LMS, LS, RLS, QR-RLS, order-recursive algorithms. Applications include equalization, noise cancellation, system identification, sensor array processing. Numerical linear algebra: eigenanalysis, SVD, matrix factorizations. Transversal filters, lattice filters, systolic arrays. Performance: convergence, learning curves, misadjustment, tracking in nonstationary environments. Additional topics such as adaptive IIR filters, neural networks and quantization effects may be covered as time allows. Extensive use of MATLAB.
3 credits. Prerequisite: ECE 111

ECE 417 Design for Custom DSP Hardware
Design of programmable and custom digital signal processors, and realization of DSP algorithms in specialized architectures. Features of programmable DSPs such as data-stationary and time-stationary coding, MAC and ACS ALUs, circular buffers. Very Long Instruction Word (VLIW) processors. Applications of graph theory and passivity theory to map DSP algorithms to custom structures: SFGs, DFGs, retiming, folding and unfolding, lattice and orthogonal filters, scheduling and allocation, systolic architectures. Optimization with respect to number of hardware units, speed (sample period and latency), VLSI area, power consumption and performance (quantization effects). Special CAD tools and languages for rapid prototyping. Case studies and programming exercises.
3 credits. Prerequisites: ECE 310 and ECE 151

ECE 418 Digital Video
Digital video coding, compression, processing and communications. Target applications from low bit-rate, low quality to high bit-rate, high quality. Two- and three-dimensional sampling, color spaces, motion representation. Motion estimation: optical flow, block-matching; constrained optimization: Bayesian methods, simulated annealing, Gibbs random fields. Mathematical basis for compression standards such as JPEG and MPEG, and digital television including HDTV. Rate-distortion based compression for optimal bit allocation via dynamic programming (Viterbi algorithm). Scalability in multimedia systems.
3 credits. Prerequisite: ECE 310

ECE419 Digital Image Processing
This course covers a variety of methods for image representation, analysis, enhancement and compression. Color spaces, geometric projections and transformations. Multidimensional signals and systems: Fourier analysis, sampling, filtering. Transforms (e.g., DCT and wavelet). Gibbs-Markov random fields, Bayesian methods, information theoretic methods. Multiresolution schemes (e.g., pyramidal coding). Morphological and nonlinear methods. Edges, boundaries and segmentation. Applications of PDEs (e.g., anisotropic diffusion). Compressive sensing. Technical readings and projects in MATLAB (or other suitable language).
3 credits. Prerequisites: ECE310 and MA224.

ECE 421 Advanced Control System Design
Design of control systems using two-degrees of freedom and PID compensators. Ackermann's formula, H-infinity control theory and applications. Analysis and design for nonlinear systems using describing function, state-variables, Lyapunov's stability criterion and Popov's method. Introduction to optimal control theory (dynamic programming). Design problems and extensive use of MATLAB.
3 credits. Prerequisites: ECE 310 and either ECE 320 or ME 151

ECE 425 Digital Control Systems
Basic components of digitally controlled dynamic systems. Sampling and reconstruction: the ideal sampler, zero and higher order hold elements. The pulse transfer function and the z-transfer function description of dynamic systems. Stability criterion and analysis by the Nyquist, root locus and Bode methods. The modified Routh-Hurwitz and Jury stability criteria. The state-variable approach: state equations of dynamic systems with sample and hold devices, state equations of systems with all-digital elements. Digital simulation and approximation. Controllability, observability and stability. State and output feedback, state observers and the separation principle. Digital control system design by state feedback.
3 credits. Prerequisite: ECE 320

ECE 431 Microwave Engineering
Passive circuits, open-boundary waveguides, perturbation theory, coupled modes, waveguide junctions, microstrip. Two- and three-terminal devices; varactor diodes, Gunn diodes; IMPATT and MESFET technology. Design of RF amplifiers and phase-shifters. Computer-aided simulation and design.
3 credits. Prerequisite: ECE 335

ECE 433 Optical Communications Devices & Systems
PIN, avalanche and Schottky photodiodes; risetime, noise, amplifier requirements. Semiconductor optical devices: radiative and non-radiative recombination, quaternary semiconductors, heterojunctions, quantum wells, bandwidth minimization, lasers, distributed feedback, vertical cavity structures. Internal and external modulation, electro-optic modulators, Stark effect. Optical fibers: mode structure, attenuation, dispersion, PM fibers, WDM. System architecture, analog/ digital communications, terabit data links. Solitons.
3 credits. Prerequisite: ECE 142; Corequisite: ECE 335

ECE 434 Bioelectricity
Electrical behavior of cellular membranes. Ion transport, electrochemical equilibrium, applications of circuit and cable theory, Hodgkin-Huxley model, resting and action potentials. Generation and propagation of signals within the nervous system and the heart. Case studies and consideration of topics of current research interest, such as: developmental biology, regenerative medicine, neural prostheses, tissue engineering.
3 credits. Prerequisites: ECE 141 or ESC 120, PH 213

ECE 441 Digital Integrated Circuit Engineering
Design of static and dynamic CMOS combinational logic gates, layout and simulation. Standard cell construction. Sequential logic systems—registers, latches, clocks. Design of arithmetic building blocks, ALU, multipliers. Memory circuits and organization. FPGAs. System design—hardware description languages, floorplanning, system architecture. A major component of the course is the design and fabrication of an ASIC using a variety of VLSI CAD tools.
3 credits. Prerequisite: ECE 341

ECE 442 Communication Electronics
Circuit design for advanced communications applications. Design of high-frequency amplifiers, oscillators and mixers using large signal analysis. Effects of noise and non-linearities are examined from the diode and transistor level to board level. Communication subsystems of interest include phase locked loops, modulators and demodulators (AM, PM FM), and signal processors for multiple access systems (TDMA, FDMA, CDMA). Course work includes computer-aided simulation and design projects.
3 credits. Prerequisites: ECE 300, and ECE 142. Corequisite: ECE 335

ECE 443 Thin-Film Electronics
Properties of polycrystalline, amorphous, liquid and organic semiconductors. Methods of deposition: vacuum and nonvacuum techniques, epitaxial and nonepitaxial growth. Assessment of thin film semiconductors: structural, optical, electrical. Thin film semiconductor devices: transistors, displays, photovoltaics, flexible conductors. Optical coatings and architectural applications. Thin film superconductors: metallic, allow and high Tc, fabrication and assessment. Superconducting devices: Cooper pairs, Josephson junctions, SQUIDS, Josephson computers.
3 credits. Prerequisite: ECE 142

ECE 445 Design with Operational Amplifiers
Analysis and design of operational amplifier circuits with various applications, including amplifiers, filters, comparators, signal generators, D/A and A/D converters and phase-locked loops. Introduction to issues such as static and dynamic limitations, noise and stability. Use of industry standard CAD software.
3 credits. Prerequisite: ECE 142

ECE 446 Low-Voltage, Low-Power Electronic Circuit Design
The physics and modeling of submicron MOS transistors for analog and digital circuit design. Circuit techniques for the design of low-power, low-voltage digital combinatorial logic, multipliers, memory and system design. Circuit techniques for the low-power, low-voltage analog circuits including the design of low-voltage constant g_m differential amplifiers. The use of switched capacitor circuits for analog signal processing. The course will culminate with the design and simulation of a low-voltage low-power mixed signal circuit.
3 credits. Prerequisites: ECE 142, ECE 341 or permission of instructor

ECE 453 Advanced Computer Architecture
This course studies modern, advanced techniques used to design and produce current, state-of-the-art computer architectures. Technology, performance and price. The quantitative principle and Amdahl's law. Instruction sets; addressing modes, operands and opcodes; encoding instruction sets. RISC versus CISC architectures; MIPS. Pipelining; the classic five-stage pipeline, hazards, exceptions, floating point operations. Advanced pipelining techniques: dynamic scheduling, branch prediction. Multiple issue, speculation. Limits of parallelism. Compiler support for parallelism, VLIW. Caches. Examination of modern processors.
3 credits. Prerequisite: ECE 151

ECE 460 Selected Topics in Computer Engineering
Advanced topics in computer hardware or software engineering selected according to student and instructor interest. Prerequisites will depend on the topics to be covered.
3 credits. Prerequisite: permission of instructor

ECE 462 Interactive Engineering Graphics
Graphical primitives, windows, clipping and viewports. Two- and three-dimensional geometric transformations and translations; rotation, pan and zoom. Hidden line and surface removal. Region filling and shading. The architecture of high performance graphical engines. Representing lighting, shading and textures. Rendering. Rotation. GUIs. Animation. Course work includes design projects.
3 credits. Prerequisite: ECE 164

ECE 464 Databases
Engineering and design of databases. Topics to be covered may include: data models, database and scheme design; schema normalization and integrity constraints; query processing and optimization; distributed and parallel databases; SQL and XML.
3 credits. Prerequisite: ECE 164

ECE 465 Cloud Computing
Critical, foundational technology components that enable cloud computing, and the engineering advancements that have led to today's ecosystem. Students design, build and test representational software units that implement different distributed computing components. Multi-threaded programming in Java. Functional programming (MapReduce). Hadoop: a programmer's perspective; building and configuring clusters; Flume as an input engine to collect data; Mahout as a machine learning system to perform categorization, classification and recommendation; Zookeeper for systems coordination.
3 credits. Prerequisites: ECE151, ECE164.

ECE 466 Compilers
The theory, design and implementation of a practical compiler. Finite automata, LL and LR parsing, attribute grammars, syntax-directed translation, symbol tables and scopes, type systems and representations, abstract syntax trees, intermediate representation, basic blocks, data and control flow optimizations, assembly language generation including register and instruction selection. Students apply tools such as Flex and Bison to writing a functional compiler for a subset of a real programming language such as C.
3 credits. Prerequisite: ECE 164

ECE 467 Natural Language Processing
This course focuses on computational applications involving the processing of written or spoken human languages. Content may vary from year to year. Theoretical subtopics will likely include word statistics, formal and natural language grammars, computational linguistics, hidden Markov models, and various machine learning methods. Applications covered will likely include information retrieval, information extraction, text categorization, question answering, summarization, machine translation and speech recognition. Course work includes programming projects and tests.
3 credits. Prerequisite: ECE 164

ECE 468 Computer Vision
Visual perception and imaging geometry. Pixels, pixel neighborhoods and pixel connectivity. Image transforms: Fourier, Hadamard, Walsh, Discrete Cosine, Haar, Slant and others. Techniques for image manipulation and enhancement in both the frequency and spatial domains. Histogram equalization, image subtraction and local averaging. Filtering, homomorphic methods.Color models and use of monochrome techniques on RGB channels. Image restoration: camera movement cancellation, scratch removal. Image compression techniques, lossy and lossless. Image segmentation, edge detection, edge linking, boundary detection; region growing, splitting and merging. Image representation as a hierarchical collection of objects, chain codes, Fourier descriptors. Object recognition, signatures.
3 credits. Prerequisites: ECE 111 and ECE 161, or ECE 164

ECE 469 Artificial Intelligence
This course covers many subtopics of AI, focusing on a few important subtopics in detail. The "intelligent agent" approach is explained and forms a foundation for the rest of the course. Intelligent search: uninformed search, depth-first search, breadth-first search, iterative deepening; informed search, best-first search, A*, heuristics, hill climbing; constraint satisfaction problems; intelligent game playing, minimax search, alpha-beta pruning. Machine learning: probability, Bayesian learning; decision trees; statistical machine learning, neural networks, Naive Bayes, k-nearest neighbors, support vector machines. Natural language processing: syntax, semantics and pragmatics; real-world knowledge; parsing; statistical NLP. Philosophy of AI: AI and consciousness, the Turing test, the Chinese room experiment. Coursework includes two large individual programming projects.
3 credits. Prerequisite: ECE 164

ECE 491 Selected Topics in Electrical & Computer Engineering
Subjects may include study in electrical and computer engineering, or seminars on topics related to advances in technology, This course may not be used to expand the number of credits of thesis, or cover material related to the thesis.
1-3 credits. Prerequisite: permission of instructor

ECE 499 Thesis/Project
Master's candidates are required to conduct, under the guidance of a faculty adviser, an original individual investigation of a problem in electrical and computer engineering and to submit a written thesis describing the results of the work.
6 credits over 1 year.

Mechanical Engineering

UNDERGRADUATE

ME 100 Stress and Applied Elasticity
Three-dimensional theory of elasticity; state of stress, state of strain, elastic stress-strain relations. Applications include elementary three-dimensional problems, plane stress and plane strain, Saint Venant's long cylinder, beams and plates. Computer-aided design projects.
3 credits. Prerequisite: ESC 101

ME 101 Mechanical Vibrations
Mechanical systems with single and multiple degrees of freedom; longitudinal, torsional and lateral vibrations; free and forced oscillations; vibration testing, dynamic stability, vibration isolation, design criteria. Computer-aided design assignments.
3 credits. Prerequisites: ESC 101 and Ma 240

ME 105 Drawing and Sketching for Engineers (same as EID 105)
This course introduces engineering students to the fundamentals of free-hand drawing and sketching with an emphasis on the interpretation and communication of insights, concepts and dimensioned solutions. Drawings and sketches are often the first steps in innovative engineering solutions and invention. The primary goal of this course is to provide a comprehensive foundation in traditional drawing and sketching methods for engineers.
2 credits. Prerequisites: none

ME 116 Musical Instrument Design (same as EID 116)
Theory and use of musical scales, including just intonation and equal temperament systems. Musical harmony and basic ear training. Human hearing and the subjective measures of sound: pitch, loudness and timbre. Acoustic analysis of design and operating principles of traditional instruments, including members of the percussion, string and wind families. Prototyping and testing of original musical instrument concepts.
3 credits. Prerequisite: permission of instructor

ME 130 Advanced Thermodynamics
Equations of state; properties of pure substances; ideal and real gas and gas-vapor mixture properties, fundamental process and cycle analysis of ideal and real systems; modern gas and vapor power cycles and refrigeration cycles. Computer applications to problem solving.
3 credits. Prerequisite: ESC 130

ME 131 Energetics (same as EID 131)
Current and near-term energy sources, including coal, oil, natural gas, nuclear fission, hydroelectric, oil shale and refuse. Description of contemporary methods of energy conversion including conventional utility power plants and nuclear power plants. Introduction to direct energy conversion; magneto-hydrodynamics, fuel cells, thermionic and thermoelectric. Design of the thermodynamic operation of a steam power plant.
3 credits. Prerequisite: ESC 130

ME 142 Heat Transfer: Fundamentals and Design Applications
One-dimensional steady-state conduction. Two-dimensional steady-state conduction and transient conduction: finite-difference equations and computational solution methods. Convection; introduction to laminar and turbulent viscous flows; external and internal forced convection problems, including exact and numerical solution techniques; free convection. Introduction to radiation heat transfer and multimode problems. Open-ended design projects will include application to fins, heat exchangers, tube banks and radiation enclosures and will make use of computer-aided design techniques.
3 credits. Prerequisite: ESC 140

ME 151 Feedback Control Systems
Modeling and representation of dynamic physical systems: transfer functions, block diagrams, state equations, and transient response. Principles of feedback control and linear analysis including root locus and frequency response methods. Practical applications and computer simulations using MATLAB. Discussions of ethics will be integrated into the curriculum.
3 credits. Prerequisites: Ma 240 and ESC 161

ME 153 Mechatronics (same as EID 153)
Topics include computer architecture, PIC processor overview, dynamic modeling, sensors, data acquisition, digital PID control theory, and utilization of assembly language to code the controller. Students will design, build and test a controller board and present a final prototype of a control system. Engineering economics will be introduces and integrated into the final project.
3 Credits. Prerequisite: ME 151 or ECE 121 or ChE 152

ME 155 Design and Prototyping
A mechanical engineering hands-on workshop geared towards the understanding and practice of basic engineering design and fabrication tools. Topics include hand tools, simple machining, mold making, casting, materials, fasteners, adhesives, and finishes. 3-D digitizing, solid modeling, rapid prototyping and computer interfacing will also be presented. Team projects will familiarize the students with typical tools and processes employed in realizing a design concept, from sketch to functional prototype. Each student will participate in and contribute to the team-learning and creation process.
2 credits. Prerequisites: EID 101 and EID 103

ME 160 Engineering Experimentation
Selection, calibration and use of subsystems for the measurement of mechanical, thermal/fluid and electrical phenomena. Laboratory work includes investigations of heat exchangers, fluid systems and internal combustion engines. Emphasis is placed on data collection and statistical reduction, computational methods and written and oral presentation skills.
3 credits. Prerequisites: none

ME 163 Mechanical Engineering Projects
Original investigations, involving design and experimental work which allow the application of engineering sciences to the analysis and synthesis of devices or systems and permit the deepening of experience in engineering decision making. Projects are carried out in small groups and are supervised by the instructor in accordance with professional practice.
3 credits. Prerequisite: permission of instructor

ME 164 Capstone Senior ME Design
The application of open-ended design work to the synthesis of engineering devices and systems for the satisfaction of a specified need. Consideration of market requirements, production costs, safety and esthetics. Projects are carried out in small groups and are supervised by the instructor in accordance with professional practice. The goal of the course is to create a working design, clearly defined in drawings and specifications.
3 credits. Prerequisite or corequisite: ME 163

ME 165 Sound and Space (same as EID 165)
Basics of acoustics, including sound waves, room and hall acoustics and metrics of sound. Audio engineering, including microphones, signal processors, amplifiers and loudspeakers. Skills and techniques using Pro Tools brand audio editor system to create original sonic and musical compositions. Public exhibition of an electronic music program.
3 credits. Prerequisite: permission of instructor

ME 312 Manufacture Engineering (same as EID 312)
Study of metal processing theory and application with emphasis on casting, machining, and metal deformation processes; plastic forming; special processing techniques; work-holder design principles. Specific areas studied include stages of processing, mathematical modeling of processes, equipment determination, relationship of plant layout, tooling, metrology, and product design to product cost.
3 credits. Prerequisites: ME 142 and ME 155

ME 322 Fundamentals of Aerodynamics
Study of incompressible potential flow around bodies of aerodynamic interest, by the use of equations of motion, method of singularities and conformal transformation. Investigation of experimental results and techniques. Consideration of the effects of viscosity and transition from laminar to turbulent flow. A design-oriented project, usually involving application of computer methods, will be required.
3 credits. Prerequisite: ESC 140

ME 324 Space Dynamics
Fundamental principles of advanced dynamics; kinematics, transformation or coordinates; particle and rigid body dynamics. Application to space problems; satellite orbits; gyro-dynamics, space vehicle motion; performance and optimization. Generalized theories of mechanics; virtual work, D'Alembert's principle; Lagrange's equation; Hamilton's principle.
3 credits. Prerequisite: ESC 100

ME 330 Internal Combustion Engine Design
A broad analytical and experimental review of the governing parameters involved in piston engine design and optimization. Thermodynamics, fluid mechanics, heat transfer, combustion, emissions, thermochemistry, dynamic and static loading, and fuel efficiency, as they apply to different engine cycles and types, are covered. Varied research examples from industry, government, and academia, with particular emphasis on automotive engine design, are analyzed from first principles. Students develop hands-on learning skills through computational and experimental assignments.
3 credits. Prerequisite: ME 130

ME 336 Design Elements
Application of the principles of mechanics to the design of basic machine elements; study of components subjected to static, impact and fatigue loading; influence of stress concentration; deflection of statically determinate and indeterminate structures by the energy method. Design projects apply basic criteria to the design of shafts, springs, screws and various frictional elements; design projects make use of computer, experimental and modeling techniques.
3 credits. Prerequisite: ME 100

ME 338 Mechanical Design
Mechanical design of basic transmission elements; design optimization by blending fundamental principles and engineering judgment; design criteria for the various frictional machine elements. Design projects provide authentic involvement in problems from industry; design projects make use of computer, experimental and modeling techniques.
3 credits. Prerequisite: ME 336

ME 350 Introduction to Industrial Design
The collaborative relationship between art, engineering and industrial design, academically and professionally, is a pivotal relationship in the development of new ideas. This course serves as an introduction to the world of industrial design and its wide-ranging applications. The students will learn about the history of design and design concepts and methodology through lectures, discussions, and small projects; and will explore, develop, and execute a term design as part of a class project as the course progresses. The main goals of this course are to develop a better understanding of the perspective of an industrial designer and to gain experience in the practice of industrial design.
3 credits. Prerequisite: ME155 or permission of instructor

ME 363-364 Selected Topics in Mechanical Engineering
This course will deal with current technological developments in various fields of mechanical engineering. Projects and design will be emphasized.
3 credits each. Prerequisite: ME faculty permission

ME 365 Mechanical Engineering Research Problem
An elective course available to qualified students. Students may elect to consult with an ME faculty member and apply to carry out independent research on problems of mutual interest in theoretical or applied mechanical engineering.
3 credits. Prerequisites: ME faculty permission and senior standing. May be repeated

GRADUATE

ME 401 Advanced Mechanical Vibrations
Combined analytical and experimental approach to mechanical vibration issues; characterization of the dynamic behavior of a structure in terms of its modal parameters; digital data acquisition and signal processing; experimental modal analysis procedures and excitation techniques; extraction of modal parameters from measured frequency response functions. Students will acquire hands-on experience with impact hammer and shaker data acquisition and analysis.
3 credits. Prerequisite: ME 101

ME 405 Automotive Engineering Fundamentals
An introductory course in modern automotive design, covering aspects of prime movers, aerodynamics, brakes, tires, steering, transmission, suspension and handling, chassis and advanced hybrid powertrain concepts. Simulations and physical prototyping give students a hands-on approach to the design, optimization, fabrication and testing of various vehicle subsystems in a team-based learning environment.
3 credits. Prerequisite: ME 130 or permission of instructor

ME 407 Introduction to Computational Fluid Dynamics
The need for and applications of computational fluid dynamics (CFD). Introduction to CFD analysis and commercially available codes. Governing equations and numerical solution methodologies for basic fluid flow systems. Geometric modeling and grid generation. Examination of various physical models. Use of a commercial CFD code.
3 credits. Prerequisite: ESC 140

ME 408 Introduction to Computer Aided Engineering (CAE)
Theory and practical applications of computer aided engineering methodologies, and use of multiphysics software, in mechanical engineering practices. Topics include principal modeling and solution techniques, computational geometry applications, modeling of mechanical engineering problems, and non-linear and dynamic problem solving. Students use typical commercial software packages to work on practical case studies.
3 credits. Prerequisite: ESC 101

ME 412 Autonomous Mobile Robots
This course introduces basic concepts, technologies, and limitations of autonomous mobile robots. Topics include digital and analog I/O, tactile sensing, IR sensing and range finding, light sensing, sonar, magnetic field sensing, encoders, DC motor actuators, servo motor actuators, high-level microprocessor control, low-level microprocessor control, power management, and prototyping. Students will form teams to design and build autonomous mobile robots configured to compete with each other in a singles-match game, or to perform a team-oriented task.
3 credits. Prerequisite: ME 153 or ECE 151

ME 413 Microelectromechanical Systems (MEMS)
Advances in the design, fabrication, analysis and control of mircoelectromechanical systems (MEMS) have positioned MEMS at the forefront of high-value, cutting-edge technologies. The scope of this course covers both the fundamental and advanced aspects of MEMS. Topics include introduction to MEMS, materials and fabrication processes, sensors and actuators, microfluidics, scaling principles, device concepts and system design. MEMS processing simulation and modeling, testing and packaging of MEMS will also be presented. Furthermore, exposure to basic MEMS processing and cleanroom protocol will be included.
3 credits. Prerequisite: ESC 110 or ESC 110.1

ME 415 Introduction to Nanotechnology
Understanding and control of matter at dimensions in the range from one to 100 nanometers for novel applications are the main objectives of nanotechnology. The scope of this course encompasses nanoscale science and engineering. Typical topics will include the unique properties of some nanometer scale materials, processiong and fabrication technologies for nanomaterials, imaging, measuring, modeling and manipulating matter at this length scale. In addition, laboratory demonstrations on nanomaterials processing, nanoarchitecturing and self-assembling of nanostructures will be included.
3 credits. Prerequisite: ESC 110 or ESC 110.1

ME 430 Thermodynamics of Special Systems (same as EID 430 and ChE 430)
Thermodynamic analyses of solid systems undergoing elastic strain and of magnetic, electric and biological systems. Equations of state for these and other fluid and non-fluid systems. Thermodynamics of low temperature systems. Recent advances in obtaining real fluid and solid properties.
3 credits. Prerequisite: ME 130

ME 432 Introduction to Nuclear Power Plant Technology
Nuclear power provides a high-potential form of alternative energy, with significant safety constraints. The course centers on the study of a typical US commercial nuclear power plant—its design philosophy and analysis of nuclear steam supply system and balance of plant systems (including heat exchangers, pumps, relief valves, etc.) for normal operation and steady state and transient accident analysis, and longer term spent fuel storage. The course utilizes disciplines/methods of thermodynamics, heat transfer and fluid flow, and plant drawings and data. Analysis includes Three Mile Island Accident, a small break loss-of-coolant accident. When feasible, this course includes a tour of an operating nuclear power plant.
3 credits. Prerequisites: ESC 130 and ESC 140

ME 433 Rocket Science (same as ChE 433)
Transient and steady-state control volume balances (mass, momentum and energy) that involve compressible flow phenomena are applied to (primarily) aerospace applications. Fundamental topics include variable mass accelerating control volumes, variable area adiabatic flows, normal and oblique shock waves, expansion fans, friction effects (Fanno flow) and heat transfer effects (Rayleigh flows). Numerical and analytical techniques are developed. Applications include basic trajectories, water rockets, converging/diverging rocket nozzles, RAM and SCRAM jets, supersonic wakes from underexpanded and overexpanded nozzles, gas exchange in reciprocating engines.
3 credits. Prerequisite: ESC130 and ESC140

ME 434 Special Topics In Combustion (same as ChE 434)
Analysis of diffusion and premixed flame processes, including droplet and particle flames, combustion in sprays, chemical reactions in boundary layers, combustion instability in liquid and solid rocket engines and gas burner flames. Consideration of ignition and quenching processes and flammability limits.
3 credits. Prerequisite: ESC 130

ME 440 Advanced Fluid Mechanics (same as EID 440 and ChE 440)
Introduction to the fundamental constitutive relations and conservation laws of fluid mechanics. Steady and transient velocity distributions of viscous flow. Stream functions, potential flow, and creeping flow. Boundary layer theory. Modeling of turbulent flow. Special topics may include: hydrodynamic stability, vorticity dynamics and mixing, waves in fluids, airfoil theory, lubrication theory, compressible flow, multiphase flow, bubbles and droplets, non-Newtonian flow, and computational fluid dynamics.
3 credits. Prerequisites: ESC 140 and permission of instructor

ME 458 Industrial Robots (same as EID 458)
Basic concepts, techniques, and limitations of modern industrial robots; industrial automation; robot programming languages; definition and description of a robot work space; application of transform and operator matrices in industrial robotics. Student projects include computer programming of forward and inverse kinematics, and application programming with an industrial robot.
3 credits. Prerequisite: ME 151 or ECE 320

ME 493-494 Selected Advanced Topics in Mechanical Engineering
These courses will deal with current advanced technological developments in various fields of mechanical engineering. Projects and design will be emphasized.
3 credits. Prerequisites: ME faculty permission and graduate standing

ME 499 Thesis/Project
Master's candidates are required to conduct, under the guidance of a faculty adviser, an original investigation of a problem in mechanical engineering, individually or in a group and to submit a written thesis describing the results of the work.
6 credits for full year.

Chemistry

UNDERGRADUATE

Ch 110 General Chemistry
An introduction to the general scientific principles associated with chemistry. This course will deal with fundamental ideas such as the concept of the atom, the molecule, the mole and their applications to chemical problems. The classical topics include: dimensional analysis and significant figures; atomic weights; periodic properties; chemical reactions and stoichiometry; redox reactions; ideal gas law and real gas equations of state; the liquid state and intermolecular forces; solution concentrations; chemical equilibrium and equilibrium constants; acids and bases; solubility equilibria; nomenclature of inorganic and organic compounds. The topics for atomic and molecular properties include: atomic structure and the quantum theory; electronic structure of atoms; the covalent bond and bond properties; molecular geometries and hybridization; molecular orbital theory.
3 credits. Prerequisites: none

Ch 111 General Chemistry Laboratory
Methods of quantitative analysis are used to explore chemical reactions and analyze unknowns. Modern chemical instrumentation as well as "classic" wet chemistry analytical techniques are covered. Statistical analysis of the experimental data is used to analyze results. Chemical laboratory safety and industrial chemical regulations are covered, as are the fundamentals of writing a technical report.
1.5 credits. Prerequisite: Ch 110; corequisite: Ch 160

Ch 160 Physical Principles of Chemistry
The study of physicochemical properties will be extended and advanced. The laws of thermodynamics, which involve energy, enthalpy, entropy and free energy concepts, will be applied to chemical systems. Other topics include: vapor pressures and colligative properties of solutions; the phase rule; kinetics of homogeneous reactions; electrolytic conductance and electrochemistry.
3 credits. Prerequisite: Ch 110, Ma 111

Ch 231 Organic Chemistry I
Bond types and strengths, structural theory, bond angles and hybrid bonds; covalent bonds, polarity of bonds and molecules; dipole moments; molal refraction; melting points and boiling points relative to properties and natures of molecules; solubilities based on structures; functional groups; critical temperature, pressure and volume as a function of structure and functional groups, prediction of vapor pressure curves, latent heats. Nomenclature isomers and properties. Resonance and delocalization of charge phenomena; acidity and basicity (Lewis concept).
3 credits. Prerequisite: Ch 160

Ch 232 Organic Chemistry II
Extension of Ch 231 to systematic study of aliphatic and aromatic compounds, with emphasis on functional behavior and interpretation of mechanisms and bond types, spectroscopy, carbonyl chemistry, amines, and polymer chemistry.
3 credits (3 lecture hours). Prerequisite: Ch 231; corequisite Ch 233

Ch 232.1 Principles of Organic Chemistry II
Selection of topics from Ch 232. This class meets with Ch 232 for the first ten (10) weeks.
2 credits. Prerequisite: Ch 231; corequisite Ch 233

Ch 233 Organic Chemistry Laboratory
Laboratory work will cover subject matter studied in Ch 231 and Ch 232, including synthesis and type reactions and identification of organic compounds.
2 credits (4 laboratory hours) Prerequisites: Ch 111 and Ch 231

Ch 250 Analytical Chemistry
Fundamental principles, operation, and limitations of instrumental methods in scientific research will be covered. This involves determining the best analytical method for analyses, assessing the reliability of the measurements and understanding the meaning of S/N and how to optimize it. Specific instrumental methods include electroanalytical techniques (potentiometry, coulometry, voltammetry), spectroscopic techniques (infrared, and UV-visible molecular spectroscopy, as well as atomic absorption spectroscopy), microscopy methods (atomic force and scanning tunneling microscopy), and analytical separations (high pressure liquid chromatography and gas chromatography).
3 credits. Prerequisites: Ch 110, Ch 111, or permission of instructor.

Ch 251 Instrumental Analysis Laboratory
Fundamental principles of instrumental methods will be covered, including laboratory applications and limitations in scientific research. Specific methods include electrometric, such as polarography, electro-gravimetry and potentiometry; optical (such as visible and ultraviolet absorption), spectroscopy, emission spectroscopy and infrared spectroscopy; and other techniques such as chromatography and mass spectroscopy shall be included.
2 credits (4 laboratory hours). Prerequisite: Ch 160 and Ch 233

Ch 261 Physical Chemistry I
With an emphasis on the basic theoretical justifications underlying observed physical phenomena, quantum mechanics will be developed and applied to the study of chemical systems with an emphasis on interpreting spectroscopic data. Modern methods of computational molecular modeling are introduced. Statistical mechanics is introduced as a link between quantum mechanics and thermodynamics.
3 credits. Prerequisites: Ch 160 and Ph 214

Ch 262 Physical Chemistry II
Continuation of Ch 261 with emphasis on electrochemistry, chemical kinetics and solid state chemistry. Selected topics.
2 credits. Prerequisite: Ch 261

Ch 340 Biochemistry
This course in the fundamentals of biochemistry will cover the following: Chemistry of carbohydrates, lipids, amino acids, proteins, and nucleotides; bioenergetics; kinetics and mechanisms of enzymes; and an introduction to molecular genetics, and biochemical dynamics of DNA and RNA.
3 credits. Prerequisites: Bio 101 and Ch 231

Ch 370 Inorganic Chemistry
The vast and fascinating chemistry of inorganic compounds and materials will be covered. Atomic structure and the periodic table; molecular symmetry and spectroscopy selection rules; coordination chemistry; ligand-field theory and other electrostatic bonding models; superacids; reaction mechanisms; organometallic chemistry; chemistry of the heavy elements; nuclear chemistry. Chemistry and physics of ionic and molecular solids; atomic and molecular clusters; chemisorption and physisorption of surface-bound species; cage compounds and catalysts; bioinorganic chemistry. A useful course for chemical engineers to extend their knowledge of inorganic chemistry beyond the content of Ch 110. Strongly recommended for students interested in graduate work in chemistry.
3 credits. Prerequisites: Ch 110, Ch 160, Ch 231 and Ch 261

Ch 380 Selected Topics in Chemistry
Study of topics related to specialized areas as well as advanced fundamentals.
2-6 credits. Prerequisite: Chemistry faculty approval required

Ch 391 Research Problem I
An elective course available to any qualified and interested student irrespective of year or major. Students may approach a faculty member and apply to carry out independent research on problems of mutual interest, in pure or applied chemistry. Topics may range from the completely practical to the highly theoretical, and each student is encouraged to do creative work on his or her own with faculty guidance.
3 credits. Prerequisite: permission of research adviser and student's adviser(s)

Ch 392 to 398 Research Problem II to VIII
This is intended to allow students to continue ongoing research.
3 credits each. Prerequisite: permission of research adviser and student's adviser(s)

GRADUATE

Ch 433 Advanced Organic Chemistry (Previously Ch 333, Advanced Organic Chemistry)
Modern areas of organic chemistry, including synthesis, structure determination, stereo-chemistry and conformational analysis, reaction mechanisms, photochemistry, conservation of orbital symmetry, molecular rearrangements and other selected topics. Advanced laboratory studies in research problem form. Typical problems would involve studies of the synthesis, structure and properties of organic compounds, utilizing modern instrumental techniques. Independent laboratory work may be arranged.
3 credits. (4 laboratory hours) Prerequisite: Ch 232

Ch 440 Biochemistry II (continuation of Ch 340)
Discussion of metabolism: Glycolysis, Glycogen Metabolism, Transport through membranes including ATP-Driven Active Transport and Ion Gradient-Driven Active Transport, Citric Acid Cycle, Electron Transport and Oxidative Phosphorylation, Lipid Metabolism including Fatty Acid Oxidation and Biosynthesis, Cholesterol Metabolism, Arachidonate Metabolism: Prostaglandins, Prostacyclins, Thromboxanes and Leukotrienes; DNA Repair and Recombination, Eukaryotic Gene Expression including Chromosome Structure, Genomic Organization, Control of Expression, Cell Differentiation.
3 credits. Prerequisite: Ch 340

Ch 451 Nanomaterials
Nanoscience is the study and manipulation of matter on an atomic and molecular level. At this scale, materials often exhibit new properties that do not exist in their large-scale counterparts because of the increased importance of surface area/ volume ratios and quantum effects. This course will focus on understanding the physical properties and methodologies for the formation (i.e. molecular self-assembly, photolithographic patterning, scanning probe lithography), and characterization (i.e. optical spectroscopy, atomic force microscopy, scanning tunneling microscopy, and electron microscopy) of nanomaterials.
3 credits. Prerequisites: Ch 160, Ch 231, Ch 250, Ch 251, Ch 261 and Ph 213 or instructor's permission

Ch 452 Electrochemistry
Electrochemistry allows the simultaneous recording of kinetic and thermodynamic information about a chemical reaction. This makes it a powerful tool in a wide variety studies. Since the reactions that define electrochemistry only occur within a few nanometers of the electrode's surface, mass transport coefficients and surface properties can be uncovered using electrochemical methods. The course will present the fundamentals electrochemistry, including electrical potentials, standard reduction potentials, batteries, reference electrodes, ion-selective electrodes, ionic mobilities, calculating junction potentials. Modern electrochemical methods, including cyclic voltammetry, electrogravimetry, ultra-microelectrodes and nanoelectrodes.
3 credits. Prerequisites: Ch 231, Ch 250, Ch 251, Ch 262.

Ch 460 Advanced Physical Chemistry (previously Ch 363, Advanced Physical Chemistry)
Modern applications of physical chemistry and chemical physics are developed. Topics covered include: Quantum and classical statistical mechanics, phase space, and fluctuations. Intermolecular forces and their experimental/theoretical determination. Computational molecular modeling, including ab initio, semiempirical and molecular mechanics predictions of molecular properties, as well as Monte Carlo and molecular dynamics methods. Some projects will require computer programming. Applications to liquids, nanoclusters, polymers, surface adsorbates and biomolecules are considered. Guest speakers from academia and industry are invited to share their perspectives.
3 credits. Prerequisites: Ch 261, Ch 262 (or by permission from instructor).

Mathematics

UNDERGRADUATE

Ma 110 Introduction to Linear Algebra
Vectors in two- and three-dimensions, vector algebra, inner product, cross product and applications. Analytic geometry in three dimensions: lines, planes, spheres. Matrix algebra; solution of system of linear equations, determinants, inverses, complex numbers.
2 credits. Prerequisites: none

Ma 111 Calculus I
Functions; limit of functions, continuity. The derivative and its applications: curve sketching, maxima and minima, related rates, velocity and acceleration in one dimension; trigonometric, exponential, logarithmic and hyperbolic functions. Definite and indefinite integrals; area, the fundamental theorem, techniques of integration.
4 credits. Prerequisites: none

Ma 113 Calculus II
Applications of definite integrals: area, volume, improper integrals, work, arc length, surface area, centroid. Polar coordinates. Parametric curves in two and three dimensions: velocity, speed and accelerations. Partial derivatives and the chain rule, properties of the gradient. Maxima and minima. Sequences and series: convergence of sequences and series, Taylor and Maclaurin series, power series.
4 credits. Prerequisite: Ma 111; prerequisite or corequisite: Ma 110

Ma 151.1 Mathematics in Art
This course deals with the period beginning with Pythagoras in ancient Greece and goes up to the present day. Topics include: Goedel's incompleteness theorem. Euclidean and non-Euclidean geometries, infinity, paradoxes, soap film experiments. Also discussed are black holes, the Big-Bang theory, relativity and quantum theory. The course is open to all Cooper Union students but is primarily oriented toward making the above-mentioned concepts comprehensive to those with very little mathematics in their background. Engineering students should see the Mathematics faculty and their adviser(s) for permission to take this course. The relatedness of seemingly distant fields (science, art, mathematics, music) is a central theme of the course.
3 credits. Prerequisites: none

Ma 223 Vector Calculus
Double and triple integrals and their applications. Vector fields. Gradient, divergence and curl. Line and surface integrals. Theorems of Green, Gauss and Stokes. Path independence of line integrals.
2 credits. Prerequisites: Ma 110 and Ma 113. Usually given in fall and spring semesters

Ma 224 Probability
Sample spaces. Random variables. Probability. Distribution and density functions. Expectation. Mean and variance. Moments and generating function. Central limit theorem.
2 credits. Prerequisite: Ma 113; corequisite: Ma 223. Usually given in both fall and spring semesters

Ma 224.1 Probability and Statistics
This course deals with sample spaces, random variables, probability. Distribution and density functions. Expectation. Mean and variance. Moments and generating function. Central limit theorem. Point estimation. Confidence intervals. Hypothesis tests. Chi-square. ANOVA. Estimations, sampling theory.
3 credits. Prerequisite: Ma 113; corequisite Ma 223

Ma 240 Ordinary and Partial Differential Equations
Ordinary differential equations of the first order. Linear equations of higher order with constant coefficients. Power series solutions. Laplace transformation. Fourier series. Partial differential equations: method of separations of variables, applications to vibration and heat flow.
3 credits. Prerequisite: Ma 113

Ma 326 Linear Algebra
Field, vector space, linear independence, subspace, basis, and dimension. Finite-dimensional vector space theory, including linear transformations, rank, matrix representation, coordinate transformation, systems of linear equations, and matrix algebra. Determinants, eigenvalues, and eigenvectors. Inner product space theory, including orthogonal matrices and quadratic forms. Canonical form.
3 credits. Prerequisite: Ma 223

Ma 336 Mathematical Statistics
Statistical central limit theorem. Decision theory. Estimation: properties of estimators, point estimation, confidence intervals. Hypothesis testing: simple and composite hypothesis, Neyman-Pearson lemma, sequential methods, relationship to estimation. Normal distribution tests: t-test, chi-square, F-test. Introduction to non-parametric methods, regression and analysis of variance.
3 credits. Prerequisites: Ma 223 and Ma 224

Ma 337 Operations Research
Linear programming, simplex method, graphs and network theory, dynamic programming, game theory, queues, variational techniques, duality, Markov chains, Monte Carlo simulation, decision theory. Special topics depending on student interest, possibly including language questions, integer programming, nonlinear programming and topics from mathematical biology, econometrics and other applications of mathematics to the sciences and social sciences.
3 credits. Prerequisite: Ma 224

Ma 341 Differential Geometry
Theory of curves and surfaces, curvature, torsion, mean and Gaussian curvatures length, area, geodesics, 1st and 2nd quadratic forms, conformal mapping, minimal surfaces, tensor formulation and applications.
3 credits. Prerequisites: Ma 223 and permission of instructor

Ma 344 Tensor Analysis
Tensor algebra, covariant and contravariant tensors, metric tensors, Christoffel symbols and applications.
3 credits. Prerequisite: Ma 326

Ma 345 Functions of a Complex Variable
Topological properties of complex plane, complex analytic functions, Cauchy-Riemann equations, line integrals, Cauchy's integral theorem and formula. Taylor series, uniform convergence, residues, analytic continuation, conformal mappings and applications.
3 credits. Prerequisite: Ma 223

Ma 347 Modern Algebra
Sets and mappings, the integers: well ordering, induction residue class arithmetic, Euler-Fermat theorems. Permutation groups: cyclic decompositions. transpositions, conjugate classes of permutations. Abstract groups: morphisms, subgroups, cyclic groups, coset decompositions. Factor and isomorphism theorems. Direct products of groups. Sylow's theorems.
3 credits. Prerequisite: Ma 326

Ma 350 Mathematical Analysis I
Sets and functions, topological properties of real line, continuity and uniform continuity, differentiability, mean value theorems, the Riemann-Stieltjes integral and Taylor's theorem. Metric spaces, connected and compact sets, uniform convergence.
3 credits. Prerequisite: Ma 223

Ma 351 Mathematical Analysis II
Uniform convergence. Differentitation of transformations, inverse and implicit function theorems. Introduction to measure and integration theory. Applications to geometry and analysis.
3 credits. Prerequisite: Ma 350

Ma 352 Discrete Mathematics
Relations. Mathematical structures. Number theory. Algorithms. Complexity of algorithms. Cryptology. Recurrence relations. Graph theory. A shortest-path algorithm. Planar graphs. Trees. A maximal flow algorithm. Finite-state automata. Languages and grammars. Turing machines. The Church-Turing thesis. Unsolvable problems.
3 credits. Prerequisite: Ma 110

Ma 370 Selected Topics in Mathematics
This is a seminar course involving discussion of topics in pure or applied mathematics that will be chosen by mutual agreement between the students and the instructor. Students will work independently on projects that may be of special interest to them.
3 credits. Prerequisites: Ma 326 and permission of the mathematics faculty

Ma 381 Seminar
Individual investigation of selected topics in pure or applied mathematics, centered on a subject to be agreed on between students and the faculty leader. Emphasis will be on training in independent reading of mathematical literature, oral presentations and group discussions of the theory and problems.
Credits and class hours to be determined by faculty on individual basis. Prerequisite: Ma 223

Ma 382 Seminar
(continuation of Ma 381)
Credits to be determined by faculty on individual basis. Prerequisite: Ma 381

Ma 391 Research Problem 1
An elective course available to qualified upper division students. Students may approach a faculty member and apply to carry out independent research on problems of mutual interest in pure or applied mathematics. Each student is encouraged to do independent creative work with faculty guidance.
3 credits. Prerequisites: Ma 240 and permission of research adviser

Ma 392 Research Problem 2
(Continuation of Ma 391)
This is intended to allow students to continue ongoing research.
3 credits. Prerequisites: Ma 391 and permission of research adviser

GRADUATE

Ma 401 Boundary Value Problems
Orthogonal polynomials, Fourier series; properties of Legendre polynomials and Bessel functions. Applications to the wave equation and the differential equations of heat transfer in several dimensions.
3 credits. Prerequisites: Ma 223 and Ma 240

Ma 402 Numerical Analysis
Techniques for the solutions of ordinary and partial differential equations, the classical problems of linear algebra, integration and systems of nonlinear equations. Error analysis, convergence and stability theory. Course assignments will include use of computing facilities.
3 credits. Prerequisites: Ma 223 and Ma 240

Ma 403 Special Topics in Applied Mathematics
Introduction to the general theory of partial differential equations; existence and uniqueness of solutions; integral equations; computational techniques using finite-element and probabilistic methods. Other current topics in engineering may be included also.
3 credits. Prerequisites: Ma 223 and Ma 240

Ma 415 Wavelets and Multiresolution Imaging
(same as ECE 415)
3 credits. Prerequisites: ECE 114 and Ma 326 or permission of instructor

Ma 417 Mathematics of Medical Imaging
Mathematical basis for various medical imaging methods including CT, MRI, PET. Radon transform, tomography (recovery from projections), inverse problems, artifacts and noise. Mathematical physics of related topics such as wave propagation, signal generation and detection, quantum mechanics.
3 credits. Prerequisites: Ma 240, Ma 326 or permission of instructor

Ma 470 Selected Advanced Topics in Mathematics
Selected topics in Mathematics treated at an advanced level.
Credits to be determined by Mathematics faculty. Prerequisites: Ma 326 and permission of faculty member

Physics

UNDERGRADUATE

Ph 112 Physics I: Mechanics
Static equilibrium, kinematics, Newton's Law's, non-inertial frames of reference, system of particles, work and energy, linear and angular momentum, rigid body motion, conservation laws, oscillation.
4 credits. Prerequisites: Ma 110, Ma 111; corequisite: Ma 113

Ph 165 Concepts of Physics I
An introduction to physics with an emphasis on statics and dynamics.
2 credits. Cannot be used to satisfy any degree requirement in the School of Engineering

Ph 166 Concepts of Physics II (continuation of Ph 165)
Additional topics include optics, waves and an introduction to structural analysis.
2 credits. Prerequisite: Ph 165. Cannot be used to satisfy any degree requirement in the School of Engineering.

Ph 213 Physics II: Electromagnetic Phenomena
Oscillations; transverse and longitudinal waves. Electric fields; Gauss' Law; electric potential; capacitance; D.C. circuits; magnetic fields; Faraday's law; inductance; A.C. circuits; electromagnetic waves.
4 credits. Prerequisite: Ph 112; corequisite: Ma 223

Ph 214 Physics III: Optics and Modern Physics
Geometric and physical optics. Special theory of relativity. The quantum theory of light. The quantum theory of matter. Atomic structure. Nuclear structure and radioactivity.
3 credits. Prerequisite: Ph 213

Ph 215 Microcontroller Projects in Physics
This course will introduce students to the Arduino prototyping platform, diverse sensors and output devices that may be interfaced to the Arduino, and the programming languages ("Arduino" and "Processing") required for stand-alone operation or interaction with an attached PC. A typical project will involve developing hardware and associated software that requires the study of, and ultimately illustrates, basic physics principles—for example, the construction of a self-focusing telescope. Ideally, student projects will be integrated into the physics lecture courses as demonstration apparatus. The basics of circuit theory that are required for this course will be taught

to those who have not yet completed Ph 213. (Students need not be skilled programmers or have any prior knowledge of circuits for this course.)
3 credits. Prerequisites: CS102, Ph112, and permission of instructor

Ph 235 Physics Simulations
Students will be taught how to numerically solve ordinary differential equations using 4th order techniques such as *Runge-Kutta* and *Adams-Bashforth-Moulton* in the Python programming language. These techniques will be used to solve diverse physics problems not amenable to simple analytical solution, such as n-body gravitational motion, the motion of charged particles in a magnetic bottle, the behavior of a car's suspension on a bumpy road. Emphasis is placed on physically accurate modeling (e.g. satisfying conservation laws to high accuracy) and the effective use of computer graphics/animation for the presentation of results. (Students need not have significant programming experience for this course.)
3 credits. Prerequisites: CS102, Ph112, Ma113, and permission of instructor

Ph 291 Introductory Physics Laboratory
Physical measurements and analysis of experimental data. The experiments test and apply some basic principles selected from the following fields: mechanics, sound, electromagnetism, optics and modern physics. Experiments and topics may vary each semester. Digital and analog laboratory instruments; computer acquisition and analysis of data. Estimate of systematic and random error, propagation of error, interpretation of results. This course complements three lecture courses, Ph 112, Ph 213, Ph 214.
1.5 credits. Prerequisite: Ph 112; corequisites: Ph 213

Ph 327 Topics in Modern Physics
Seminar course with student participation in several topics of current interest in experimental and theoretical science.
3 credits. Prerequisite: Ph 214

Ph 328 Relativity and Electrodynamics
Introduction to tensors; formulation of electromagnetic theory. Special and general theories of relativity. Topics include space time transformations, electromagnetic stress-energy momentum tensor, four space curvature and gravitational field equations, description of basic experiments, gravitational waves, cosmological models.
2 credits. Prerequisite: PH 214

Ph 346 Quantum Physics of Solids
Why do silicon, calcite and copper have very different properties even though they have similar densities of electrons? The answer is quantum mechanics and its application to band theory. Band theory provides some of the most direct tests of quantum mechanics. The course will develop the theory to explain thermal and electrical properties of everyday materials. We shall see how quantum mechanics and Fermi statistics successfully explained these properties when classical physics could not. The course will provide the concepts and quantum mechanical training needed to understand, for example, the workings of semiconductor devices. It will also provide theoretical understandings of material properties like thermal and electrical conductivity, optical reflection and transmission coefficients that you have seen in mechanics, E&M and modern physics. Topics covered will include: Drude and Sommerfield Models; Bloch's Theorem and periodic potentials; the nearly free electron model; tight binding model; band structures; semiconductors and insulators; band structure engineering. The mathematics required to understand the concepts will be developed as we go through the topics.
3 credits. Prerequisites: Ph 112, Ph 213, and Ph 214

Ph 360 Special Projects in Physics
Special projects in experimental or theoretical physics.
Credits and prerequisites determined in each case by the physics faculty.

GRADUATE

Ph 429 Deterministic Chaos with Engineering Applications
A simple mathematical formalism explains how a nonlinear system with no random element may be intrinsically unpredictable even when its governing equations are known. The mathematics of chaos (including fractals) will be presented, with applications drawn from mechanical, biological, chemical processes; the weather; electric circuits; lasers; general relativity; models of war; the economy; the spread of epidemics, etc.
3 credits. Prerequisites: Ph 214, Ma 113 (Ma 240 preferred) and CS 102

Biology

Bio 101 Biology for Engineers I
This course will examine in depth the genetics, molecular and cellular biology, pathology, toxins, microbiology and environment as they relate to humans and disease using organ-based or systems biology approaches (e.g., gastro-intestinal pulmonary, cardiovascular, urinary endocrine, etc.) Major assignments will be individualized to student's interests and majors when possible. As such, this course will provide the biological fundamentals for further study in biotransport, biochemistry, graduate school in biomedical engineering, etc. Combined with Biology 102 and Biochemistry, it will provide a solid foundation for medical school.
3 credits (includes lab experience). Prerequisites: Ch 110 and Ch 160 or permission of instructor

Bio 102 Biology for Engineers II
This course will provide human biology fundamentals to springboard into research projects at the intersection of biology and engineering Topics will include anatomy and physiology of musculoskeletal and other major organ systems not covered in Bio 101, imaging modalities, concepts behind diagnostic and therapeutic surgical procedures, and their limitations, human body repair, artificial organs, tissue engineering, immunology and cancer. Students will develop an extensive biological vocabulary and have requisite knowledge for further study in biomechanics, rehabilitation medicine, biomaterials, bioremediation, etc.
3 credits. Prerequisite: Sophomore standing preferred, but freshman with AP Biology welcome

Computer Science

CS 102 Introduction to Computer Science
Introduction to Engineering Problem Solving using algorithms and their design. Logics and basic analysis techniques are explored using programming languages C and Python. Students will also master one or more significant engineering design packages such as MATLAB, AUTOCAD, Solid Works, etc. Projects will be assigned.
3 credits. Prerequisites: none

Engineering Sciences

ESC 000.1–000.4 Engineering Professional Development Seminars
The Engineering Professional Seminars and Workshops offer students an introduction to the profession of engineering as well as aspects of their development as students. The Cooper Union's CONNECT program is an integral part of these courses and provides intensive training in effective communications skills. Additionally, a wide range of topics is covered including ethics, environmental awareness, lifelong learning, career development, interpersonal skills, work-place issues, and professional licensure.
0 credits. Attendance required by all first and second year students. Pass/Fail grade based on attendance. Failing grade does not affect GPA or ability to graduate and does not appear on the final transcript. Successful completion will be noted on the final transcript.

ESC 100 Engineering Mechanics
Equivalent system of forces, distributed forces; forces in structure; friction forces. Particle and rigid body mechanics; kinematics, kinetics. Newton's laws of motion; work and energy; impulse and momentum.
3 credits. Prerequisite: Ph 112

ESC 101 Mechanics of Materials
Introduction to solid mechanics; analysis of stress and deformation. Extension; flexure; torsion. Axisymmetric problems, beam theory elastic stability, yield and failure theory.
3 credits. Prerequisite: ESC 100

ESC 110 Materials Science
The objective of this course is to promote an understanding of the relationship between the molecular structure of a material and its physical properties. Topics include bonding in atoms and molecules, crystallinity, metals and alloys, polymers, mechanical properties of inorganic materials and composite materials.
3 credits. Prerequisites: none

ESC 110.1 Materials Science for Chemical Engineers
Understanding relationships among atomic or molecular structures, physical properties and performances of substances. Bonding, crystallinity, metals, alloys and polymers. Mechanical properties of inorganic and composite materials. Selection of materials for process equipment design, its effect on economics. Design concerning effect of corrosion and its prevention.
3 credits.

ESC 120 Principles of Electrical Engineering
Survey of Electrical Engineering for the non-major. Signal and circuit analysis, DC and AC circuits, transients, frequency response and filters, power systems. Additional topics may be covered as time permits.
3 credits. Prerequisite: Ma 113

ESC 121 Basic Principles of Electrical Engineering
Selection of topics from ESC 120. This class meets with ESC 120 for the first ten (10) weeks.
2 credits. Prerequisite: Ma 113

ESC 130 Engineering Thermodynamics I
Rigorous development of the basic principles of classical thermodynamics. Zeroth, first and second laws of thermo-dynamics and their applications to open and closed systems. Analysis of thermodynamic processes, properties of real substances and thermodynamic diagrams.
3 credits. Prerequisites: none

ESC 140 Fluid Mechanics and Flow Systems
Introductory concepts of fluid mechanics and fluid statics. Development and applications of differential forms of basic equations. Dynamics of inviscid and viscous fluids, flow measurement and dimensional analysis with applications in fluid dynamics. Friction loss and friction factor correlation; design of piping systems.
3 credits. Prerequisites: none

ESC 161 Systems Engineering
An introductory course to the mathematical modeling of systems. Topics include mechanical elements and systems, electric circuits and analogous systems, fluid elements and systems, analysis of systems using transfer functions, state space equations, analog simulation and digital simulation. Also covered are block diagrams, Laplace transforms, and linear system analysis. Computer projects will be assigned that will use MATLAB software.
3 credits. Prerequisites: none

Interdisciplinary Engineering

UNDERGRADUATE

EID 101 Engineering Design and Problem Solving
Students work on cutting-edge, exploratory design projects in inter-disciplinary groups of 20 to 25. Each project has an industrial sponsor/partner who is available for student/faculty consultation and support. Oral and visual presentations as well as formal written reports are required for all projects. Professional competencies, teamwork, human values and social concerns are stressed in the engineering design.
3 credits. Prerequisites: none

EID 103 Principles of Design
This course is designed to introduce students from all disciplines to the concepts of rational design. It is open to first-year students and sophomores. In the first part of the course students will learn by hands-on experience the importance of giving attention at the design stage to consideration of accessibility, repair, replacement, choice of materials, recycling, safety, etc. Students will develop the ability to make observations and record them in suitable form for further analysis of the design process. From this, concepts of "good" design will be developed, and students will be introduced to the formal design axioms and principles. This will lead to the second part of the course which will consist of a comprehensive, realistic design problem. Creativity, intuition and cultivation of engineering "common sense" will be fostered within the framework of design principles and axioms. The course will constitute a direct introduction to the disciplines in their interdisciplinary context.
3 credits. Prerequisite: EID 101

EID 105 Drawing and Sketching for Engineers (same as ME 105)
2 credits. Prerequisites: none

EID 110 Engineering Design Graphics
This course is for students who are well versed in basic AutoCAD and want to develop their 3D modeling skills plus learn how to customize the system. Course work includes writing custom AutoCAD menus and programs that are useful for the various engineering disciplines, using the Lisp programming language. Students will be given a number of 3D modeling assignments throughout the semester, building up to a final term project that utilizes their 3D modeling skills as well as their programming and customization knowledge.
3 credits. Prerequisite: permission of instructor

EID 116 Musical Instrument Design (same as ME 116)
3 credits. Prerequisite: permission of instructor

EID 120 Foundations of Bioengineering
An introduction to the engineering study of biological systems. Basic physiochemical and organization principles applicable to biological systems. Topics include membrane structure and function, physiology of the circulatory system, and an introduction to biorheology and biological transport phenomena.
3 credits. Prerequisite: Ch 160

EID 121 Biotransport Phenomena
Engineering principles are used to mathematically model momentum, heat and mass transfer processes that occur in biological systems. After a general introduction to human anatomy and physiology, topics examined include blood rheology, circulatory system fluid dynamics, whole body heat transfer, vascular heat transfer, oxygen transport in tissue and blood, pharmacokinetics and the design of an artificial kidney (hemodialysis).
3 credits. Prerequisite: junior standing

EID 122 Biomaterials
A study of both natural and synthetic materials, especially those for orthopaedic applications. Mechanical properties, design considerations, bio-compatibility, potential for allergic response and carcinogenic ramifications, mechanical compatibility and effects of long-term implantation. Metallics, ceramics and polymers. Relative advantages and disadvantages of various materials. Materials for cardiovascular applications. Corrosion and chemical degradation.
3 credits. Prerequisite: permission of instructor

EID 124 Injury Biomechanics and Safety Design
Frequency and severity of common injuries. Mechanisms of musculoskeletal, soft tissue and brain injuries. Injury criteria, reference values and their role in safety design. Experimental and computational methods for safety design and accident reconstruction. Automotive safety. Biomechanical test dummies. Seatbelts, airbags, and energy absorbing structures and materials. Repetitive stress injuries and occupational health. Government regulation and legal liability. Expert witness practice and qualifications.
3 credits. Prerequisites: ESC 100 and ESC 110

EID 125 Biomechanics
An in-depth treatment of orthopaedic biomechanics, including freebody analysis applied to the musculoskeletal system, applied statics, dynamics and kinematics. Clinical problems relating to biomechanics. Lubrication theory applied to hard and soft tissues. Mechanical testing of tissue, including both static tests and dynamics tests. Tensor treatment of kinematic motions. Extensive reference to current literature. Muscle function, evaluation and testing. Exploration of the concepts of development of muscular power, work and fatigue.
3 credits. Permission of instructor

EID 131 Energetics (same as ME 131)
3 credits. Prerequisite: ESC 130

EID 140 Environmental Systems Engineering (same as CE 141)
3 credits. Prerequisite: permission of instructor

EID 142 Water Resources Engineering (same as CE 142)
4.5 credits (3 hours of lecture, 3 hours of laboratory). Prerequisite: ESC 140

EID 153 Mechatronics (same as ME 153)
3 Credits. Prerequisite: ME 151 or ECE 121 or ChE 152

EID 160 Acoustics, Noise and Vibration Control
Interdisciplinary overview of acoustics and its applications in industrial and environmental noise control, acoustics of buildings, vibration systems and control. Topics include: sound levels, decibels and directivity, hearing, hearing loss and psychological effect of noise, noise control criteria and regulations, instrumentation, source of noise, room acoustics, acoustics of walls, enclosures and barriers, acoustics materials and structures, vibration control systems; design projects.
3 credits. Prerequisite: permission of instructor

EID 165 Sound and Space (same as ME 165)
3 credits. Prerequisite: permission of instructor

EID 170 Engineering Economy
Comparison of alternatives in monetary terms; meaning and use of interest rates; results evaluation including intangibles; risk in alternatives; principles underlying the determination of economic life; depreciation and depreciation accounting; financing business ventures; financial statement analysis; replacement of capital assets.
3 credits. Prerequisite: Ma 113

EID 176 Legal and Ethical Aspects of Engineering
A survey of the courts and their jurisdiction; civil and criminal law; equity jurisprudence; expert witness, contracts and the importance of business law to the engineer. Other topics include patents, trademarks and copyrights; product liability; unfair competition; professional ethics and professional advancement.
3 credits. Prerequisites: none

EID 300 Special Research Project
Students will work on individual projects in engineering under supervision of faculty. Problems will vary according to individual interest. permission to register is required from the Office of the Dean of Engineering. Students on academic probation are ineligible for registration.
3–6 credits. Prerequisite: permission of faculty and dean's office

EID 312 Manufacturing Engineering (same as ME 312)
3 credits. Prerequisite: EID 101

EID 320 Special Topics in Bioengineering
Seminars on topics of current interest in biotechnology.
3 credits. Prerequisites: a basic understanding of engineering mechanics and materials and permission of instructor. May be repeated

EID 325 Science and Application of Bioengineering Technology
The overall purpose of the course is to provide the student with a general overview of the scope of bio-engineering. The major areas in the course are design in biomedical engineering, tissue engineering, medical imaging, cardiovascular, vision, rehabilitation, masculaskeletal system, robotic surgery and medical business.
3 credits. Prerequisite: permission of instructor

EID 327 Tissue Engineering
Tissue Engineering involves the application of engineering and the life sciences to gain a fundamental understanding of structure-function relationships in normal and pathological tissues and the development of biological substitutes to restore, maintain or improve tissue functions. This course will provide an introduction to the science, methods and applications of tissue engineering. Topics include quantitative cell biology, tissue characterization, engineering design and clinical implementation.
3 credits. Prerequisites: working knowledge of engineering fundamentals, senior standing or instructor approval

EID 357 Sustainable Engineering and Development
Sustainable engineering is examined, starting with an analysis of resources, (materials, energy, water) upon which manufacturing is based. Each resource is critically examined in terms of its availability and form and the ultimate impact of its usage on the state of the planet. A comparison of the design and construction of contemporary and primitive structure is used to illustrate the differences between the required infrastructure and environmental footprint, leading to a definition of "green" design. The technologies required to support contemporary lifestyles in the developed and the developing world are discussed within the context of manufacturing techniques, usage of natural resources and the generation of waste. Workshops, guest lectures and a term project incorporating the concepts of minimalism, materials usage, and aesthetic design are used to present students with a unique perspective engineering.
3 credits. Prerequisite: material covered in core engineering science and mathematics in Freshman and Sophomore years

EID 362 Interdisciplinary Senior Project I
Individual or group design projects in interdisciplinary areas of engineering. These projects are based on the interest of the students and must have the approval of their adviser(s) and course instructor. Periodic and final engineering reports and formal presentations are required for all projects. In addition to technical aspects projects must also address some of the following: economic feasibility environmental impact social impact, ethics, reliability and safety.
3 or 4 credits. Prerequisite: students are required to have completed necessary preparatory engineering courses related to the project topic

EID 363 Interdisciplinary Senior Project II (continuation of EID 362)
3 or 4 credits. Prerequisite: EID 362

EID 364 Interdisciplinary Engineering Research Problem
An elective course, available to qualified upper division students. Students may approach a faculty mentor and apply to carry out independent or group projects in interdisciplinary fields.
3 credits. Prerequisite: permission of adviser(s)

EID 365 Engineering and Entrepreneurship
Students will learn the fundamentals of being an entrepreneur and operating a successful business. From its original idea to the open market, students will choose an engineering related project or service and learn the principles of accounting, marketing, managing, financing, and continuing research. Students are required to choose their own service or product and write a business plan as their final project. Lectures include case studies on the various projects and guest speakers from the industry. Readings include articles from journals and textbooks.
3 credits. Prerequisite: EID 101

EID 370 Engineering Management
An exploration of the theories and techniques of management beginning with the classical models of management and continuing through to Japanese and American contemporary models. The course is specifically directed to those circumstances and techniques appropriate to the management of engineering. Lecture, discussion and case studies will be used.
3 credits. Prerequisite: permission of instructor

EID 372 Global Perspectives in Technology Management
Current global political, social and economic developments and future trends as they relate to technology management are discussed. Students learn to address issues of international technology transfer, multinational sourcing, quality control, diverse staff management, environmental considerations, etc. Working in teams on case studies and projects, students learn to conduct international negotiations and develop solutions to complex business problems. Special emphasis is placed on team cooperation and personal leadership. Oral presentations and written reports are required.
3 credits. Prerequisite: EID 101

EID 373 Patent Law
In this course a student will study patent law in detail: the requirements for obtaining a patent ("utility, novelty and non-obviousness"); "trade secrets" as an alternative to patent protection; computer software and "business methods" as patentable subject matter. The class will focus on the theoretical (patent cases from the U.S. Supreme Court and the Federal Court, the patent statute, 35 U.S.C.) and the practical (analysis of issued patents; individual and group exercises in drafting and critiquing patent claims, familiarity with the Manual of Patent Examining Procedure). The course is open to juniors, seniors, graduate students and faculty.
3 credits. Prerequisite: permission of instructor

EID 374 Business Economics
In this course, the class will carry out a real-time forecast of the U.S. economy and explore its implications for the bond and stock markets. The course will build upon principles of both macro- and micro-economics. It will provide an introduction to the work done by business economists and the techniques they use. Students will become familiar with the database looking for relationships between key economic variables, and studying movements in interest rates over the period 1960-present. The class will be divided into teams of two students with each team choosing a particular aspect of the economy to forecast. The class will also work with various leading indicators of economic activity and will prepare forecasts of the key components of gross domestic product and other important variables. A formal presentation of the economic with invited guests from the Wall Street investment world will take place. To put forecasting exercise in context, there will be class discussions of business cycles, credit cycles, long waves in inflation and interest rates and the impact of the Internet on the economy and the stock market.
3 credits. Prerequisite: either S 334, S 347, EID 170 or permission of instructor

EID 376 Economics of Alternative Energy
The goal of this course is to explore the economics of alternative energy technologies. As always, engineering considerations determine the feasibility of any technology while economics determine the practicality of the technology in the likely environment of the next five years. The students participating in this course will explore a wide range of alternative energy technologies. It is expected that their analyses will combine both economic and engineering principles in an interesting and creative way. Each student will choose a particular technology to analyze in depth: wind, solar-photovoltaic, passive solar, geothermal, bio-fuels, etc. There will be periodic presentations of their work to the class as a whole. One goal of these class discussions will be to highlight the advantages and disadvantages of the various technologies. At the end of the semester, there will be a formal presentation of the students' conclusions to an audience of Cooper faculty, industry experts and Wall Street analysts.
3 credits. Prerequisite: EID 170, EID 374, or permission of the instructor

GRADUATE

EID 414 Solid Waste Management (same as CE 414)
3 credits. Prerequisite: permission of instructor

EID 422 Finite Element Methods (same as CE 422)
3 credits. Prerequisite: CE 122 or ME 100

EID 424 Bioengineering Applications in Sports Medicine
Application of engineering principles to athletic performance and injury. Topics include athletic training; mechanical causes of sport injuries; methods of injury prevention; design of protective and prophylactic sport devices; proper application of wound dressing, taping and bandaging; first aid for musculoskeletal sports injuries and healing and rehabilitation. Students will work in teams on case studies and projects.
3 credits. Prerequisite: permission of instructor

EID 425 Structural Dynamics (same as CE 425)
3 credits. Prerequisite: CE 122

EID 430 Thermodynamics of Special Systems (same as ChE 430 and ME 430)
3 credits. Prerequisite: ChE 131 or ME 130

EID 438 Industrial Waste Treatment Design (same as CE 440)
3 credits. Prerequisite: permission of instructor

EID 439 Water and Wastewater Technology (same as CE 441)
3 credits. Prerequisite: permission of instructor

EID 440 Advanced Fluid Mechanics (same as ChE 440 and ME 440)
3 credits. Prerequisite: ESC 140

EID 441 Advanced Heat and Mass Transfer (same as ChE 441)
3 credits. Prerequisite: EID 440 or ChE 440

EID 446 Pollution Prevention or Minimization (same as CE 446)
3 credits. Prerequisite: permission of instructor

EID 447 Sustainablitiy and Pollution Prevention (same as ChE 447)
3 credits. Prerequisite: permission of instructor

EID 448 Environmental and Sanitary Engineering (same as CE 448)
3 credits. Prerequisite: permission of instructor

EID 449 Hazardous Waste Management (same as CE 449)
3 credits. Prerequisite: permission of instructor

EID 458 Industrial Robots (same as ME 458)
3 credits. Prerequisite: ME 151

EID 470 Urban Security (same as CE 470)
3 credits. Prerequisites: CE 122 or ME 101 and permission of instructor

EID 488 Convex Optimization Techniques (same as ChE 488)
3 credits. Prerequisites: ChE 151 or ESC 161, Ma 326 (co-enrollment is fine) and permission of instructor

FACULTY

Administration

Richard J. Stock
Acting Dean, Albert Nerken School of Engineering

Anita Raja,
Associate Dean of Research and Graduate Programs

George J. Delagrammatikas
Program Director, STEM/Outreach

Kukuwa Adofo-Mensah
Budget Manager

Victoria Bill
Student Programs Coordinator

Christopher Lent
Director of Academic Computing
Assistant to the Dean for Student Advisement

Gerardo del Cerro, *Director, Assessment and Evaluation*

Daria Sapienza
Administrative Associate to the Dean

Maureen Deol, *Secretary, Electrical Engineering, Mathematics and Physics Faculties*

Elizabeth Leon, *Secretary, Chemical Engineering and Chemistry Faculties*

Maria Jimenez, *Secretary, Civil and Mechanical Engineering Faculties*

Department of Information Technology

Robert P. Hopkins
Chief Technology Officer and Director of the Computer Center; Associate Professor of Mathematics

Gearoid Dolan, *Director, Computer Studio; Senior Academic Associate (Art)*

Jeff Hakner,
Director of Telecommunications

Ian Hochstead, *Information Technology Support Specialist*

John A. Kibbe,
Director of Administrative Systems

Christopher Lent,
Director of Academic Computing

Paul Tummolo, *Director, Multimedia*

Wayne Adams,
Academic Support Specialist

Craig Branum,
Academic Support Specialist

Dennis Delgado,
Academic Support Specialistt

Bernie Brandell,
Audio-Visual Technician

John Enxuto,
Academic Support Specialist

Sara Foley,
Senior Audio-Visual Technician

Joyce Lee,
Academic Support Specialist

Marget Long,
Academic Support Specialist

Lawrence Mesich,
Academic Support Specialist

Keith Ng, *Senior Systems/Software Engineer*

C.V. Starr Research Foundation
Yashodhan C. Risbud, *Director*
Robert Dell, *Reasearch Fellow*
Sarah Lerner, *Secretary Assistant*

The Aba and Leja Lefkowitz Program for Professional Development

Richard Stock, *Director, CONNECT Program*
Coordinator for Professional Development Seminar

John Osburn, *Associate Director CONNECT Program*

Professors

Om Agrawal
Professor and Chair of Mathematics
B.A., Kalahandi College, India;
M.A., Sambalpur University, India;
M.A., Ph.D., SUNY at Stony Brook

Jameel Ahmad
George Fox Professor of Urban Infrastructure Design, and Chair of Civil Engineering
B.S., Punjab University, Pakistan;
M.S., University of Hawaii;
Ph.D., University of Pennsylvania

Paul M. Bailyn
Professor of Mathematics
B.M.E., The Cooper Union;
M.S., Ph.D., New York University, Courant Institute of Mathematical Sciences

Irving Brazinsky
Professor of Chemical Engineering and Chair
B.Ch.E., The Cooper Union;
M.S., Lehigh University;
Sc.D., Massachusetts Institute of Technology

Joseph C. Cataldo
Professor of Civil Engineering
B.C.E., M.S.C.E., Ph.D., City University of New York; P.E.

Toby J. Cumberbatch
Professor of Electrical Engineering
B.Sc.(Hons.), M.Sc., Ph.D., University of Manchester Institute of Science and Technology; C.Eng.

Fred L. Fontaine
Jesse Sherman Professor of Electrical Engineering and Chair of Electrical Engineering
B.E., M.E., The Cooper Union;
M.S., New York University, Courant Institute of Mathematical Sciences;
Ph.D., Stevens Institute of Technology

Vito A. Guido
Professor of Civil Engineering
B.S.C.E., M.S.C.E., Ph.D., Polytechnic University; P.E.

Andrea Newmark
Professor and Chair of Chemistry
B.A., Queens College, CUNY;
M.S., Ph.D., Columbia University

O. Charles Okorafor
Professor of Chemical Engineering
B.Sc., University of Lagos;
M.A.Sc., Ph.D., University of British Columbia

Anita Raja
Professor of Computer Science
B.S., Temple University;
M.S., University of Massachusetts Amherst;
Ph.D., University of Massachusetts Amherst

George W. Sidebotham
Professor of Mechanical Engineering
B.S., Trinity College;
M.A., Ph.D., Princeton University

Richard J. Stock
Professor of Chemical Engineering
B.Sc (Hons), University of Nottingham, England;
M.S., Ph.D., West Virginia University

Robert Q. Topper
Professor of Chemistry
B.S., Florida State University;
M.S., M. Phil., Ph.D. Yale University

Cosmas Tzavelis
Professor of Civil Engineering
Diploma, National Technical University of Athens, Greece;
M.S., M.Phil., Ph.D., Columbia University; P.E.

Leonid Vulakh
Professor of Mathematics
M.A., Ph.D., Moscow State University, USSR

Chih-Shing Wei
George Clark Professor of Mechanical Engineering and Chair
B.S., National Chung Hsing University, Taiwan;
M.S., SUNY at Buffalo; Ph.D., Georgia Institute of Technology

Alan N. Wolf
Professor and Chair of Physics
B.S., SUNY at Stony Brook;
M.A., Ph.D., University of Texas;
J.D. Yeshiva University (CSL)

David M. Wootton
Professor of Mechanical Engineering
B.S.M.E., Cornell University;
M.S., Massachusetts Institute of Technology;
Ph.D., Georgia Institute of Technology

Constantine Yapijakis
Professor of Civil Engineering
Diploma, National Technical University of Athens, Greece;
M.S., New York University;
Ph.D., Polytechnic University; P.E.

Associate Professors

Melody Baglione
Associate Professor of Mechanical Engineering
B.S.M.E., Michigan Technological University;
Ph.D., University of Michigan

George J. Delagrammatikas
Associate Professor of Mechanical Engineering
B.S.M.E., Massachusetts Institute of Technology;
M.S.M.E., Ph.D., University of Michigan

Robert P. Hopkins
Associate Professor of Computer Science
B.S., St. Joseph's College, Indiana;
M.B.A., Fordham University

Sam Keene
Assistant Professior of Electrical Engineering
B.S., Boston University;
M.S., Columbia University;
Ph.D., Boston University

Stuart Kirtman
Associate Professor of Electrical Engineering
B.E., M.E., The Cooper Union;
Ph.D., Brown University

Marcus Lay
Associate Professor of Chemistry
B.S., Ph.D., University of Georgia

Daniel H. Lepek
Associate Professor of Chemical Engineering
B.E., The Cooper Union;
Ph.D., New Jersey Institute of Technology

Eric G. Lima
Associate Professor of Mechanical Engineering
B.A., SUNY Purchase;
B.E., The Cooper Union;
Ph.D., Columbia University

Carl Sable
Associate Professor of Computer Engineering
B.S.E.E., Princeton University;
M.S., Ph.D., Columbia University

Ruben Savizky
Associate Professor of Chemistry
B.E., The Cooper Union;
M.S., Ph.D., Yale University

Robert W. Smyth
Associate Professor of Mathematics
B.S., The Cooper Union;
M.S. New York University;
Ph.D., Rutgers University

Philip Yecko
Associate Professor of Physics
S.B., Massachusetts Institute of Technology
Ph.D., Columbia University

Assistant Professors

Benjamin J. Davis
Assistant Professor of Chemical Engineering
B.S., Cornell University;
Ph.D., U.C.L.A.

Martin Luchtenberg
Assistant Professor of Mechanical Engineering
M.S. Delft University of Technology, The Netherlands
Ph.D., Berlin University of Technology, Germany

Oliver Medvedic
Visiting Assistant Professor of Biology
B.A. Hunter College
Ph.D., Harvard Universtiy

Stanislav Mintchev
Assistant Professor of Mathematics
B.S., George Washington University;
M.S., Ph.D., New York University, Courant Institute of Mathematical Sciences

Adjunct Professors

As of time of publication, for Fall 2015 and Spring 2016 semesters only

Zinoviy Akkerman
Adjunct Professor of Physics
M.S., Novosibirsk State University, Russia;
Ph.D., Institute of Semiconductor Physics, Russia

Michael Bambino
Adjunct Professor of Mechanical Engineering
B.E., The Cooper Union
Master of Industrial Design, Pratt Institute

Robert Barrett
Adjunct Associate Professor of Industrial Engineering
B.E., Pratt Institute;
M.S., New York University

Svetlana Bashkova
Adjunct Professor of Chemistry
B.S., M.S., Riga Technical University, Latvia
M.S., City College of New York
Ph.D., City University of New York

Peter Bastos
Adjunct Professor of Chemistry
B.S., Rutgers University;
M.S. Stevens Institute;
Ph.D. University of Nijmegen, Holland

Alan D. Berenbaum
Adjunct Professor of Computer Engineering
B.A., Yale University;
M.A., Princeton University

Scott N. Bondi
Adjunct Professor of Mecha nical Engineering
B.S., Polytechnic University;
M.S., Ph.D., Georgia Institute of Technology

Michael Brodsky
Adjunct Professor of Physics
M.S., St. Petersburg Technical University, Russia
Ph.D., Massachusetts Institute of Technology

Tom Carberry
Adjunct Assistant Professor of Chemistry
B.S., Fordham University
Ph.D., New York University

Dong Chang
Adjunct Professor of Civil Engineering
B.E., M.E., The Cooper Union;
Ph.D., Columbia University; P.E.

Sean Cusack
Adjunct Assistant Professor of Computer Science
B.S., The Cooper Union

Brian Cusack
Adjunct Associate Professor of Mechanical Engineering
B.E., M.E., The Cooper Union

Partha P. Debroy
Adjunct Professor of Physics
B.S., M.S., Calcutta;
M.S., Ph.D., Carnegie Mellon University

Robert Dell
Adjunct Professor of Mechanical Engineering;
Director, Center for Innovation and Applied Technology
B.S., SUNY Oneonta;
M.F.A., SUNY New Paltz

Gabriel Giraldo
Adjunct Instructor of Physics
B.S., M.E., Rutgers University

Jeff Hakner
Adjunct Professor of Electrical Engineering
B.E., M.E., The Cooper Union

Adam Hapij
Adjunct Associate Professor of Civil Engineering
B.E., M.E., The Cooper Union;
P.E.

William Hyman
Adjunct Professor of Biomedical Engineering
B.S., M.E., The Cooper Union
M.S., Sc.D., Columbia University

Lawrence S. Hausman
Adjunct Professor of Electrical Engineering
B.E., The Cooper Union;
M.S., Polytechnic University; P.E.

Timothy R. Hoerning
Adjunct Professor of Electrical Engineering
B.E., M.E., The Cooper Union

Neil Jackman
Adjunct Professor of Electrical Engineering
B.E., SUNY;
M.S.E.E., Columbia University;
Ph.D., Stevens Institute of Technology

Kevin S. Kolack
Adjunct Professor of Chemistry
B.S., University of Virginia;
Ph.D., Indiana University

Steven Kreis
Adjunct Associate Professor of Physics
B.S., University of Missouri;
M.S., Hunter College

Ian J. Kremenic
Adjunct Professor of Biomedical Engineering
B.E., M.E., The Cooper Union

Michael Kumaresan
Adjunct Instructor of Math
B.E., The Cooper Union
M.S., Imperial College of Science, Technology and Medicine

Lembit Kutt
Adjunct Professor of Mechanical Engineering
B.E., The Cooper Union;
M.S., M.Phil., Ph.D., Columbia University

Lawrence Lennon
Adjunct Professor of Civil Engineering
B.E., The Cooper Union
M.B.A., New York Universtiy
M.S. Polyytech Institute of NYU, P.E.

Christopher P. Lent
Adjunct Associate Professor of Computer Science
B.E., M.E., The Cooper Union

Erik Lessac-Chenen
Adjunct Assistant Professor of Physics
B.S., Stanford University
M.S. New York University

Ericson Mar
Adjunct Associate Professor of Mechanical Engineering
B.E., M.E., The Cooper Union

Robert Marano
Adjunct Professor of Electrical Engineering
B.E., The Cooper Union;
M.S.E.E., University of Pennsylvania

Keith Ng
Adjunct Instructor of Civil Engineering
B.E., M.E., The Cooper Union

Karl Orishimo
Adjunct Associate Professor of Biomedical Engineering
B.S.E., University of Pennsylvania;
M.S., Univeristy of Virginia

Tom Panayotidi
Adjunct Professor of Civil Engineering
B.S., M.S., Eng. Sc. Doctorate, Columbia University

Katherine Panchyk
Adjunct Assistant Professor of Graphics
B.S., City College of New York

David Petrillo
Adjunct Instructor of Mechanical Engineering
B.S., Lehigh University

Yashodhan C. Risbud
Adjunct Professor of Electrical Engineering
B.E., M.E., The Cooper Union

Ryan Ronan
Adjunct Instructor of Math
B.E., The Cooper Union

Vincent Salvatoriello
Adjunct Professor of Civil Engineering
B.S., M.S., New Jersey Institute of Technology
Ph.D., Stevens Institute of Technology

Omar A. Sharafeddin
Adjunct Professor of Chemistry
B.S., Baylor University;
Ph.D., University of Houston

Stanley M. Shinners
Adjunct Professor of Electrical Engineering
B.E.E., CUNY City College;
M.S.E.E., Columbia University; P.E.

Susan Slome
Adjunct Professor of Math
Graduate Preparatory Accelerated Program, New York University, Courant Institute
Ph.D., State University of New York, Stony Brook

Robert Smilowitz
Adjunct Professor of Civil Engineering
B.E., The Cooper Union;
Ph.D., University of Illinois; P.E.

Daniel M. Speyer
Adjunct Professor of Mechanical Engineering
B.E., M.E., Ph.D., New York University

Leonid Srubshchik
Adjunct Professor of Mathematics
B.S., M.S., Rostov State University, USSR;
Ph.D., FSU Institute of Mathematics, USSR

Thomas Synnott, III
Adjunct Professor of Industrial Engineering
B.A., Williams College;
M.A., Ph.D., Yale University

Nina Tandon
Adjunct Professor of Electrical Engineering
B.E., The Cooper Union
M.S., MIT
Ph.D. Columbia University

Kevin Tien
Adjunct Professor of Electrical Engineering
B.E., The Cooper Union
M.S., Columbia University

Steven Ungar
Adjunct Professor of Electrical Engineering
B.E., The Cooper Union;
M.S., Ph.D., Stanford University

Joseph Viola
Adjunct Associate Professor of Civil Engineering
B.E., M.E., The Cooper Union;
P.E.

Samuel Wiener
Adjunct Professor of Chemistry
B.S., M.A., Brooklyn College;
M.S., Pace University

Hui (Grace) Yu
Adjunct Professor of Mechanical Engineering
B.S., Wuhan Institute of Chemical Engineering;
M.S., Huazhong University of Science and Technology;
Ph.D., Hong Kong University of Science and Technology;
Ph.D., Boston University

Lori Zaikowksy
Adjunct Professor of Chemistry
B.S., M.S., Ph.D., Stony Brook University

Emeriti Faculty/Administration

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Technicians

Estuardo Rodas
Mechanical Engineering Technician and Project Coordinator

Patrick Chiu, *Technician*
Chemistry Laboratories

Radmila Janjusevic, *Technician*
Kanbar Center for Biomedical Engineering

Sinisa Janjusevic, *Technician*
Student Machine Shop

Victoria Joyce, *Technician*
Chemistry Laboratories

Aladino Melendez, *Senior Technician*
Electrical Engineering Laboratories

Jorge Ortega, *Senior Laboratory Technician*
Mechanical Engineering Laboratories

Luis Vega, *Technician*
Civil Engineering Laboratories

Michael Westbrook, *Technician*
Chemical Engineering Laboratories

Brian Yudin, *Technician*
Student Shop/ME Design Studio

Engineering Advisory Council

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Seth Dubin, Esq.
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Jack D. Goodman (ME'51)
President
Sprague-Goodman Electronics, Inc.

Dr. Russell Hulse, Ph.D. (BS'70)
Nobel Laureate
Associate Vice President for Strategic Initiatives
University of Texas–Dallas

Thomas Iovino, P.E.
C.E.O., Judlau Contracting Inc.

Stanley Lapidus (EE'70)
Chairman and C.E.O.
Helicos Biosciences

Jay LeBoff
President and C.E.O.
C.E.O. Hotseat Chassis Inc.

Jay Moskowitz (Phy'70)
SPD Control Systems Corp.

Frank Napolitano (ME'88)
President, Lakeside Energy, LLC.

Eduardo F. Palacio (EE'75)
Vice President for Programs, ITT Electronic Systems

Gerry Posner
C.E.O., Bolder Sensors
Chairman, Aegis Software Systems

Steven Silberstang (CE'70)
President, Foolhardy Investors

Joel Spira
Chairman and Director of Research
Lutron Electronics Co., Inc.

Nina Tandon (EE'01)
Adjunct Professor of Electrical Engineering, The Cooper Union

Donald Toman (EE'55)
Senior Staff Consultant (retired)
Lockheed Martin

Richard Tomasetti,
P.E. Chairman
Thornton-Tomasetti Group, Inc.

Willard Warren (EE'50)
Willard Warren Associates

Philip Weisberg (EE'89)
C.E.O.
FX Alliance

Marie Wieck (BSE'82)
Vice President, WebSphere Platform
IBM

Technology Transfer Advisory Board

Robert Aquilina (CE'78)
Co-chairman and General Management Adviser
Flag Telecom

Mike Borkowsky (ME'61)
Vice President
Bristol-Meyers Consultant (retired)

Mark L. Epstein (A'76)
Ossa Properties, Inc.

Stanley Lapidus (EE'70)
Chairman and C.E.O.
Helicos Biosciences

Barry E. Negrin (ME'89)
Partner
Levisohn, Lerner, Berger and Langsam, LLP

Lawrence Ng (EE'78)
Senior Vice President for Business Development
Moneyline Network