

School of Engineering

E

Engineering Education in a University Setting	280
Degree Programs in Engineering	282
Special Programs	285
Honors	287
Academic Regulations	289
Courses of Study	294
Engineering Courses	317
Administration and Faculty	334

Engineering Education in a University Setting

VANDERBILT University School of Engineering is the largest and oldest private engineering school in the South. Classes offering engineering instruction began in 1879, and seven years later Engineering was made a separate department with its own dean. The school's program emphasizes the relationship of the engineering profession to society and prepares engineers to be socially aware as well as technically competent.

The mission of the School of Engineering is threefold: to prepare undergraduate and graduate students for roles that contribute to society; to conduct research to advance the state of knowledge and technology and to disseminate these advances through archival publications, conference publications, and technology transfer; and to provide professional services to the community.

The school strives to meet the undergraduate education portion of its mission by offering degree programs in fields of engineering relevant to the needs of society. An objective of these programs is to provide a technical education integrated with strong humanities, fine arts, and social sciences subject matter to provide the requisite foundation for life-long learning. The availability of second majors and minors in subject areas in other schools and colleges of the university increases opportunities for engineering students to enhance their education by pursuing studies in the non-technical disciplines. Engineering students take close to 50 percent of their courses outside of the School of Engineering and associate daily with peers from other schools and colleges within the university.

Another objective is to accommodate students who will continue their studies at the graduate level in engineering or in other professional fields, as well as those who intend to enter engineering practice upon graduation. To this end, our programs emphasize mathematics and engineering sciences, yet provide significant exposure to engineering design and hands-on laboratory experiences.

A large fraction of the student body is destined for management positions early in their working careers. To meet these students' needs, the Engineering Management program offers a well-integrated curriculum, including a minor. In addition, a joint program with the Owen Graduate School of Management is available.

The bachelor of engineering serves those programs in engineering where professional registration through state boards is desirable or necessary. Typically, about 90 percent of the students are enrolled in programs that are accredited by the Engineering Accreditation Commission of ABET, Inc. To publicize professional registration and to serve the needs of engineers in the community who desire registration, the school sponsors a review course for the Fundamentals of Engineering Examination (FE).

The bachelor of science addresses the needs of those students seeking specialized programs not served by conventional engineering degree programs. The degree provides students with a general scientific and engineering background while allowing individual curricular desires to be addressed. For example, students who want to use a degree from the School of Engineering to enter the primary or secondary education fields

may include the necessary courses in education from Peabody College in their engineering degree program.

Students at all levels have the opportunity to work with faculty in the generation of new knowledge. Those planning for graduate studies and research may participate in individual topics and research courses to fulfill that desire. Engineering students also participate in the university's Summer Research Program for Undergraduates.

Facilities

The School of Engineering is housed in four buildings on campus. The new William W. Featheringill Hall provides a focal point for the School, housing a three-story atrium designed for student interaction and social events, more than fifty teaching and research laboratories with the latest equipment and computer resources, and project rooms. School administrative offices and several classrooms are located on the ground floor of the Science and Engineering Building in the Stevenson Center, which also houses the Biomedical Engineering Department on the eighth and ninth floors. Jacobs Hall, which flanks the new Featheringill Hall, contains laboratories, offices and classrooms serving both the Civil and Environmental Engineering Department and the Electrical Engineering and Computer Science Department. The Olin Hall of Engineering houses Chemical and Biomolecular Engineering, Mechanical Engineering, and Materials Science.

In all its engineering programs, Vanderbilt recognizes the valid place of experimental and research laboratories in the learning experience. Laboratories are planned to provide the strongest personal contact between students and faculty members consistent with enrollment.

Well-equipped undergraduate laboratories are maintained by the Departments of Chemistry and Physics in the College of Arts and Science, which offers mathematics and basic science courses required of all engineering students. Graduate and undergraduate divisions of these departments maintain teaching and research facilities in the Stevenson Center for the Natural Sciences, as does the Department of Earth and Environmental Sciences. Another supporting department, Biological Sciences, is housed in Medical Research Building III. Most classes in humanities and the social sciences are conducted in Buttrick, Calhoun, Furman, Garland, and Wilson halls.

Accreditation

All programs leading to the B.E. degree are accredited by the Engineering Accreditation Commission of ABET, Inc. (www.abet.org)

Employment of Graduates

Of the recent Vanderbilt graduates with baccalaureate degrees in engineering, about 60 percent entered directly into professional practice. Forty percent continued with graduate education or chose military service careers. Others pursued diverse careers or other interests. Additional information regarding the employment of engineering graduates is available in the Career Center.

Supporting Organizations

Vanderbilt Engineering Council

The Engineering Council is a student organization whose main goal is facilitating communication between administration, faculty, and students in the School of Engineering. Officers of the Engineering Council are elected by the engineering student body, and representatives from the professional societies complete the organization's membership. While the council has no administrative power, it provides students with a voice in the decision-making process in the School of Engineering.

Professional Societies

The leading national engineering societies have chartered branches or student sections at Vanderbilt. These organizations are run locally by students with the help of a faculty adviser. Meetings are devoted to matters of a technical nature, including films, outside speakers, plant trips, and other subjects of interest to the membership.

Student speakers from the Vanderbilt groups compete annually with speakers from other groups in their region in technical paper competitions.

Freshmen and sophomores are cordially invited to attend meetings—and juniors and seniors are urged to join—as they will find the work of the professional societies beneficial in orienting them in their careers.

The student professional societies are:

- American Institute of Aeronautics and Astronautics (A.I.A.A.)
- American Institute of Chemical Engineers (A.I.Ch.E)
- American Society of Civil Engineers (A.S.C.E.)
- American Society of Mechanical Engineers (A.S.M.E.)
- American Society for Metals (A.S.M.)
- Association for Computing Machinery (A.C.M.)
- Institute of Electrical and Electronics Engineers (I.E.E.E.)
- International Society for Hybrid Microelectronics (I.S.H.M.)
- National Society of Black Engineers (N.S.B.E.)
- Society of Automotive Engineers (S.A.E.)
- Society of Hispanic Professional Engineers (S.H.P.E.)
- Society of Engineering Science (S.E.S.)
- Society of Women Engineers (S.W.E.)
- Vanderbilt Biomedical Engineering Society

Graduating seniors may join the Order of the Engineer, a society that recognizes the commitment of its members to the profession of engineering.

Degree Programs in Engineering

BACHELOR of engineering degree programs are offered in the areas of biomedical, chemical, civil, computer, electrical, and mechanical engineering. Many of these programs allow considerable flexibility—but students are required to include in their courses of study those bodies of knowledge fundamental to each discipline.

Bachelor of science degree programs offered in the interdisciplinary engineering disciplines often allow strong concentration in other areas of engineering or in the College of

Arts and Science. The B.S. is awarded in the areas of computer science and engineering science.

The School offers the master of engineering (M.Eng.), with emphasis on engineering design and practice, in most areas of study. The Graduate School, through departments of the School of Engineering, offers the research-oriented Ph.D. degree in eight major fields. Degree programs offered by the School of Engineering are shown below.

Degree Programs

	B.E.	B.S.	M.Eng.	M.S.	Ph.D.
Biomedical Engineering	•		•	•	•
Chemical Engineering	•		•	•	•
Civil Engineering	•		•	•	•
Computer Engineering	•				
Computer Science		•		•	•
Electrical Engineering	•		•	•	•
Engineering Science		•			
Environmental Engineering			•	•	•
Materials Science and Engineering				•	•
Mechanical Engineering	•		•	•	•

Undergraduate Degrees

Bachelor of Engineering

The bachelor of engineering is offered in biomedical, chemical, civil, computer, electrical, and mechanical engineering. The B.E. degree requirements vary from 126 to 128 semester hours. Students seeking double majors will require somewhat more credit hours.

Bachelor of Science

The bachelor of science is offered in computer science and engineering science. Each major requires 120 semester hours. These programs have more flexibility in elective choice than the B.E. degree programs.

The Freshman Year

Many courses normally scheduled for the freshman year are common to both the B.E. and B.S. degree programs. While the curriculum for the freshman year is generally the same for all

students, there are important variations. For example, some major programs require a full year of introductory chemistry; others do not. Students should become familiar with requirements of those programs in which they have an interest and confer with their adviser at the time of enrollment and throughout the freshman year to work out a program of study that will keep options open as long as possible.

Specimen curricula for the engineering programs are given in the Courses of Study chapter. Requirements for the B.E. and B.S. degrees for the various programs vary in the minimum amount of work and specific course requirements in the basic sciences and in specific subject requirements in mathematics.

Included in the freshman year is the course Engineering Science 140 (Introduction to Engineering), which introduces the student to design tools used in all areas of engineering.

Some students may qualify for advanced placement or advanced credit in mathematics, science, the humanities and social sciences, or computer science. If advanced credit is awarded, it will not affect the student's Vanderbilt grade point average.

Mathematics and Physics

Entering engineering students will be placed in the appropriate level mathematics course by the director of the undergraduate mathematics program. Students offering one full year or more of high school credit in analytic geometry and calculus may qualify for advanced placement in a regular sequence by scoring well on the Advanced Placement Examination.

Students with high mathematical ability and achievement may apply for enrollment in the honors mathematics sequence. For more information, see the course descriptions under Mathematics in the Arts and Science section of this catalog.

Students with inadequate backgrounds in mathematics may be required to take Math 133 (Pre-calculus Mathematics). Taking this course constitutes an additional requirement for graduation.

Math 127AB (Probability and Statistical Inference) and Math 140 (Survey of Calculus) cannot be credited toward a degree in the School of Engineering.

Pre-calculus physics courses 105, 110, and 111 cannot be credited toward a degree in the School of Engineering.

Engineering Freshman Seminars

The School of Engineering provides optional seminars to give freshmen the opportunity to experience the creative process of using engineering concepts to solve real-world problems. These seminars offer students a unique opportunity to work closely, typically in small groups, with seasoned engineering professors.

Designed to challenge and engage freshmen intellectually, provide practice in communication skills, and aid in the selection of a specific engineering major, seminars are offered on a variety of topics. Some focus on research projects in the professor's area of engineering expertise, others concentrate on current scientific and technical problems of particular interest to the engineer, and others survey engineering practice in a variety of specialties and topics. Helping students learn problem-solving skills that can be applied across many disciplines throughout life, the seminars can be invaluable components of the freshman curriculum.

All freshman seminars carry 1 hour of open elective credit for engineering students. They are optional, but the Engineering School faculty consider this seminar program to be very important for both students and professors. Freshmen wishing to take a seminar will enroll in Engineering Science 101, Engineering Freshman Seminar.

Seminar offerings vary from year to year. During the summer preceding the freshman year, the Office of the Dean will mail the booklet, *Freshman Seminars*, describing seminar topics for the upcoming year.

Liberal Arts Core

In order to provide the elements of a general education considered necessary for responsible practice as an educated engineer, the School of Engineering requires each student to complete at least 18 hours in the Liberal Arts Core. The Liberal Arts Core will be selected from courses in the five distribution categories designated in the AXLE Curriculum Course Distribution of the College of Arts and Science:

- a) Humanities and the Creative Arts, including English 100
- b) International Cultures, including Arabic 210A, Chinese 201, French 101A, German 101, Greek 201, Hebrew 111A, Italian 101A, Japanese 200AB and 201, Latin 101, Portuguese 100A, Russian 101, Spanish 100 and 101
- c) History and Culture of the United States, including Engineering Science 155
- d) Social and Behavioral Sciences, including Engineering Management 244
- e) Perspectives, including Computer Science 151

and the distribution categories of:

- f) Music Composition and Performance
All MUSC, MUSE, MUSO, and MUSP courses in the Blair School of Music
- g) Cognition and Development
All Peabody College courses in Psychology and Human Development numbered 1200-2000, 2230-2470, and 2560-2610, and in Human and Organizational Development numbered 1000, 1100, 1200-1800, and 2240-2280

Within the 18-hour requirement, the student must meet the following distribution requirements:

1. At least 3 credit hours in each of at least three different categories
2. At least 6 credit hours in one category

Open Electives

Courses excluded from the listings in the Liberal Arts Core may be taken as open electives.

Officer education courses Military Science 113, 151, 152, and Naval Science 231 and 241 may be taken as open electives. NS 121 may be used as an open elective if the student has not taken ME 220A. No other officer education courses earn credit toward a degree. AFROTC students may count 6 hours of their military courses as open electives.

Master of Engineering

The master of engineering (M.Eng.) is an advanced professional degree awarded by the School of Engineering and especially designed for engineering practitioners who may prefer to work while doing professional study. It is also suitable for individuals who apply directly from undergraduate school—but the thrust of the program is toward professional practice in engineering rather than research or teaching. The degree is currently offered in biomedical engineering, chemical engineering, civil engineering, electrical engineering, environmental engineering, and mechanical engineering.

Students must complete 30 hours of approved course work. For information on the Accelerated Graduate Program in Engineering degrees, see the chapter on Special Programs. A maximum of 6 hours of graduate-level work may be transferred from another institution. Residency requirements are flexible, and a maximum period of seven years is allowed to complete the degree. An extensive, written design report shall be submitted on a project approved by the student's committee.

Admission to the Master of Engineering program normally requires graduation from an approved undergraduate program in engineering or a related scientific discipline, attainment of a B average in undergraduate courses applicable to the student's career goals, and recommendations containing favorable appraisals of professional promise and attitude. A period of successful work experience prior to application to the program will also be given consideration. Application for admission should be sent to the associate dean of the School of Engineering. Further information about the program may be obtained by writing to the same office.

For information on integrated bachelor and master of engineering degrees, see the chapter on Special Programs.

Special Programs

Honors Programs

Honors programs allow selected undergraduate students to develop individually through independent study and research. Individual honors programs are described in the Courses of Study chapter.

Requirements vary somewhat but, in general, to qualify for consideration a student should have (a) completed the technical course requirements of the first two years, (b) attained a minimum grade average of 3.5 in all work taken for credit, and (c) shown evidence indicating a capacity for independent study and/or research. Formal admission is by election of the department concerned. Once admitted, candidates remain in the program only if they maintain a 3.5 or higher grade average.

Accepted candidates normally begin honors study in the junior year, but exceptions may be made for outstanding seniors. Honors students are usually exempt from some junior and senior class work in their major field in order to devote more time than other students to research, independent study, and graduate level courses. A comprehensive examination or written research report is required.

Successful candidates are awarded Honors in their area of interest. This designation appears on their diplomas.

Teacher Education

Students who are interested in preparing for licensure as secondary school teachers should plan their programs in consultation with the associate dean in the School of Engineering. The School of Engineering and Peabody College offer a teacher education program leading to secondary school licensure in physics (grades 9 through 12) and computer technology. Students major in engineering science in the School of Engineering and complete a second major in education at Peabody College.

More specific information on professional education course requirements can be found under the Licensure for Teaching chapter in the Peabody College section of this catalog. Inquiries can also be made to the Office of Teacher Licensure at Peabody.

Double Major

It is possible for a student to combine an engineering field with a second area outside the School of Engineering. The student must obtain prior approval of each department and satisfy the requirements of each major, including the requirement regarding minimum grade point average.

Certain double majors involving two programs within the School of Engineering have been approved by the faculty. The approved double majors are biomedical engineering/electrical engineering, and biomedical engineering/chemical engineering.

The double major is indicated on the student's transcript. Only one degree is awarded, from the school in which the student is enrolled.

Minors

A minor consists of at least five courses of at least 3 credit hours each within a recognized area of knowledge. A minor offers students more than a casual introduction to an area, but

less than a major. A minor is not a degree requirement, but students may elect to complete one or more. Courses may not be taken on a Pass/Fail basis. A minor for which all designated courses are completed with a grade point average of at least 2.0 will be entered on the transcript at the time of graduation.

When a minor is offered in a discipline that offers a major, only those courses that count toward the major may be counted toward the minor. Students should refer to the appropriate sections of this catalog for specific requirements. Currently, minors are offered in engineering management, materials science and engineering, computer science, environmental engineering, energy and environmental systems, scientific computing, and most disciplines of the College of Arts and Science, Blair School of Music, and Peabody College.

Students should declare their intention to pursue minors by completing forms available in the Student Services Office of the School of Engineering. Departments and programs assign advisers to students who declare minors in their areas. Students are responsible for knowing and satisfying all requirements for the minors they intend to complete.

PAVE

PAVE (Preparatory Academics for Vanderbilt Engineers) is a six-week summer engineering program designed to allow a faster adjustment to college, to show students what is expected academically and how to go about accomplishing it. The curriculum is multidisciplinary so as to strengthen students academically. The program involves in-depth problem solving, computer skills, laboratory experiments, and technical writing—all in an engineering/science environment. The participants have access to all campus academic and recreational facilities. Optional non-academic weekend activities are planned to provide a well-balanced summer. The program is open to students in the eleventh or twelfth grade or to high school postgraduates.

Three-Two Program

The School of Engineering recognizes a Three-Two program with certain liberal arts colleges. This plan allows students to attend a liberal arts college for three years of undergraduate study, usually majoring in mathematics or science, where they meet the residence requirements for a degree from that institution. They then transfer to the Vanderbilt University School of Engineering for two years of technical work in an engineering curriculum. Upon completion of the five years, students receive two bachelor's degrees, one from the liberal arts college and one from the School of Engineering.

To complete all required technical courses at Vanderbilt in two years, students enrolled in the Three-Two program should complete, before coming to Vanderbilt, as many as possible of the mathematics and science courses listed in the specimen curriculum—in general, mathematics through differential equations, a year of physics, a year of another laboratory science (usually chemistry), and a semester of computer programming. Students should plan their three years of liberal arts study so as to satisfy as nearly as possible the freshman and sophomore requirements of the particular engineering curriculum in which they will major at Vanderbilt.

Admission to the Three-Two program must be certified by the liberal arts college and is recognized by Vanderbilt University School of Engineering through special agreement between Vanderbilt and each of the liberal arts colleges participating in the Three-Two program.

Dual Degree Program with Fisk University

A coordinated dual degree program between the Vanderbilt University School of Engineering and Fisk University is especially designed to permit students to obtain an A.B. degree in biology, chemistry, computer science, physics, or mathematics from Fisk and a B.E. or B.S. degree in engineering from Vanderbilt, generally within five years.

For the first three years, the student is enrolled at Fisk in a science curriculum and, by cross-registration in the second and third years, takes introductory engineering courses at Vanderbilt. During the fourth and fifth years, the student is enrolled at Vanderbilt, following principally an engineering curriculum at Vanderbilt and completing science courses at Fisk. At the end of five years, the student should be able to satisfy the requirements for both bachelor's degrees.

Financial aid is available for qualified, deserving students. Additional information is available from the director of transfer admissions in the Office of Undergraduate Admissions.

Integrated Bachelor of Science/Master of Business Administration

In the five-year joint program in engineering and management, the student spends three undergraduate years in the engineering science major in the School of Engineering followed by two years at the Owen Graduate School of Management. First-year Owen School courses are used to meet the student's elective requirements for the B.S. in Engineering Science, with a concentration in Engineering Management. Successful students receive the B.S. from the School of Engineering after their first year at the Owen School and the MBA from the Owen School the following year.

Application to the Owen School normally is made during the student's junior year. Successful completion of the undergraduate curriculum in engineering science does not ensure admission to the Owen School.

Bachelor of Science in Computer Science/Master of Science in Finance

A program of study is available in which students can obtain a B.S. in computer science from the School of Engineering in four years and be well prepared for admission to the M.S. in Finance program in the Owen Graduate School of Management. Students spend their fifth year of study at the Owen School. Admission to the M.S. in Finance program is contingent upon performance. Students receive a strong background in computer programming and economics; minors in engineering management and mathematics are facilitated, providing further depth in preparation for the M.S. in Finance. The recommended curriculum is maintained on the computer science portion of the webpages of the Department of Electrical Engineering and Computer Science.

Integrated Bachelor and Master of Engineering

On the basis of recommendations containing favorable appraisals of professional promise, undergraduate students in the School of Engineering who have completed at least 75 hours with at least a *B* average may be accepted into an integrated Bachelor of Engineering–Master of Engineering program. The last two years of a student's program is planned as a unit and may thereby include a broader choice of technical work.

Completion of all work toward both degrees is required before either degree is awarded. To protect the option of dropping back to the bachelor of engineering as a terminal degree, students who enter the integrated B.E.–M.Eng. program are advised to satisfy all requirements for the bachelor of engineering degree as promptly as feasible. Further information about the program is available from the chair of the student's major department.

Accelerated Graduate Program in Engineering

Students who enter Vanderbilt with a significant number of credits (20 to 30 hours), earned either through Advanced Placement tests or in college courses taken during high school, may be eligible for the Accelerated Graduate Program in Engineering. Through this program, a student is able to earn both a bachelor's degree and an M.S. degree in about the same time required for the bachelor's degree. To be eligible for the program a student must complete 86 hours (senior standing) by the end of the sophomore year with at least a 3.5 grade point average. With the approval of the faculty in their major department, students apply through the Associate Dean for Research and Graduate Studies for provisional admission and take one course approved for graduate credit each semester of the junior year. These courses will be credited toward the M.S. degree. Upon successful completion of these courses, the student is admitted to the Graduate School.

During the fourth year the student takes three courses (9 hours) for graduate credit each semester, and the remaining 6 to 10 undergraduate hours required for the bachelor's degree. The student receives the bachelor's degree at the end of the fourth year and spends the summer finishing a master's thesis to complete the M.S. degree. Further information can be obtained from the chair of the student's major department.

Honors

Founder's Medal

The Founder's Medal, signifying first honors, was endowed by Commodore Cornelius Vanderbilt as one of his gifts to the university. The recipient is named by the Dean after consideration of faculty recommendations and the grade point averages of the year's summa cum laude graduates.

Latin Honors Designation

Honors noted on diplomas and published in the Commencement Program are earned as follows:

Summa Cum Laude. Students whose grade point average equals or exceeds that of the top 5 percent of the previous year's Vanderbilt graduating seniors.

Magna Cum Laude. Students whose grade point average equals or exceeds that of the next 8 percent of the previous year's Vanderbilt graduating seniors.

Cum Laude. Students whose grade point average equals or exceeds that of the next 12 percent of the previous year's Vanderbilt graduating seniors.

Dean's List

The Dean's List recognizes outstanding academic performance in a semester. Students are named to the Dean's List when they earn a grade point average of at least 3.500 while carrying 12 or more graded hours, with no temporary or missing grades in any course (credit or non-credit) and no grade of *F*.

Honor Societies

TAU BETA PI. The Tennessee Beta chapter of the Tau Beta Pi Association was installed at Vanderbilt University 7 December 1946. Members of Tau Beta Pi are selected from undergraduate students in the School of Engineering who have completed at least four semesters of required work, are in the upper eighth of their class scholastically, and have shown marked qualities of character and leadership; seniors in the upper fifth of their class scholastically are also eligible for election.

CHI EPSILON. The Vanderbilt chapter of Chi Epsilon, installed 18 March 1967, is restricted to undergraduate civil engineering students in the top third of their class. Election is based on grade point average, faculty recommendation, and exceptional achievements in extracurricular campus activities.

ETA KAPPA NU. The Epsilon Lambda chapter of the Eta Kappa Nu Association was established 22 April 1966. Undergraduate members are selected from the upper third of the class in electrical engineering. Eta Kappa Nu recognizes leadership and scholastic accomplishment twice annually, selecting members also from the professional body of practicing engineers.

ALPHA SIGMA MU. The Vanderbilt chapter of Alpha Sigma Mu was installed in 1977. Senior materials engineering students in the upper twenty percent of their graduating class are eligible upon recommendation of departmental faculty.

PI TAU SIGMA. The Delta Alpha chapter of Pi Tau Sigma was installed on the Vanderbilt campus 22 April 1971, for the purpose of recognizing scholastic achievement and professional promise in junior and senior mechanical engineering students. Students are elected to membership twice each year on the basis of academic excellence and recommendations from the faculty and chapter members.

SIGMA XI. The Vanderbilt chapter of the Society of the Sigma Xi recognizes accomplishment, devotion, and originality in scientific research. Associate members are elected annually from graduate-level students of the university.

HONOR SOCIETIES FOR FRESHMEN. Freshmen who earn a grade point average of 3.5 or better for their first semester are eligible for membership in the Vanderbilt chapter of Phi Eta Sigma and Alpha Lambda Delta.

Other Awards and Prizes

DEAN'S AWARD FOR OUTSTANDING SERVICE. Awarded to the senior candidate in the School of Engineering who has shown remarkable leadership qualities and who has also made the greatest contribution in personal services to the School.

DEAN'S AWARD FOR OUTSTANDING SCHOLARSHIP. Awarded to each member of the senior class who graduates summa cum laude.

PROGRAM AWARDS. The faculty associated with each of the departments of the school annually bestows a certificate and a prize to one member of the graduating class who is judged to have made the greatest progress in professional development during his or her undergraduate career.

AMERICAN INSTITUTE OF CHEMISTS AWARD. Awarded to an outstanding undergraduate student majoring in Chemical Engineering on the basis of a demonstrated record of leadership, ability, character, scholastic achievement, and potential for advancement of the chemical professions.

GREG A. ANDREWS MEMORIAL AWARD. Endowed in 1969 and awarded to the senior in civil engineering who has been judged by the faculty to have made the greatest progress in professional development and who plans to do graduate work in environmental and water resources engineering.

THOMAS G. ARNOLD PRIZE. Endowed in 1989 and awarded by the biomedical engineering faculty to the senior who presents the best design of a biomedical engineering system or performance of a research project in the application of engineering to a significant problem in biomedical science or clinical medicine.

WALTER CRILEY PAPER AWARD. Endowed in 1978 and awarded in electrical engineering for the best paper on an advanced senior project in electrical engineering.

JAMES SPENSER DAVIS AWARD. Given annually by the student chapter of Eta Kappa Nu in memory of Mr. Davis, this award recognizes excellence in the undergraduate study of electronics.

ARTHUR J. DYER JR. MEMORIAL PRIZE. Endowed in 1938 and awarded in civil engineering to the member of the senior class doing the best work in structural engineering.

WALTER GILL KIRKPATRICK PRIZE IN CIVIL ENGINEERING. Endowed and awarded in the School of Engineering to the most deserving third-year undergraduate student in civil engineering.

WILSON L. AND NELLIE PYLE MISER AWARD. Awarded to the senior engineering student who has been judged by the faculty of mathematics to have excelled in all aspects of mathematics during his or her undergraduate career.

STEIN STONE MEMORIAL AWARD. Endowed in 1948 and awarded in the School of Engineering to the member of the graduating senior class who has earned a letter in sports, preferably in football, and who is adjudged to have made the most satisfactory scholastic and extramural progress as an undergraduate.

W. DENNIS THREADGILL AWARD. Awarded to a graduating chemical engineering senior for outstanding achievement in the undergraduate program in honor of a former faculty member and department chair.

Academic Regulations

Honor System

All academic work at Vanderbilt is done under the honor system (see Life at Vanderbilt chapter).

Responsibility to Be Informed

It is the responsibility of the student to keep informed of course requirements and scheduling. Failure to do so may jeopardize graduation.

Academic Advising

A faculty adviser is appointed for each student. This adviser is chosen from the faculty in the student's major, when the major is known. For students who have not chosen a major upon entry, an adviser is selected from faculty in any department. If a student later chooses a different department for his or her major, a corresponding change of adviser is made. Engineering students are required to see their advisers at registration and any other time changes must be made in their programs of study. Any student who has academic difficulty is expected to see his or her faculty adviser for counsel. Faculty advisers can also provide useful career guidance.

Accreditation and Professional Registration

Legislation exists in the various states requiring registration of all engineers who contract with the public to perform professional work. Although many engineering positions do not require professional certification, Vanderbilt supports registration and encourages its graduates to take the Fundamentals of Engineering examinations given by the Tennessee State Board of Architecture and Engineering Examiners as soon as they become eligible.

Bachelor of engineering degrees in biomedical engineering, chemical engineering, civil engineering, computer engineering, electrical engineering, and mechanical engineering are accredited by the Engineering Accreditation Commission of ABET, Inc. (www.abet.org) Students in these programs may take the Fundamentals of Engineering examinations as seniors. In addition, proven professional experience is a requirement for registration. Other state boards may have different rules.

Graduate Record Examination

Most graduate schools, including Vanderbilt's, require or strongly encourage submission of Graduate Record Examination scores as a condition for admission. As a service to students the Psychological and Counseling Center administers the GRE periodically. Further information can be obtained from the Counseling Center or by writing the Educational Testing Service, Box 6000, Princeton, New Jersey 08540.

Credit Hour Definition

Credit hours are semester hours; e.g., a three-hour course carries credit of three semester hours. One semester credit hour represents at least three hours of academic work per week, on average, for one semester. Academic work includes, but is not necessarily limited to, lectures, laboratory work, homework, research, class readings, independent study, internships, practica, studio work, recitals, practicing, rehearsing, and recitations.

Some Vanderbilt courses may have requirements which exceed this definition. Certain courses (e.g., dissertation research, ensemble, performance instruction, and independent study) are designated as repeatable as they contain evolving or iteratively new content. These courses may be taken multiple times for credit. If a course can be repeated, the number of credits allowable per semester will be included in the course description.

Normal Course Load

Each semester, regular tuition is charged on the basis of a normal course load of 12 to 18 semester hours. No more than 18 or fewer than 12 hours may be taken in any one semester without authorization from the dean. There is an extra charge for more than 18 hours at the current hourly rate. Students permitted to take fewer than 12 hours are placed on probation, unless their light load is necessary because of illness or outside employment.

Grading System

Work is graded by letter. *A*, *B*, *C*, and *D* are considered passing grades. The grade *F* signifies failure. A student who withdraws from a course before the date given in the Academic Calendar is given the grade *W*. A student may not withdraw from a course after that date.

Grade Point Average

A student's grade point average is obtained by dividing the total grade points earned by the number of hours for which the student registered, excluding courses taken for no credit, those from which the student has withdrawn, those with the temporary grade of *I* or *M*, and those that are completed with the grade *Pass*.

Defined Grades with Corresponding Grade Points Per Credit Hour

A	= 4.0	C	= 2.0
A-	= 3.7	C-	= 1.7
B+	= 3.3	D+	= 1.3
B	= 3.0	D	= 1.0
B-	= 2.7	D-	= 0.7
C+	= 2.3	F	= 0.0

Pass/Fail Course Provision

Students may elect to take a limited number of courses on a Pass/Fail basis. To enroll for a course on a Pass/Fail basis, students must have completed at least two semesters at Vanderbilt, must have achieved at least sophomore standing, and must not be on academic probation.

In addition, the following regulations apply to students enrolled in the School of Engineering:

1. No more than 9 hours graded Pass will be accepted toward the B.S. or B.E. degree.
2. No more than 6 hours of introductory level courses may be included in the total of Pass hours.
3. No more than two courses may be taken on a Pass/Fail basis in any one semester.

4. A minimum of 12 hours must be taken on a graded basis in any semester that a Pass/Fail course is taken. However, a graduating senior who needs fewer than 12 hours to graduate may take courses on a Pass/Fail basis as long as he or she takes the number of hours needed to graduate on a graded basis.
5. No required courses may be taken on a Pass/Fail basis.
6. The Pass/Fail option applies only to courses classified as open electives; elective courses offered in the College of Arts and Science, Blair School of Music, and Peabody College; and technical electives not considered part of the student's major field as defined by the curriculum committee of the major field.

Students may register for grading on a Pass/Fail basis until the close of the Change Period at the end of the first week of classes. Students may change from Pass/Fail to graded status until the deadline date for dropping a course that is published in the Academic Calendar.

Those electing the Pass/Fail option must meet all course requirements (e.g., reports, papers, examinations, attendance, etc.) and are graded in the normal way. Instructors are not informed of the names of students enrolled on a Pass/Fail basis. At the end of the semester, a regular grade is submitted for the student enrolled under the P/F option. Any grade of *D-* or above is converted in the Student Records System to a *P*, while an *F* will be recorded if a student enrolled under this option fails the course. The *P* grade is not counted in the grade point average or used in the determination of honors. The grade of *F* earned under the Pass/Fail option is included in the calculation of the grade point average.

Temporary Grades

Temporary grades are placeholders that are assigned under defined circumstances with a specified deadline by which they will be replaced with a permanent grade. A student who receives a temporary grade is ineligible for the Dean's List.

I: Incomplete

The Incomplete (*I*) is a temporary placeholder for a grade that will be submitted at a later date. The grade of *I* is given only under extenuating circumstances and only when a significant body of satisfactory work has been completed in a course. The *I* is not intended as a replacement for a failing grade, nor should it be assigned if a student simply misses the final examination. The grade of *M* is used for the latter purpose. The request for an *I* is generally initiated by the student but must be approved and assigned by the instructor. When assigning an Incomplete, the instructor specifies (a) a deadline by which the *I* must be resolved and replaced by a permanent grade and (b) a default course grade that counts the missing work as zero. The deadline may be no later than the end of the next regular semester. Extension beyond that time must be approved by the associate dean. If the work is not completed by the deadline the default grade will become the permanent grade for the course. The Incomplete is not calculated in the GPA, but a student who receives an Incomplete is ineligible for the Dean's List.

M: Missed Final Examination

The grade of *M* is given to a student who misses the final examination and is not known to have defaulted, provided the

student could have passed the course had the final examination been successfully completed. The grade of *F* is given if the student could not pass the course even with the final examination. It is the student's responsibility to contact the Office of the Dean before the first class day of the next regular semester to request permission to take a makeup examination. The makeup examination must be taken on or before the tenth class day of the next regular semester. If the request has not been submitted by the proper time, or if the student fails to take the makeup examination within the prescribed time, the *M* grade will be replaced by a default grade submitted by the instructor when the *M* is assigned.

F: Failure

A subject in which the grade *F* is received must be taken again in class before credit is given. A student who deserts a course without following the correct procedure for dropping it will receive an *F* in the course.

Senior Re-examination. A candidate for graduation who fails not more than one course in the final semester may be allowed one re-examination, provided the course failed prevents the student's graduation, and provided the student could pass the course by passing a re-examination. Certain courses may be excluded from re-examination. The re-examination must be requested through the student's Dean's Office, and, if approved, it is given immediately after the close of the last semester of the student's senior year. A student who passes the re-examination will receive a *D-* in the course. The terms and administration of senior re-examination are the responsibility of the school that offers the course. For engineering students taking engineering courses, the senior re-examination policy applies if a student fails not more than one course in the senior year.

RC: The Repeated Course Designator

Courses in which a student has earned a grade lower than *B-* may be repeated under certain conditions. A course in which the student earned a grade between *D-* and *C+*, inclusive, may be repeated only once. The repeat must be accomplished within one year of the first attempt for courses offered every year, or, for courses not offered within a year, the first time the course is offered. Failed courses may be repeated at any time. A course may be repeated only on a graded basis, even if the course was originally taken Pass/Fail. Courses taken Pass/Fail in which the student earned a Pass may not be repeated. When registering for a course previously completed, the student must indicate that the course is being repeated.

Students should note that repeating a course may improve the grade point average, but it may also lead to problems in meeting minimum hour requirements for class standing and progress toward a degree. Repeating a course does not increase the number of hours used in calculation of the grade point average. All grades earned will be shown on the transcript, but only the latest grade will be used for computation of grade point averages.

W: Withdrawal

A student may withdraw from a course at any time prior to the deadline for withdrawal published in the Academic Calendar. The deadline is usually the Friday following the date for reporting mid-semester deficiencies. The *W* is recorded for any course from which a student withdraws. A course

in which a *W* is recorded is not used in figuring grade point averages.

Requirements for the Degree

Candidates for a degree must have completed satisfactorily all curriculum requirements, have passed all prescribed examinations, and be free of indebtedness to the university.

Grade Average Requirements

To be eligible for graduation, a student must have passed all required courses, including the technical electives, and shall have earned a minimum average grade of *C* in (a) all courses taken, (b) courses taken within the School of Engineering, and (c) department courses of each major.

Any student who has been on probation for failure to meet the semester grade point average requirements in two successive semesters may be dropped for failure to meet the requirement in a third successive semester.

Hours Required for Graduation

The specific course requirements and total hours required for the bachelor's degree vary with the student's major program. Detailed requirements for each program are shown in the specimen curricula in the Courses of Study section. If graduation requirements change during the time students are in school, they may elect to be bound by the requirements published in the catalog in either their entering or their graduating year.

If a student elects or is required to take Mathematics 133 (Pre-calculus Mathematics), the minimum semester hours required for graduation shall be raised by the hours earned in that course.

Transfer Credit

It is the student's responsibility to provide all information needed for an assessment of the program for which transfer of credit is requested. Work transferred to Vanderbilt from another institution will not carry with it a grade point average. No course in which a grade below *C-* was received will be credited toward a degree offered by the School of Engineering.

Transfer students must complete at least 60 hours of work at Vanderbilt. Two of the semesters must be the senior year.

Summer Work at Another Institution

Work that a student contemplates taking at a summer school other than Vanderbilt is treated as transfer work and must be approved in advance in writing by the student's adviser and the associate dean in the School of Engineering, at which time a course description must be submitted. A course a student has taken at Vanderbilt may not be repeated in another institution to obtain a higher grade.

Credit by Examination

In certain circumstances students may be awarded course credit by departmental examination. (This procedure is distinct from the award of credit through the College Board Advanced Placement Examinations, taken prior to a student's first enrollment at Vanderbilt or another college.)

Students who want to earn credit by departmental examination should consult the associate dean concerning procedures. To be eligible, students must be in good standing.

Students must obtain the approval of the chair of the department that is to give the examination and of the instructor designated by the chair. Students may earn up to 8 hours of credit by examination in any one department, although this limitation might be raised on petition to the Administrative Committee. Students may attempt to obtain credit by examination no more than twice in one semester, no more than once in one course in one semester, and no more than twice in one course.

Credit hours and grade are awarded on the basis of the grade earned on the examination, subject to the policy of the department awarding credit. Students have the option of refusing to accept the credit hours and grade after learning the results of the examination.

Students enrolled for at least 12 hours are not charged tuition for hours for which credit by examination is awarded, so long as the amount of credit falls within the allowable limits of an 18-hour tuition load, including no-credit courses dropped after the change period of registration. Students in this category must pay a fee of \$50 for the cost of administering the examination. Full-time students with a tuition load exceeding 18 hours and students taking fewer than 12 hours pay tuition at the regular rate with no additional fee.

Registration

A period is designated in each semester during which continuing students, after consultation with their advisers, register for work to be taken during the next term. Students can access both their registration appointment times and the registration system via YES (Your Enrollment Services) at <https://yes.vanderbilt.edu>.

See the explanation of late registration fees in the chapter on Financial Information.

Auditing

Regularly enrolled students in the School of Engineering who want to audit courses in any of the undergraduate schools of the university must get the oral consent of the instructor to attend the class but do not register for the course. No record is kept of the audit. Regular students may audit classes each semester free of charge.

Change of Course

During the change period of registration as defined in the Academic Calendar, students may add or drop courses without academic penalty after securing approval from their adviser. After the change period, new courses may not be added, except under very unusual circumstances and with the approval of the adviser, the course instructor, and the associate dean.

A student may drop a course without entry on the final record, provided the course is dropped during the change period of registration. After the first week of classes and extending to the end of the eighth week, a course may be dropped with approval of the student's adviser; a *W* (with-drawal) will be recorded.

To drop a course or change sections after the change period ends, the student must procure a Change of Course card from the Student Services Office. The student then obtains the signature of his or her adviser and of all instructors involved in the proposed change and returns the card to the Student Services Office.

Examinations

Examinations are usually given at the end of each semester in all undergraduate courses except for certain laboratory courses or seminars. The instructor may exempt students who have excelled in course work from the final examinations. Exams will be no longer than three hours in length and are given according to the schedule published in the *Schedule of Courses* (the School of Engineering does not offer an alternate examination schedule). All examinations are conducted under the honor system.

Residence Requirements

A minimum of four semesters including the last two semesters shall be spent in residence in the School of Engineering. During these four or more semesters, the student must have completed at least 60 semester hours of an approved curriculum in one of the degree programs. In unusual cases, an exception to this requirement may be made by the Administrative Committee upon the recommendation of the department concerned.

Class Standing

To qualify for sophomore standing, a student must earn a minimum of 24 hours and maintain a grade point average of at least 1.8 and have completed two regular semesters. Freshmen who fail to qualify for sophomore standing after two semesters are placed on probation. Freshmen who fail to qualify for sophomore standing in three semesters may be dropped. The summer session counts as a semester for this purpose.

To qualify for junior standing, a student must earn a minimum of 54 hours and maintain a grade point average of at least 1.9 and have completed four regular semesters. Sophomores who fail to qualify for junior standing at the end of two semesters after qualifying for sophomore standing are placed on probation. A student who has been on probation for failure to qualify for junior standing and who does not qualify for junior standing in one extra semester may be dropped.

A student who has qualified for junior standing has two semesters to qualify for senior standing. Senior standing requires the completion of 86 hours and a minimum grade point average of 2.0 and have completed six regular semesters. Juniors who do not qualify for senior standing at the end of the second semester after qualifying for junior standing will be placed on probation. A student who has been on probation for failure to qualify for senior standing and who does not qualify for senior standing in one extra semester may be dropped.

Seniors who do not qualify for graduation at the end of the second semester after being promoted to the senior class will be placed on probation and given one more semester to complete the graduation requirements. A senior who has been on probation for failing to complete the graduation requirements and who fails to complete the requirements in one additional semester may be dropped.

Probation

A freshman who fails to complete 9 hours and earn a 1.7 grade point average during any semester is placed on probation. A sophomore, junior, or senior who fails to complete 12 hours and earn a 2.0 grade point average during any semester is placed on probation. The student is removed from probation after completing 12 hours and earning a 2.0 grade point average during any semester provided that sufficient credit hours are obtained for promotion to the next class.

Full-time sophomores are removed from probation after earning 12 hours and a 2.0 grade point average in a given semester, except that those who have not qualified for junior standing after two semesters as a sophomore must in the next semester fulfill the requirement for junior standing. Failure to do so will cause the student to be dropped.

A student who fails all courses in any semester will be dropped.

To remain in good standing, a student must pursue a program leading toward a degree in the School of Engineering. A student who is deemed by the Administrative Committee not to be making satisfactory progress toward a degree in engineering will be dropped.

A student authorized by the Administrative Committee to carry fewer than 12 hours because of illness or outside employment, or for some other valid reason, may be placed on probation if the student's work is deemed unsatisfactory by the Administrative Committee and will be removed from probation when the committee deems the work satisfactory.

Class Attendance

Students are expected to attend all scheduled meetings of each class in which they are enrolled. At the beginning of each semester, instructors will explain the policy regarding absences in each of their classes. Students having excessive absences will be reported to the Office of the Dean. If class attendance does not improve thereafter, the student may be dropped from the class with the grade *W*, if passing at the time, or the grade *F*, if failing at the time. Class attendance may be a factor in determining the final grade in a course.

Scholarship Requirements

Those students having honor scholarships are expected to maintain a 3.0 grade point average while taking a minimum of 12 hours. Failure to maintain a 3.0 grade point average will result in the cancellation of the scholarship.

Grade Reports

A grade report will be available to the student on the Access to Academic Information webpages as soon as possible after the conclusion of each semester. This report will give the total hours and grade points earned during the semester, as well as the cumulative hours and grade points earned through that semester. Students should examine these reports carefully and discuss them with their faculty advisers. Any errors should be reported immediately to the Student Services Office of the School of Engineering.

A grade reported and recorded in the University Registrar's Office may be changed only upon written request of the instructor and with approval of the Administrative Committee. The committee will approve such a change only on certification that the original report was in error.

Undergraduate Enrollment for Graduate Credit

A qualified Vanderbilt senior may enroll in courses approved for graduate credit by the graduate faculty and receive credit which, upon admission to the Vanderbilt University Graduate School, may be applicable toward a graduate degree. The principles governing this option are as follows:

1. Work taken under this option is limited to those 200- and 300-level courses approved for graduate credit and listed as such in the catalog of the Graduate School, excluding thesis

- and dissertation research courses and similar individual research and reading courses.
- Such work must be in excess of that required for the bachelor's degree.
 - The student must, at the time of registration, have a *B* average in the preceding two semesters.
 - The total course load, graduate and undergraduate courses, must not exceed 18 hours in any one semester.
 - Undergraduate students who want to count for graduate credit courses taken under this option must consult the instructor of each course and must, at the time of registration, declare their intention on a form available in the Dean's Office.
 - Permission for Vanderbilt undergraduates to enroll in graduate courses does not constitute a commitment on the part of any program to accept the student as a graduate student in the future.
 - An undergraduate student exercising this option will be treated as a graduate student with regard to class requirements and grading standards.

All students who want to take 300-level courses, whether under this option or not, must obtain the written approval of their academic adviser, the instructor of the course and the Associate Dean for Research and Graduate Studies in the Engineering School.

Interested students should consult their faculty advisers and with the Graduate School office before attempting to register for graduate courses under this option.

Leave of Absence

A student at Vanderbilt or one who has been admitted to Vanderbilt may, with the approval of his or her academic dean, take an official leave of absence for as much as two semesters and a summer session. Leave of absence forms are available in the Student Services Office. A student who fails to register in the university at the end of the leave will be withdrawn from the university.

Change of Address

Any change of address should be reported to the School of Engineering Student Services Office or the University Registrar. The university will consider notices or other information delivered if mailed to the address on file in the University Registrar's office.

Special Students

The normal program of study is 12 to 18 hours per semester. Students authorized by the Administrative Committee to register for fewer than 12 hours are classified as special students.

Withdrawal from the University

A student proposing to withdraw from the university must notify the Student Services Office of the School of Engineering so that proper clearance may be accomplished and that incomplete work is not charged as a failure against the student's record.

Courses of Study

Hours are semester hours. The bracketed [3] indicates 3 semester hours of credit for one semester, and [3-3] for a two-semester course.

100-199 courses are primarily for freshmen and sophomores.

200-299 courses are normally taken by juniors and seniors but are open also to qualified sophomores and freshmen. Courses numbered 200-299 are eligible for graduate credit if they are listed in the *Graduate School Catalog*.

300-399 courses are graduate courses and are not open to undergraduates without the consent of the instructor, the adviser, and the associate dean for research and graduate studies.

W symbols used in course numbers designate courses that meet departmental writing requirements.

Abbreviations

BME	Biomedical Engineering
CE	Civil Engineering
ChBE	Chemical and Biomolecular Engineering
CmpE	Computer Engineering
CS	Computer Science
EECE	Electrical Engineering and Computer Engineering
ENGM	Engineering Management
ES	Engineering Science
ENVE	Environmental Engineering
ME	Mechanical Engineering
MSE	Materials Science and Engineering
SC	Scientific Computing

The Freshman Year

The freshman year curriculum for all of the engineering disciplines is:

Specimen Curriculum

FALL SEMESTER		Semester hours
Chemistry 102A	General Chemistry	3
Chemistry 104A	General Chemistry Laboratory	1
Mathematics 155A	Accelerated Single-Variable Calculus I	4
	Elective	3
Engineering Science 140 A-C	Introduction to Engineering	3
	Total	14

SPRING SEMESTER		Semester hours
Chemistry 102B and Chemistry 104B ‡	General Chemistry and General Chemistry Laboratory	3 1
or Materials Science 150 ‡	Materials Science I	4
Mathematics 155B	Accelerated Single-Variable Calculus II	4
Physics 116A	General Physics	3
Physics 118A	General Physics Laboratory	1
Engineering Science 101	Engineering Freshman Seminar (optional)	1
Computer Science 101 or 103	Programming and Problem Solving	3
	Total	15-16

‡ Chemical engineering and biomedical engineering majors must take Chemistry 102B and 104B.

Biomedical Engineering

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DIRECTOR OF GRADUATE STUDIES E. Duco Jansen

ASSOCIATE DIRECTOR OF GRADUATE STUDIES W. David Merryman

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Anna W. Roe, Thomas E. Yankeelov

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RESEARCH ASSOCIATE PROFESSORS Andre Diedrich, Daniel J.

France, Paul A. Harris

ASSISTANT PROFESSORS Eduard Y. Chekmenev, Zhaohua Ding, Craig L.

Duvall, William Grissom, Scott Guelcher, H. Charles Manning, W. David

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Jeffry S. Nyman, Baxter P. Rogers, Patricia K. Russ, Veniamin Sidorov

ADJUNCT ASSISTANT PROFESSORS Valerie Guenst, Judy T. Lewis

ADJOINT ASSISTANT PROFESSOR Bennett A. Landman

THE foundations of biomedical engineering are the same as those in other engineering disciplines: mathematics, physics, chemistry and engineering principles. Biomedical engineering builds on these foundations to solve problems in biology and medicine over the widest range of scales—from the nanoscale and molecular levels to the whole body. Biomedical engineering provides a robust platform for employment in the medical device and instrumentation industries as well as careers in companies that specialize in the development and application of biologics, biomaterials, implants and processes. Our graduates gain entry into nationally recognized graduate schools for continuing studies in biomedical engineering. Biomedical engineering is also a rigorous path for admission to and success in medical school for those students willing and able to excel in mathematics, physics, chemistry, biology, physiology and engineering.

The Department of Biomedical Engineering at Vanderbilt is unique among biomedical engineering programs in its immediate proximity to the world class Vanderbilt Medical Center, located on our compact campus. Our School of Medicine is among the top ten in funding from the National Institutes of Health and includes a National Cancer Institute-recognized Comprehensive Cancer Center, a major children's hospital and a Level I trauma center. This proximity and the strong relationships among faculty across multiple schools stimulate high impact research and provide unique educational and research opportunities for students.

Degree Programs. The Department of Biomedical Engineering offers courses of study leading to the B.E., M.S., M.Eng., and Ph.D. Vanderbilt biomedical engineering is a well established program with undergraduate degrees granted continuously since 1965. Our undergraduate curriculum undergoes regular review and revision to ensure relevancy and to maintain full ABET accreditation. Students have complete flexibility in the selection of biomedical engineering, program,

and open electives. This allows focus and depth in areas such as biomaterials and tissue engineering, biomedical imaging, biophotonics, bionanotechnology, modeling, therapy guidance systems, and biomedical instrumentation. Double majors with electrical engineering and with chemical engineering are available.

Facilities. The Department of Biomedical Engineering is located in Stevenson Center. Undergraduate instructional laboratories are equipped for study of biomedical processes, measurement methods and instrumentation. These facilities are equipped with embedded systems for instrumentation, design, and testing that mirror professional practice. Specialized facilities for biomedical imaging, biophotonics, technology-guided therapy including surgical guidance systems, biomaterials and tissue engineering, and nanobiotechnology for cellular engineering and nanomedicine are used both for faculty-led research and instructional purposes.

Undergraduate Honors Program. With approval of the Honors Program director, junior and senior students in biomedical engineering who have achieved a minimum grade point average of 3.5 may be accepted into the undergraduate Honors Program. Students in the program take at least 6 credit hours of 300-level (graduate) biomedical engineering courses, which can be counted toward the 127-hour undergraduate degree requirements as biomedical engineering electives or which can be taken for graduate school credit. Students in the Honors Program must also complete a two-semester-long research project and present a research report; this is generally accomplished through the BME 240A and 240B Undergraduate Research elective courses. Honors students must make a grade point average of 3.0 in these classes and maintain an overall 3.5 GPA to be designated as an honors graduate. The diploma designation is Honors in Biomedical Engineering.

Curriculum Requirements

The B.E. in biomedical engineering requires a minimum of 127 semester hours, distributed as follows:

1. Mathematics (15 hours): 155A-B, 175, 196.
2. Basic Science (24 hours): Chemistry 102A-B, 104A-B, Physics 116A-B and 118A-B, Biological Sciences 110/111A, and a second approved biological sciences course with laboratory.
3. Introductory engineering and computing (6 hours): ES 140A-C and either CS 103 (preferred) or CS 101.
4. Electrical engineering (7 hours): EECE 112, 213, 213L.
5. Biomedical engineering (31 hours): BME 101, 103, 210, 251, 252, 255, 260, 271, 272, 273, 297.
6. Biomedical engineering electives (11 hours) from an approved departmental list.
7. Program electives (9 hours): science, engineering, and math courses from an approved departmental list.
8. Liberal Arts Core (18 hours) to be selected to fulfill the Liberal Arts Core requirements listed under Degree Programs in Engineering.
9. Open electives (6 hours).

Undergraduates in biomedical engineering may apply the pass/fail option only to courses taken as liberal arts core or open electives, subject to school requirements for pass/fail.

Specimen Curriculum for Biomedical Engineering

		Semester hours	
		FALL	SPRING
SOPHOMORE YEAR			
BioSci 110A/111A	Introduction to Biological Sciences	4	–
	Biological Sciences course*	–	4
BME 101	Introductory Biomechanics	3	–
BME 103	Biomedical Materials	–	3
Math 175	Multivariable Calculus	3	–
Math 196	Differential Equations with Linear Algebra		4
Phys 116B, 118B	General Physics with Laboratory	4	–
EECE 112	Circuits I	–	3
	Liberal Arts Core	3	3
		17	17

* A second biological sciences course with laboratory must be selected from the departmental list of approved courses.

JUNIOR YEAR

BME 210	Physiological Transport Phenomena	3	–
BME 251–252	Systems Physiology	3	3
BME 260	Analysis of Biomedical Data	–	3
BME 271	Biomedical Instrumentation**	–	4
EECE 213, 213L	Circuits II	4	–
	Biomedical Engineering or program elective ***	3	4
	Liberal Arts Core	–	3
	Open elective	3	–
		16	17

SENIOR YEAR

BME 255W	Biomedical Engineering Laboratory	3	–
BME 272–273	Design of Biomedical Engineering Systems I, II	2	3
BME 297	Senior Engineering Design Seminar	1	–
	Biomedical Engineering or program elective***	7	6
	Liberal Arts Core	3	3
	Open elective	–	3
		16	15

** BME 271 may also be taken in the fall of the senior year.

*** BME and program electives must be selected from a list of approved courses available in the department office.

Course descriptions begin on page 317.

Chemical and Biomolecular Engineering

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CHEMICAL engineers play key roles in the development and production of commodity chemicals, pharmaceuticals, and bioengineered materials, high strength composites and specialty polymers, semiconductors and microelectronic devices, and a wide range of ultrapure fine chemicals. Indeed, chemical engineering is essential for the operation of contemporary society. The solutions to many of the problems that we face today—e.g., energy, the environment, development of high-performance materials—will involve chemical engineers.

The undergraduate program in chemical and biomolecular engineering prepares students to contribute to the solution of these and similar problems. Graduates find meaningful careers in industry, in government laboratories, and as private consultants. Some continue their education through graduate studies in chemical engineering, business, law, or medicine.

Mission. The mission of the Department of Chemical and Biomolecular Engineering is to educate those who will advance the knowledge base in chemical engineering, become practicing chemical engineers, and be leaders in the chemical and process industries, academia, and government; to conduct both basic and applied research in chemical engineering and related interdisciplinary areas; and to provide service to the chemical engineering profession, the School of Engineering, Vanderbilt University, the country, and the world.

Degree Programs. The Department of Chemical and Biomolecular Engineering offers the bachelor of engineering in chemical engineering and graduate study leading to the M.Eng., M.S., and Ph.D.

Undergraduate chemical and biomolecular engineering students acquire a solid background in mathematics, chemistry, biology, and physics. The chemical and biomolecular engineering program has as its basis courses in transport phenomena, thermodynamics, separations, and kinetics. Other courses deal with the principles and techniques of chemical engineering analysis and design, along with economic analysis, process control, chemical process safety, and engineering ethics. Laboratory courses offer the student an opportunity to make fundamental measurements of momentum, heat, and mass transport and to gain hands-on experience with bench scale and small scale pilot-plant apparatus, which can be computer controlled. Report writing is a principal focus in the laboratory courses. Many students have the opportunity to carry out individual research projects.

A specimen curriculum for a chemical engineering major follows. This standard program includes a number of electives.

Students, in consultation with their faculty advisers, may choose elective courses that maintain program breadth or may pursue a minor or focus area with their chemical engineering major. Double majors may be arranged in consultation with a faculty adviser.

The chemical and biomolecular engineering department recommends that students consider taking the Fundamentals of Engineering Examination (FE) in their senior year. This is the first step in obtaining a license as a professional engineer. The following courses are recommended for preparation for the FE: EECE 112, CE 180, and ME 190.

Undergraduate Honors Program. The professional Honors Program in chemical engineering provides an opportunity for selected students to develop individually through independent study and research. General requirements are described in the Special Programs chapter. The Chemical and Biomolecular Engineering Department requires a minimum overall GPA of 3.5. Acceptance to the program is made by petition to the faculty during the junior year. Transfer students meeting other requirements may be considered for admission after completing one semester at Vanderbilt. Candidates for honors choose their technical courses with the consent of a faculty honors adviser. At least 6 hours of courses 250 and above from the graduate catalog must be taken, plus 6 hours of ChBE 246 and 247. A formal written research report is submitted each semester ChBE 246 or 247 is taken with a final report and presentation given in the spring semester of the senior year to the ChBE Faculty and students. For honors students, ChBE 246 is substituted for ChBE 229W. The diploma designation is Honors in Chemical Engineering.

Facilities. The Chemical and Biomolecular Engineering Department is located in Olin Hall of Engineering. Departmental laboratories are equipped for study of transport phenomena, unit operations, kinetics, and process control. Current research areas for which facilities are available include molecular modeling; adsorption and surface chemistry; biochemical engineering and biotechnology; chemical reaction engineering; environment, including air pollution; materials; process modeling and control.

Curriculum Requirements

The B.E. in chemical engineering requires a minimum of 126 hours course credit. The courses and credits are distributed as follows:

1. Mathematics (14 hours). Required courses: Math 155A-B, 175, 198.
2. Basic Science (24 hours). Required courses: Chemistry 102A-B, 104A-B, 219A-B, 220A-B; Physics 116A-B, 118A-B.
3. Engineering Science (3 hours). Required courses: ES 140A-C.
4. Computer Science (3 hours). Required course: CS 103.
5. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed in the Degree Programs in Engineering.
6. Chemical and Biomolecular Engineering (32 hours). Required courses: ChBE 161, 162, 180, 223, 225, 228W, 230, 231, 233W, 234W, 297.
7. Chemical Engineering Focus Area or Double Major (32-36 hours). Students must complete one of the following:
 - a) Chemical Engineering (32 hours)
 - i) Required courses (15 hours): BioSci 110A; Chem 230; ChBE 229W, 242, 283.

- ii) Chemical and Biomolecular Engineering elective: 3 hours selected from ChBE course offerings.
- iii) Technical electives (6 hours). From this list of approved technical electives: BME (except 201, 241A-241B), ChBE, CE, CS 201 or above, EECE, ENVE, ME, MSE, ENGM 216, 254, 273, Astronomy (except 102, 130, 203), Biological Sciences 110a or above, Chemistry 202 or above, Earth and Environmental Sciences (except 100, 102, 108), Mathematics 194 or above (except 196, 252), Physics 200 or above, Neuroscience 201, 255, 269, Psychology 209, 234, 236.
- iv) Open electives (8 hours).
- b) Biotechnology (32 hours)
- i) Required courses (13 hours): BioSci 110A, 111A, 220; ChBE 282, 283.
- ii) Applied Mathematics elective: 3 hours selected from ChBE 242, 285; Chem 238; Math 216, 262.
- iii) Laboratory elective: 3 hours selected from ChBE 229W, 246, 247; BME 255W.
- iv) Technical electives: 6 hours selected from ChBE 242, 285, 286; BME 251, 252, 279, 281.
- v) Open electives (7 hours).
- vi) ChBE 242 and ChBE 285 can each be used to satisfy only one of ii) or iv).
- c) Materials (includes Minor in Materials Science and Engineering) (32 hours)
- i) Required courses (7 hours): MSE 150 and 250.
- ii) Applied Mathematics elective (3 hours): ChBE 242 or 285.
- iii) Laboratory elective: 3 hours selected from ChBE 229W, 246, 247.
- iv) Applied Materials elective: 6 hours selected from BME 274, 281; ChBE 284, 286, 287; ME 251.
- v) Science elective: 6 hours selected from Chem 203, 230, 235; Phys 225W, 229A, 254.
- vi) Chemical and Biomolecular Engineering elective (3 hours). Selected from ChBE course offerings. This requirement may be replaced by 3 hours of open electives if a ChBE course is taken to fulfill the Applied Materials elective.
- vii) Open electives (4 hours).
- d) Double Major with Chemistry (33 hours)
- i) Required courses (21 hours): Chem 203, 210, 212A, 230, 236, 295A-B; BioSci 110A, 220.
- ii) Applied Mathematics elective (3 hours): ChBE 242 or 285.
- iii) Applied Chemistry electives: 6 hours selected from BME 281; ChBE 282, 283, 284, 286, 287.
- iv) Engineering Elective: 3 hours to be selected from BME (except 201, 241A-B, 249), ChBE, CE, CS 201 or above, EECE, ENVE, ME, MSE, ENGM 216, 254, 273.
- e) Double Major with Biomedical Engineering (requires 130 total hours)
- i) Required courses (40 hours): BioSci 110A, 111A; BME 101, 103, 251, 252, 255W, 271, 272, 273, 297; EECE 112, 213, 213L; Math 196.
- ii) ChBE elective: ChBE 282 or 283.
- iii) BME elective: 3 hours to be selected from BME courses at the 200 level and higher with the exception of 201, 210, 241A-B, 260, 301-305, and 391-394.
- iv) Math 196 replaces Math 198 in the Mathematics requirement.
- v) BME 101, 272, 273, and 297 replace ChBE 180, 234W, and 297 in the ChBE Core requirement.

Specimen Curriculum for Chemical Engineering, Focus Area a)

		Semester hours	
		FALL	SPRING
SOPHOMORE YEAR			
Chem 219A-B	Organic Chemistry Laboratory	1	1
Chem 220A-B	Organic Chemistry	3	3
Math 175	Multivariable Calculus	3	–
Math 198	Methods of Ordinary Differential Equations	–	3
Physics 116B	General Physics	3	–
Physics 118B	General Physics Laboratory	1	–
ChBE 161	Chemical Process Principles	3	–
ChBE 162	Chemical Engineering Thermodynamics	–	3
ChBE 180	Modeling and Simulation in Chemical Engineering	–	3
	Liberal Arts Core	3	3
		<hr/>	<hr/>
		17	16
JUNIOR YEAR			
BioSci 110A	Introduction to Biological Sciences	3	–
Chem 230	Physical Chemistry I	3	–
ChBE 223	Phase Equilibria and Stage-Based Separations	3	–
ChBE 225	Chemical Reaction Engineering	–	3
ChBE 228W	Chemical Engineering Laboratory I	–	4
ChBE 230	Fluid Mechanics and Heat Transfer	3	–
ChBE 231	Mass Transfer and Rate-Based Separations	–	3
	Liberal Arts Core	3	3
	Technical elective	–	3
		<hr/>	<hr/>
		15	16

SENIOR YEAR		Semester hours	
		FALL	SPRING
ChBE 229W	Chemical Engineering Laboratory II	3	–
ChBE 233W	Chemical Engineering Process and Product Design	3	–
ChBE 234W	Chemical Product Design Projects	–	3
ChBE 242	Chemical Process Control	–	3
ChBE 283	Bioprocess Engineering	3	–
ChBE 297	Senior Engineering Design Seminar	1	–
	Chemical and Biomolecular Engineering elective	3	–
	Liberal Arts Core	–	3
	Technical elective	–	3
	Open elective	4	4
		17	16

Specimen curricula for focus areas and double majors b) to e) in chemical engineering can be found on the department's website.

Course descriptions begin on page 320.

Civil Engineering

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VANDERBILT'S Department of Civil and Environmental Engineering offers a broad-based education in civil and environmental engineering fundamentals, coupled with development of leadership, management, and communications skills to establish a foundation for lifelong learning and flexible career development. This goal requires going beyond technical competence in a balanced education to develop future leaders in the fields of consulting, industry, business, law, government, and research. Civil engineers must be able to face complex problems of modern society involving the development of physical facilities that serve the public while protecting the environment and preserving social values. Challenges facing civil and environmental engineers concern housing, urban transportation, pollution control, water resources development, industrial development, maintaining and advancing our nation's aging infrastructure, and exploring space. Addressing these challenges with today's limited resources requires innovative and original ideas from highly-skilled engineers.

Undergraduates majoring in civil engineering receive a strong background in mathematics, science, engineering science, and engineering design. The program also includes courses in economics, humanities, social sciences, resources management, and public policy. Students participate in design teams and laboratory studies as well as classroom activities. Use of various computer-based methods is integral to problem solving and design.

Degree Programs. At the undergraduate level, the Department of Civil and Environmental Engineering offers the B.E. in civil engineering. The curriculum includes upper-level analysis and design courses in structural, geotechnical, environmental, water resources, and transportation engineering. In addition, a major in chemical engineering with a minor in environmental engineering is available.

Vanderbilt's B.E. in civil engineering prepares students for entry-level positions in many specialty areas of civil engineering, as well as many other types of careers, such as business, construction, and law. Today, however, and even more so in the future, professional practice at a high level will require an advanced degree. We recommend that students seriously consider pursuing the M.S. or M. Eng. soon after obtaining the B.E.

At the graduate level, the department educates leaders in infrastructure and environmental engineering research and practice, with emphasis on the use of reliability and risk management. Reliability and risk management includes engineering design, uncertainty analysis, construction and repair, life-cycle and cost-benefit analysis, information management, and fundamental phenomena intrinsic to the understanding of advanced infrastructure and environmental systems. Example applications include performance, reliability and safety of structures, restoration of contaminated sites, transportation control systems, management of environmental resources, and enhancing of the eco-compatibility of industry. Development and application of advanced information systems as applied to civil and environmental engineering needs is an important part of the program.

The graduate program in civil engineering offers the M.S. and Ph.D., with emphasis in the areas of structural engineering and mechanics and transportation engineering.

The graduate program in environmental engineering offers the M.S. and Ph.D. in the areas of environmental engineering and environmental science, with emphasis on contaminant

behavior in the environment, waste management, nuclear environmental engineering, and environmental remediation. Both thesis and non-thesis options are available at the M.S. level.

The graduate programs in both civil engineering and environmental engineering also offer the master of engineering (M.Eng.), an advanced professional degree especially designed for practicing engineers wanting to pursue post-baccalaureate study on a part-time basis, and for engineers seeking greater emphasis on engineering design as part of graduate education.

B.E./M.Eng. Five Year Program. Students seeking advanced study in civil and environmental engineering may be interested in the combined B.E./M.Eng., enabling students to complete the B.E. in civil engineering and M.Eng. in civil engineering or environmental engineering in 5 years.

Construction Management Five Year Program. Students seeking advanced study in construction management may be particularly interested in the combined B.E./M.Eng., enabling students to complete the B.E. in civil engineering and M.Eng. in civil engineering (construction management emphasis) in five years.

Undergraduate Honors Program. Recognized with the diploma designation Honors in Civil Engineering, exceptional students may be invited in their junior year to participate in the civil engineering Honors Program. Designed as a unique individualized educational experience, participants work closely with departmental faculty members to tailor a selection of courses that actively immerses them in a selected field of study. Experiences include enrollment in a 3 semester hour independent study course and participation in a summer research internship. Honors Program participants are especially well-prepared to enter graduate study, and they may count the independent study course towards their civil engineering technical electives.

Facilities. The civil engineering laboratory provides for static and dynamic testing of materials and structural components and assemblies. Testing facilities include capabilities of testing composites, metals, and concrete under static loads, fatigue, base acceleration (to simulate seismic events) and intermediate to high speed impacts (to simulate responses to blast events). Full soils testing facilities are available. Hydraulics facilities include several model flow systems to illustrate principles of fluid mechanics and hydrology. The transportation laboratory is computer-based, with emphasis on transportation systems and design, intelligent transportation systems, and geographic information systems.

The newly renovated environmental laboratories are fully supplied with modern instrumentation for chemical, physical, biological, and radiological analysis of soils, sediments, water, wastewater, air, and solid waste. They include equipment for the study of biological waste treatment, physical-chemical waste treatment, contaminant mass transfer, and state-of-the-art instrumentation for gas and liquid chromatography, mass spectroscopy, atomic absorption spectroscopy, gamma spectroscopy, inductively coupled plasma mass spectroscopy, gas adsorption (for pore structure determination), thermal mechanical analysis, modulated scanning differential calorimetry, and simultaneous thermal gravimetric analysis differential scanning calorimetry/mass spectroscopy. All are available for student use in courses, demonstrations, and research.

Curriculum Requirements

The B.E. in civil engineering requires a minimum of 126 hours, distributed as follows:

1. Mathematics (14 hours). Required courses: 155A-155B, 175, 198. (Qualified students may substitute an honors mathematics sequence.)
2. Basic science (12 hours). Required courses: Chemistry 102A and 104A; and Physics 116A-B and 118A-B.
3. Basic science elective (4 hours). To be selected from the following list of scientific subjects: (a) Chemistry 102B/104B and all chemistry courses at or above 200 (recommended for students interested in environmental engineering); (b) Biological Sciences 110A, 110B, and all courses 200 and above; (c) Earth and Environmental Sciences 101 and 111, 103 and 113, 225, 226, 230, 240; (d) Physics—all courses above 130 (astronomy not accepted); and (e) Materials Science and Engineering—all courses except 209B,C and 210A,B.
4. Computing (3 hours). Required course: CS 103.
5. Engineering fundamentals (27 hours). Required courses: ES 140A-C; CE 160, 161, 180, 182, 203,204; ENGM 216; ME 190; MSE 232; ME 220A or ChBE 162 (students interested in environmental engineering are encouraged to enroll in ChBE 162).
6. Probability and statistics elective (3 hours). Select from CE 247, Math 216, or Math 218.
7. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed under Degree Programs in Engineering.
8. Open electives (6 hours).
9. Technical electives (6 hours). To be selected from the following list of technical and scientific subjects: (a) all courses in BME, ChBE, CE, ENVE, EE, ME, and ENGM 242, 273; (b) all courses acceptable as Science electives as indicated above; and (c) Math 194 and all Math courses 210 and above, except 216, 218, and 252.
10. Civil Engineering Core (27 hours). Required courses: CE 205W, 225, 226, 227, 232, 235, 240, 286, and CE 252. In addition, all students must complete CE 248-249, a two-part, major meaningful and comprehensive project design course.
11. Civil Engineering Professional Electives (6 hours). To be selected from following list of course offerings: CE 251, CE 255, CE 256, CE 257, CE 293, CE 294, CE 298, ENVE 262, ENVE 272, ENVE 276, ENVE 277, ChBE 280.

Optional Areas of Specialization

Students may desire to use open electives, technical electives, and civil engineering professional electives to gain additional depth and expertise in particular areas of emphasis in civil engineering, including environmental and water resources engineering, structural engineering, and transportation engineering. It is recommended that students discuss specific course selections with their academic adviser. Students desiring advanced topic coverage should also consider 300-level courses, with approval of their adviser.

Environmental and Water Resources Engineering	Structural Engineering	Transportation Engineering
ENVE 252	CE 251	CE 255
ENVE 254	CE 293	CE 256
ENVE 260	CE 294	CE 257
ENVE 262	CE 295	CE 293
ENVE 270	ME 259	CE 294
ENVE 271	ME 275	ENVE 262
ENVE 272		
ENVE 273		
ENVE 274		
ENVE 276		
ENVE 277		
ChBE 280		

Cross-Cutting Courses. The following selected courses are multi-disciplinary in nature, cross-cutting multiple areas of specialization: CE 247, CE 259, CE 290, ENVE 220A, ENVE 220B, ENVE 220C, ENVE 264, ENVE 296, and MATH 194.

Specimen Curriculum for Civil Engineering

		Semester hours	
		FALL	SPRING
SOPHOMORE YEAR			
Math 175	Multivariable Calculus	3	–
Physics 116B	General Physics	3	–
Physics 118B	General Physics Laboratory	1	–
CE 160	Civil and Environmental Eng. Information Systems I	2	–
CE 180	Statics	3	–
CE 225	Transportation Systems Engineering	3	–
Math 198	Methods of Ordinary Differential Equations	–	3
CE 161	Civil and Environmental Eng. Information Systems II	–	2
ME 190	Dynamics	–	3
CE 182	Mechanics of Materials	–	3
	Thermodynamics (ME 220A or ChBE 162)	–	3
	Liberal Arts Core	–	3
		15	17
JUNIOR YEAR			
CE 203	Fluid Mechanics	3	–
CE 204	Fluid Mechanics Laboratory	1	–
CE 226	Introduction to Environmental Engineering	3	–
CE 232	Introduction to Structural Analysis	3	–
MSE 232	Strength and Structure of Engineering Materials	1	–
CE 240	Geotechnical Engineering	3	–
	Liberal Arts Core	3	–
CE 205W	Civil and Environmental Engineering Laboratory	–	2
ENGM 216	Engineering Economy	–	3
CE 227	Introduction to Water Resources Engineering	–	3
CE 235	Introduction to Structural Design	–	3
	Probability and Statistics Elective	–	3
	Liberal Arts Core	–	3
		17	17

SENIOR YEAR		Semester hours	
		FALL	SPRING
CE 248	Civil Engineering Design I	1	–
CE 286	Construction Project Management	3	–
	CE Professional Elective	3	–
	Technical Elective	3	–
	Open Elective	3	–
	Liberal Arts Core	3	–
CE 249	Civil Engineering Design II	–	2
CE 252	Civil and Environmental Engineering Seminar	–	1
	CE Professional Elective	–	3
	Technical Elective	–	3
	Open Elective	–	3
	Liberal Arts Core	–	3
		16	15

Pre-Architecture Program

Civil engineering students interested in pursuing architecture at the graduate level should include courses that emphasize a broad sense of art and architectural history, including courses in studio art. Before applying to graduate programs, students will need to develop a portfolio of creative work that generally includes drawing, prints, sculpture, photographs, and creative writing. Professor Michael Aurbach in the Department of Art serves as the pre-architecture adviser to Vanderbilt students. In addition, the Vanderbilt student club, BLUEprint, seeks to educate and prepare students interested in this field.

Minor in Environmental Engineering

A minor in environmental engineering is available to all non-civil engineering students. It requires a total of 15 hours of environmental engineering courses, comprising 6 hours of required courses and 9 hours of electives, chosen from the following list:

Required Courses (6 hours)

CE 226 – Introduction to Environmental Engineering
ENVE 271 – Environmental Chemistry

Elective Courses (9 hours)

CE 227 – Introduction to Water Resources Engineering
CE 259 – Geographic Information Systems
ChBE 280 – Atmospheric Pollution
ENVE 252 – Physical Hydrology
ENVE 254 – Energy and Water Resources
ENVE 260 – Solid and Hazardous Waste Management
ENVE 262 – Hydrology
ENVE 264 – Environmental Assessments
ENVE 270 – Environmental Thermodynamics, Kinetics, and Mass Transfer
ENVE 272 – Biological Unit Processes
ENVE 273 – Environmental Characterization and Analysis
ENVE 274 – Surface Water Quality Modeling
ENVE 276 – Groundwater Hydrology
ENVE 277 – Physical/Chemical Unit Processes
ENVE 285 – Introduction to Nuclear Environmental Engineering
ENVE 296 – Safety, Security, and Environmental Risk Management

Minor in Energy and Environmental Systems

The minor in energy and environmental systems is designed to provide students with a working knowledge of the fundamentals of energy systems and their impact on the environment. The future health and well-being of humanity hinge in large part on smart production and use of energy, water, and related resources, as these are central determinants of climate change,

habitable space, and human and ecological health. This program examines the relationships among individual, institutional, and societal choices for energy production and use, and the impacts and benefits of these choices on the environment and health through climate, water quality, and natural resources. It requires a total of 15 semester hours of course work, some of which may be taken as electives associated with the student's major program. Five courses are required: two core courses and three elective courses distributed among three areas (at least one course from each of two areas): Area I: Energy Systems, Area II: Environmental Engineering, and Area III: Environmental Survey.

Required Courses (6 hours)

ENVE 254 – Energy and Water Resources
ENVE 264 – Environmental Assessments

Elective Courses (9 hours)

Area I: Energy Systems

EECE 267 – Power System Analysis
ME 210 – Special Topics: Nuclear Power
ME 260 – Energy Conversion I
ME 264 – Internal Combustion Engines
ME 265 – Direct Energy Conversion

Area II: Environmental Engineering

CE 226 – Introduction to Environmental Engineering
CE 227 – Introduction to Water Resources Engineering
ChBE 280 – Atmospheric Pollution
ENVE 262 – Hydrology
ENVE 270 – Environmental Thermodynamics, Kinetics, and Mass Transfer
ENVE 273 – Environmental Characterization and Analysis
ENVE 285 – Introduction to Nuclear Environmental Engineering
ENVE 296 – Operational Risk Management
ME 262 – Environmental Control

Area III: Environmental Survey

ANTH 207 – Energy, Environment, and Culture
CE 259 – Geographic Information Systems
CE 298 – Building Systems and LEED
EES 108 – Earth and the Atmosphere
EES 201 – Global Change and Global Issues
PHIL 273 – Environmental Philosophy
SOC 270 – Human Ecology and Society

Minor in Engineering Management

A minor in engineering management is available to all students in civil engineering. This program provides students with a working knowledge of the fundamentals of business and engineering management. It requires a minimum of 15 semester

hours of course work, some of which may be taken as electives associated with the student's major program. Five courses are required: four core courses and the remaining course chosen from a list of electives. A detailed description of the engineering management minor is available in this catalog.

Study Abroad

Civil engineering students can participate in the Vanderbilt Study Abroad programs (see description of the Study Abroad programs in this catalog). Civil engineering students often participate during the fall semester of their junior year, but students may study abroad in either the sophomore or the junior year.

Civil Engineering

Course descriptions begin on page 321.

Environmental Engineering

Course descriptions begin on page 324.

Computer Engineering

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ASSISTANT PROFESSORS Yi Cui, Yuan Xue

THE program in computer engineering deals with the organization, design, and application of digital processing systems as general-purpose computers or as embedded systems, i.e., components of information processing, control, and communication systems. The program provides a strong engineering background centered on digital technology combined with an understanding of the principles and techniques of computer science. Computer engineering is design-oriented. The basic principles of engineering and computer science are applied to the task at hand, which may be the design of a digital processor, processor peripheral, or a complete digital processor-based system. Whatever the undertaking, the comprehensive academic training in this program enables engineers to evaluate the impact of their decisions, whether working with hardware, software, or the interface between the two.

The computer engineering program combines fundamental core requirements with flexibility to allow students to specialize in a variety of emphasis areas within the program. The curriculum includes requirements in the basic sciences, mathematics, and humanities; a primary core of hardware

and software courses; and a set of electives that combine breadth and depth requirements as described below. Students who major in computer engineering who wish to apply for graduate study in electrical engineering or computer science are encouraged strongly to select their elective courses to demonstrate depth in that particular area; the structure of the program enables that option. The course of study leads to a bachelor of engineering.

Undergraduate Honors Program. With faculty approval, junior and senior students may be accepted into the Honors Program. To achieve honors status, the student must:

1. achieve and maintain a minimum GPA of 3.5.
2. choose 6 hours of EE/CmpE program elective credit from among the following list:
 - a. research-based independent study credit, or
 - b. design domain expertise (DE) courses beyond the one course required by the program, or
 - c. 300-level courses.
3. complete 3 hours of research-based independent study credit (with final written report) in addition to all other requirements.

The diploma designation is Honors in Computer Engineering.

Curriculum Requirements

The B.E. in computer engineering requires a minimum of 127 hours distributed as follows:

1. Mathematics (18 hours). Required courses: 155A, 155B, 175, 196, 216 (qualified students may substitute an honors mathematics sequence).
2. Basic Science (16 hours). Required courses: Chemistry 102A, Chemistry 104A, Physics 116A-B and 118A-B, MSE 150 (or Chemistry 102B, Chemistry 104B).
3. Engineering Fundamentals (6 hours). Required courses: ES 140A-C, ES 210W.
4. Culminating Design Experience (7 hours). Required courses: EECE 295, EECE 296, EECE 297.
5. Computer Engineering Core (at least 26 hours). Required courses: EECE 112, 116/116L, 218/218L and either 213/213L or 214; CS 101, 201, 231, and 251.
6. Computer Engineering Electives (18 hours). Defined by a structure that includes the three Computer Engineering Areas of Concentration listed below. Students must complete at least two courses in each of two areas of concentration. Embedded Systems (Area 1) must include EECE 276, Computing Systems and Networks (Area 2) must include CS 281 and Intelligent Systems and Robotics (Area 3) must include EECE 257. Students must complete at least one approved design domain expertise (DE) course as designated below. Other electives from any of the Areas of Concentration or approved independent study (CS 240A-240B; EECE 203-204) to total 18 hours.

Computer Engineering Areas of Concentration

Embedded Systems

EECE 276 (DE)
 EECE 256 (DE)
 EECE 257
 EECE 258 (DE)
 EECE 275
 EECE 277 (DE)
 EECE 285 (DE)
 CS 274 (DE)

Computing Systems and Networks

CS 281
 CS 265
 CS 274 (DE)
 CS 278 (DE)
 CS 279 (DE)
 CS 282 (DE)
 CS 283 (DE)
 CS 284 (DE)
 CS 285
 EECE 261
 EECE 262

Intelligent Systems and Robotics

EECE 257
 EECE 253 (DE)
 EECE 254
 EECE 258 (DE)
 ME 271
 CS 260
 CS 269 (DE)

(DE) designates a Design Domain Expertise course

7. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed in the Degree Programs in Engineering.
8. Technical electives (15 hours).
 - a. (6-15 hours). At least 6 hours must be taken from this list of approved engineering technical electives.
 - BME (except 201, 240A-240B, 241A-241B)
 - ChBE
 - CE
 - CS (except 103, 151)
 - EECE (hours above basic requirement in sections 5 and 6 above)
 - ENGM 273
 - ME
 - MSE (except 150)
 - b. (0-9 hours). Up to 9 hours may be taken from this list of optional technical electives.
 - ENGM 216, 221, 244
 - MSE 150 (if Chemistry 102B is used as a basic science)
 - Astronomy (except 102, 115F, 203)
 - Biological Sciences (except 115F)
 - Chemistry (except 101A-B, 102A-B, 115F)
 - Earth and Environmental Sciences (except 100, 102, 115F)
 - Mathematics above 194 (except 198, 252)
 - Physics (except courses numbered 122 or below)
 - Neuroscience 201, 255, 269
 - Psychology 208, 209, 234, 236
9. Open Elective (3 hours).

Specimen Curriculum for Computer Engineering

		Semester hours	
		FALL	SPRING
FRESHMAN YEAR			
EECE 116/116L†	Digital Logic		4
CS101	Programming and Problem Solving		3
	Other freshman courses (see the engineering freshman-year specimen curriculum)	14	8
		14	15
SOPHOMORE YEAR			
Math 175	Multivariable Calculus	3	–
Math 196	Differential Equations with Linear Algebra	–	4
Physics 116B	General Physics	3	–
Physics 118B	General Physics Laboratory	1	–
MSE 150 †	Materials Science I	–	4
EECE 112	Circuits I	3	–
EECE 218/218L	Microcontrollers	–	4
CS 201	Program Design and Data Structures	3	–
CS 231	Computer Organization	–	3
	Liberal Arts Core	3	3
		16	18
JUNIOR YEAR			
Math 216	Probability and Statistics for Engineering	–	3
ES 210W	Technical Communications	3	–
EECE 276/276L	Embedded Systems		–
or CS 281	Principles of Operating Systems I	4/3	–
EECE 213/213L	Circuits II		–
or EECE 214	Signals and Systems	4/3	–
CS 251	Intermediate Software Design	3	–
	CmpE Program Elective ‡	3	6
	Liberal Arts Core	–	3
	Technical Electives	–	6
		15-17	18
SENIOR YEAR			
EECE 295	Project Management for EECE	3	–
EECE 296	EECE Design	–	3
EECE 297	Senior Engineering Design Seminar	1	–
	CmpE Program Electives ‡	3	3
	Liberal Arts Core	3	3
	Technical Electives	6	3
	Open Electives	–	3
		16	15

† Computer engineering majors are encouraged to take EECE 116 in the spring of their freshman year in lieu of MSE 150. MSE 150 may be taken in the sophomore year.

‡ As described in "Computer Engineering Degree Requirements" subsection 6. At least one design domain expertise (DE) course required prior to EECE 296.

Course descriptions begin on page 325.

Computer Science

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 ASSISTANT PROFESSOR OF THE PRACTICE Julie L. Johnson

THE program in computer science blends scientific and engineering principles, theoretical analysis, and actual computing experience to provide undergraduate students with a solid foundation in the discipline. Emphasis is on computing activities of both practical and intellectual interest, and on theoretical studies of efficient algorithms and the limits of computation. Computer facilities are available for class assignments, team projects, and individual studies. Students are challenged to seek original insights throughout their study. Working in teams, participating in summer internships, supporting student professional organizations, and developing interdisciplinary projects are strongly encouraged.

The computer science major provides an excellent background for medical studies, and the flexibility provided by its many open electives allows students to prepare for medical school while earning a degree in computer science with a normal load in four years. Interested students should discuss their plans with their computer science adviser in the fall of their first year.

In addition to the bachelor of science, the master of science, master of engineering, and doctor of philosophy are also awarded in computer science. Many students choose to double major in mathematics.

Undergraduate Honors Program. The Honors Program provides recognition for select undergraduates who have experienced advanced study in computer science. Students who have an overall GPA of 3.5 or better, a GPA of 3.5 or better in computer science classes, and six hours of any combination of undergraduate research (CS 240A, CS 240B) and 300-level courses will be granted honors in the computer science program. The diploma designation is Honors in Computer Science.

Curriculum Requirements

The B.S. in computer science requires a minimum of 120 hours, with distribution as follows:

1. Mathematics (17–22 hours). Required components:

(a) A calculus sequence (8–12 hours).

Selected from the following:

–150A, 150B, 170, 175

–155A, 155B, 175

–205A, 205B

(b) Linear algebra (3–4 hours): 194, 204, or 205B.

(c) Statistics/Probability (3 hours): 216, 218, or 247.

Elective course (3 hours):

Selected from: 198, 200, 208, 215, 219, 221, 223, 226, 247, 250, 253, 274, 275, 288.

2. Science (12 hours).

Selected from the following list. Each is a four credit hour lab course. Students are required to take at least one two-course sequence.

–Biological Sciences (110A–110B and 111A–111B)

–Biological Sciences (100, 218, 219)

–Chemistry (102A and 104A, 102B and 104B)

–Earth and Environmental Sciences (101 and 111)

–Materials Science and Engineering 150

–Physics (116A-B and 118A-B)

Recommended: Chemistry 102A and 104A, Physics 116A-B.

3. Introduction to Engineering (3 hours). ES 140A-C.

4. Writing Component (3 hours). ES 210W or one designated “W” course.

5. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed in the Degree Programs in Engineering.

6. Computer Science Core (28 hours).

–Software/Problem Solving: CS 101, CS 201, CS 251, and CS 270.

–Hardware/Systems: EECE 116, 116L, CS 231, and CS 281.

–Foundations: CS 212 and CS 250.

7. Computer Science Depth (12 hours). To be selected from computer science courses numbered CS 240 or higher, or from the following EECE courses: 253, 254, or 276; or from Math courses 226 or 288. At least one course (i.e., 3 hours) must be a designated project course selected from CS 258, 265, 269, 274, 276, 279, 282, 283, 284, or 285.

8. Technical Electives (6 hours) To be selected from computer science courses numbered CS 240 or higher; from courses within the School of Engineering outside of computer science numbered 200 or higher (students are encouraged to note the two-course sequence EECE 295-296); or from courses numbered 200 or higher in the College of Arts and Science listed in the mathematics and natural sciences (MNS) AXLE distribution requirements.

9. Open Electives (16–21 hours).

10. Computers and Ethics. Three hours from the Liberal Arts Core (#5) or Open Electives (#9) must be an approved ethics course (CS 151 or Philosophy 105).

Pass/Fail Courses. The only courses that computer science students may choose to take pass/fail are those in items 5 and 9 above.

Specimen Curriculum for Computer Science

		Semester hours	
		FALL	SPRING
FRESHMAN YEAR			
Chem 102A	General Chemistry	3	–
Chem 104A	General Chemistry Laboratory	1	–
Physics 116A	General Physics	–	3
Physics 118A	General Physics Laboratory	–	1
Math 155A	Accelerated Single-Variable Calculus I	4	–
Math 155B	Accelerated Single-Variable Calculus II	–	4
ES 140	Introduction to Engineering	3	–
CS 101	Programming and Problem Solving	–	3
	Open Electives	3	–
	Liberal Arts Core	–	3
		14	14
SOPHOMORE YEAR			
Physics 116B	General Physics	3	–
Physics 118B	General Physics Laboratory	1	–
Math 175	Multivariable Calculus	–	3
EECE 116/116L	Digital Logic	4	–
CS 201	Program Design and Data Structures	3	–
CS 212	Discrete Structures	–	3
CS 231	Computer Organization	–	3
CS 251	Intermediate Software Design	–	3
	Liberal Arts Core	–	3
	Open Elective	3	–
		14	15
JUNIOR YEAR			
Math 194	Methods of Linear Algebra	–	3
Math 218	Introduction to Math Statistics	3	–
ES 210W	Technical Communications	3	–
CS 250	Algorithms	–	3
CS 270	Programming Languages	3	–
CS 281	Operating Systems Principles	3	–
	Computer Science Project	–	3
	Liberal Arts Core	3	3
	Computer Science Depth	3	3
		18	15
SENIOR YEAR			
	Math Elective (e.g., Math 250)	3	–
	Computer Science Depth	6	6
	Liberal Arts Core	3	3
	Open Electives	3	6
		15	15

Second Major in Computer Science for Non-Engineering Students

The second major in computer science for students enrolled outside the School of Engineering requires 40 hours distributed according to items 6 and 7 of the curriculum requirements listed above.

Courses taken toward the second major may not be taken pass/fail.

Computer Science Minor

The minor in computer science requires 19 hours of computer science courses as follows:

1. Programming: CS 101	3
2. Discrete Structures: CS 212	3
3. Digital Logic Fundamentals: EECE 116/116L	4
4. Intermediate Computer Concepts: CS 201	3
5. One of CS 231 (Computer Organization), CS 250 (Algorithms), or CS 251 (Int. Software Design)	3
6. One additional CS course numbered 240 or above	3
Total hours:	19

Courses taken toward the minor may not be taken pass/fail.

Course descriptions begin on page 325.

Electrical Engineering

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RESEARCH ASSISTANT PROFESSORS Bo K. Choi, Pierre-François

D'Haese, Enxia Zhang

THE electrical engineer has been primarily responsible for the information technology revolution that society is experiencing. The development of large-scale integrated circuits has led to the development of computers and networks of ever-increasing capabilities. Computers greatly influence the methods used by engineers for designing and problem solving.

The curricula of the electrical engineering and computer engineering majors are multifaceted. They provide a broad foundation in mathematics, physics, and computer science and a traditional background in circuit analysis and electronics. Several exciting areas of concentration are available, including microelectronics, computer systems, robotics and control systems, and signal

processing. Double majors may be arranged with some programs, including biomedical engineering and mathematics. Students receive an education that prepares them for diverse careers in industry and government and for postgraduate education.

Undergraduate Honors Program. With faculty approval, junior and senior students may be accepted into the Honors Program. To achieve honors status, the student must:

1. achieve and maintain a minimum GPA of 3.5.
 2. choose 6 hours of EE/CmpE program elective credit from among the following list:
 - a. research-based independent study credit, or
 - b. design domain expertise (DE) courses beyond the one course required by the program, or
 - c. 300-level courses.
 3. complete 3 hours of research-based independent study credit (with final written report) in addition to all other requirements.
- The diploma designation is Honors in Electrical Engineering.

Facilities. Electrical and computer engineering supports undergraduate laboratories emphasizing the principal areas of the disciplines: analog and digital electronics, microcomputers, microprocessors, microelectronics, and instrumentation. In addition, several specialized facilities are available for graduate research: the advanced carbon nanotechnology and diamond labs, the Institute for Software Integrated Systems, the Institute for Space and Defense Electronics, the Medical Image Processing Laboratory, the Center for Intelligent Systems and Robotics Laboratories, the Embedded Computer Systems Laboratory, and biomedical, biosensing, and photonics laboratories.

The work in electrical and computer engineering is supported by a variety of computers and networks, including the high-performance computing facilities of the Advanced Computing Center for Research and Education. Vanderbilt is one of the founding partners in the Internet II initiative.

Curriculum Requirements

The B.E. in electrical engineering requires a minimum of 128 hours distributed as follows:

1. Mathematics (18 hours). Required courses: 155A, 155B, 175, 196, 216 (qualified students may substitute an honors mathematics sequence).
2. Basic Science (16 hours). Required courses: Chemistry 102A, Chemistry 104A, Physics 116A-B and 118A-B, MSE 150 (or Chemistry 102B, Chemistry 104B for some double majors).
3. Engineering Fundamentals (6 hours). Required courses: ES 140A-C, ES 210W.
4. Culminating Design Experience (7 hours). Required courses: EECE 295, EECE 296, EECE 297.
5. Electrical Engineering Core (24 hours). Required courses: CS 103 or 101; EECE 112, 116/116L, 213/213L, 214, 233, 235/235L.
6. Electrical Engineering Electives (18 hours). Defined by a structure that includes the five Electrical Engineering Areas of Concentration listed below. Students must complete at least two courses in each of two concentration areas. Students must complete at least one approved design domain expertise (DE) course as designated below. Other EECE electives to total 18 hours.

Electrical Engineering Areas of Concentration

Computer Engr.	Microelectronics	Signal/Image Processing	Robotics	Networking and Comm.
EECE 218	EECE 275	EECE 252	EECE 254	EECE 252
EECE 256 (DE)	EECE 280 (DE)	EECE 253 (DE)	EECE 257	EECE 261
EECE 275	EECE 283	EECE 254	EECE 258	EECE 262
EECE 276 (DE)	EECE 284	EECE 256 (DE)	ME 271	
EECE 277 (DE)	EECE 285 (DE)	BME 263		
EECE 285 (DE)	EECE 288	EECE 286		
CS 274 (DE)	BME 271	CS 258		
ME 271		BME 271		

(DE) designates a Design Domain Expertise course

7. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed in the Degree Programs in Engineering.

8. Technical electives (18 hours).

a. (9–18 hours). At least 9 hours must be taken from this list of approved engineering technical electives.

BME (except 201, 240A-240B, 241A-241B)

ChBE

CE

CS (except 101, 103, 151)

EECE (hours above basic requirement of section 5 and 6 above)

ME

MSE (except 150)

ENGM 273

b. (0–9 hours). Up to 9 hours may be taken from this list of optional technical electives.

ENGM 216, 221, 244

MSE 150 (if Chemistry 102B is used as a basic science)

Astronomy (except 102, 203)

Biological Sciences

Chemistry (except 101A-B, 102A-B)

Earth and Environmental Sciences (except 100, 102)

Mathematics above 194 (except 198, 252)

Physics (except courses numbered 122 or below)

Neuroscience 201, 255, 269

Psychology 208, 209, 234, 236

9. Open Elective (3 hours).

Double majors have special curricula that require more than 128 hours and a different distribution of electives. See the EECS webpage or the EECE double major adviser for these curricula.

Specimen Curriculum for Electrical Engineering

		Semester hours	
		FALL	SPRING
FRESHMAN YEAR †			
EECE 116 /116L†	Digital Logic	–	4
	Other Freshman Courses (see the engr. freshman-year specimen curriculum)	14	12
		14	16
SOPHOMORE YEAR			
Math 175	Multivariable Calculus	3	–
Math 196	Differential Equations with Linear Algebra	–	4
Physics 116B	General Physics	3	–
Physics 118B	General Physics Laboratory	1	–
CS 103 or 101 †	Programming and Problem Solving	3	–
EECE 112	Circuits I	3	–
EECE 213/213L	Circuits II	–	4
	Liberal Arts Core	3	3
	Technical Electives	–	6
		16	17
JUNIOR YEAR			
Math 216	Probability and Statistics for Engineering	–	3
ES 210W	Technical Communications	–	3
EECE 214	Signals and Systems	3	–
EECE 233	Electromagnetics	3	–
EECE 235/235L	Electronics I	4	–
	EE Program Electives ‡	–	9
	Liberal Arts Core	3	3
	Technical Elective	3	–
		16	18
SENIOR YEAR			
EECE 295	Project Management for EECE	3	–
EECE 296	EECE Design	–	3
EECE 297	Senior Engineering Design Seminar	1	–
	EE Program Electives ‡	6	3
	Liberal Arts Core	–	3
	Technical Electives	6	3
	Open elective	–	3
		16	15

† Electrical engineering majors are encouraged to take EECE 116 and EECE 116L in the spring of their freshman year in lieu of CS 103 or 101 (Basic Programming). Basic Programming may be taken in the sophomore year. CS 103 is recommended over CS 101 for electrical engineering majors.

‡ As described in Electrical Engineering Degree Requirements subsection 6. At least one design domain expertise (DE) course required prior to EECE 296.

Course descriptions begin on page 327.

General Engineering

DIRECTOR Christopher J. Rowe
 ASSOCIATE PROFESSORS OF THE PRACTICE David A. Berezov, John A. Bers, Benjamin T. Jordan, Kenneth R. Pence, Julie E. Sharp
 ASSISTANT PROFESSOR OF THE PRACTICE Christopher J. Rowe
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THE Division of General Engineering administers the engineering science major, the engineering management minor and the first-year introduction to engineering course. The Division oversees non-traditional engineering study and advises students on course selection to meet specific career goals that traditional engineering majors may not provide.

Engineering Science Major (Bachelor of Science)

The engineering science major is flexible and interdisciplinary—offering students the opportunity to select a program of study to meet special interests or objectives. Many students choose a program of study in engineering management, communication of science and technology, various engineering concentrations, environmental science or materials science; however, students may develop unique plans of study to specialize in areas for which facilities and faculty competence exist but which are not covered within a single existing degree program at Vanderbilt. Engineering science graduates may establish careers in engineering or science, interface with engineers (e.g., in marketing and sales), or use their analytical and problem-solving skills to build future professional careers. Defined areas of concentration exist in engineering management, communication of science and technology, secondary education, and materials science and engineering. Individual programs have been developed for students interested in careers in engineering mathematics, environmental engineering, transportation engineering, business administration, teaching, technical communications, and other areas requiring nontraditional combinations of engineering courses. Because of the flexible nature of the engineering science programs of study, accreditation has not been sought for these programs of study, and engineering science majors will not qualify for engineering licensure in most states.

Integrated Program in Management. Through a cooperative arrangement with the Owen Graduate School of Management, students majoring in engineering science may be admitted to the Owen School after their junior year. The first year of course work in management is taken during the normal senior year, meeting senior year requirements in engineering science. This reduces by one year the amount of time normally required to obtain the two degrees. Pursuit of the integrated program is contingent upon admission to the Owen School. Automatic admission is in no way implied, nor is special consideration given to engineering students. Further information may be obtained from the director of the Division of General Engineering.

Engineering Management. Engineering management is an interdisciplinary program of study designed to give students the tools to manage technology development and innovation, to enhance manufacturing quality and productivity in a competitive international environment, and to implement these objectives successfully in an organization. Engineering management links engineering, science, and the management disciplines. In addition to the core science and math courses

required of all engineering students, topics of study include entrepreneurship, human resources management, finance in technology-based organizations, technology strategy, communications, and operations.

Communication of Science and Technology. Many careers that are attractive to graduates of the engineering science program require the communication of engineering and science to people who are not technically trained. The Communication of Science and Technology interdisciplinary program prepares engineering students for careers in areas such as technical consulting, high-technology marketing and sales, environmental law, and journalism. The program combines traditional engineering and science courses with communications and humanities courses in a flexible curriculum. Engineering science majors may select from a set of program electives identified by the faculty committee of the School of Engineering and the College of Arts and Science that supervises the program.

Minors. Students may also pursue a minor consisting of at least five courses of at least three credit hours within a recognized area of knowledge. Minors are offered in engineering management, materials science and engineering, computer science, scientific computing, environmental engineering, energy and environmental systems, and most disciplines within the College of Arts and Science. Students must declare their intention to pursue minors by completing forms available in the Office of Student Services of the School of Engineering.

Curriculum Requirements

Students must complete a minimum of 120 hours. In consultation with the academic adviser, each student must identify a program concentration containing a minimum of 27 hours, not counting certain introductory-level courses, which directly contributes to meeting stated career goals. The preparation provided by this 27-hour package, together with a solid foundation in basic engineering courses, provides the engineering science student with a strong and useful career base.

1. Basic science (16 hours). Chemistry 102A and 104A plus 12 hours from the group Bio Sci 110A-B/111A-B; Chemistry 102B/104B; Physics 116A-B and 118A-B; or MSE 150/150L with two courses in a single discipline.
2. Mathematics (14 hours). Required courses (11 hours): 155A-B, 175 (qualified students may substitute an honors mathematics sequence). Electives (3 hours): to be selected from math courses numbered 194 and above.
3. Engineering (39 hours).
 - a) Engineering Fundamentals (12 hours): CS 101 or 103; ES 140A-B-C, 210W and CE 180 or BME 101.
 - b) Engineering Core (12 hours) to be selected from courses in one of the following disciplines: BME, ChBE, CE, CS, EECE, ENGM, ENVE, MSE, ME.
 - c) Engineering electives (15 hours): Any Engineering School courses may be used to complete the 39-hour engineering requirement, provided at least 9 hours are in one related area.
4. Liberal Arts Core (18 hours). To be selected in accordance with the Liberal Arts Core Requirements under Degree Programs in Engineering.
5. Open electives (6 hours).

6. Program concentration (27 hours). To be selected in such a way as to provide a meaningful sequence of courses. Course work must be planned in advance and approved by the faculty adviser.

ENGM 275	Technology Assessment and Forecasting
CE 290	Reliability and Risk Case Studies
ENVE 296	Operational Risk Management

Course descriptions begin on page 329.

Course descriptions begin on page 330.

Engineering Management Minor

Engineering management is an interdisciplinary program of study designed to expose engineering students to the concepts and theories of the management of the engineering function, the critical elements of technology development and innovation, and the implementation of such ideas in manufacturing, engineering, and technology environments. Approximately two-thirds of all engineers spend a substantial portion of their professional careers as managers. In the complex, competitive world of technology-driven industry, skilled engineers who understand the essential principles of management and business have a competitive advantage.

The program in engineering management prepares students to work effectively in developing, implementing, and modifying technologies and systems. The ability to manage and administer large technical engineering and research projects and budgets will continue to challenge engineering management skills. Undergraduates interested in engineering management have two options. They may earn the B.E. in another engineering discipline with a minor in engineering management, or they may earn the B.S. in engineering science with engineering management as their area of concentration. Courses in engineering management may be approved for minor credit in several programs. Detailed information may be obtained from <http://engm.vuse.vanderbilt.edu>.

The engineering management minor is designed to provide a working knowledge of the fundamentals of management and business. Engineering management courses include accounting and finance, applied behavioral science, engineering economics, marketing, operations and supply chain management, project planning and control, technology strategy, systems engineering, and technology-based entrepreneurship.

The minor program in engineering management consists of 15 hours of course work, some of which may be taken as electives associated with the student's major program. Five courses are required: four core courses and the remaining course chosen from a list of electives.

Program Requirements

The student must take the following four courses:

ENGM 221	Technology Strategy
ENGM 244	Applied Behavioral Science
ENGM 273	Systems Engineering
ENGM 274	Program and Project Management

The student must select one of the following courses:

ENGM 216	Engineering Economy
ENGM 242	Technology Marketing
ENGM 251	Accounting and Finance for Engineers
ENGM 253	Technology-Based Entrepreneurship
ENGM 254	Operations and Supply Chain Management

Materials Science and Engineering

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 ASSOCIATE PROFESSOR James E. Wittig
 PROFESSOR OF THE PRACTICE Amrutur V. Anilkumar

MATERIALS are the limiting factor for most technological advances. The impact of materials on history is obvious, since technological progress in a given era is demarcated by the available materials. The Stone Age was followed by the Bronze Age and the Iron Age. The present period could be identified as the Silicon Age, which is only in its first century.

New materials allow for new technology and this is especially the case for the emerging field of nanoscience. As the size scale approaches nanometer dimensions, materials exhibit new and exciting physical properties. High performance metals, ceramics, polymers, semiconductors and composites are in demand throughout the engineering world and nanotechnology is proving to be the answer for many engineering problems. The U.S. National Science Foundation identified nanoscience and nanotechnology as a critical area for our future and created a national initiative to advance the processing and performance of nanomaterials. To accomplish these tasks, there is a need for specialists in materials science and engineering with an interdisciplinary background that combines engineering disciplines with the physical sciences.

The materials science and engineering program is integrated into the extensive ongoing nanotechnology research. The Vanderbilt Institute for Nanoscience and Engineering (VINSE) is at the center of this effort. Research areas include; nanofluidics, synthesis of semiconductor quantum dots, magnetic nanocrystals, nanoscale soft materials, optical properties of nanostructures, carbon nanotubes, nanodiamond devices, biological applications of nanocrystals, and molecular modeling and simulation of these nanoscale structures. This interdisciplinary research involves faculty from all of the engineering disciplines as well as faculty from chemistry, physics, and the medical school.

Two undergraduate options involving materials science and engineering are available. Students may pursue the B.S. in engineering science with materials science and engineering as their area of concentration or they may earn the B.E. in another engineering discipline with a minor in materials science and engineering.

Materials Science and Engineering Concentration

The B.S. in engineering science with a concentration in materials science and engineering requires satisfaction of the curriculum requirements of engineering science. The student must take 27 hours of materials science and engineering program electives that include MSE 150 and MSE 250 with the additional materials science related courses selected to provide a meaningful sequence that must be planned in advance and approved by the faculty adviser.

Materials Science and Engineering Minor

The minor in materials science and engineering is designated to provide the student with an understanding of engineering materials. The goal is to complement and add to the student's major in one of the other engineering disciplines for an interdisciplinary approach to problem solving. The minor program in materials science and engineering requires 16 hours of program courses, of which 7 hours are devoted to MSE 150 and MSE 250. No more than 10 hours below the 200 level may be applied to the minor.

Program Requirements

MSE 150	Materials Science I
MSE 250	Materials Science II

The remaining 9 hours can be chosen from the following list of courses.

MSE 209C	Undergraduate Research
MSE 210AB	Special Topics
BME 101	Introductory Biomechanics
BME 103	Biomedical Materials: Structure, Property, and Applications
BME 274	Principles and Applications BioMicroElectroMechanical Systems (BioMEMS)
BME 281	Nanobiotechnology
ChBE 284	Semiconductor Materials Processing
ChBE 286	Molecular Aspects of Chemical Engineering
ChBE 287	Polymer Science and Engineering
CE 182	Mechanics of Materials
CE 235	Introduction to Structural Design
CE 293	Advanced Structural Steel Design
CE 294	Advanced Reinforced Concrete Design
CE 295	Mechanics of Composite Materials
EECE 283	Principles and Models of Semiconductor Devices
EECE 284	Integrated Circuit Fabrication and Technology
ME 202	Machine Analysis and Design
ME 251	Modern Manufacturing Processes
ME 275	Introduction to Finite Element Analysis
Chem 203	Inorganic Chemistry
Chem 230	Physical Chemistry: Quantum Mechanics, Spectroscopy, and Kinetics
Chem 235	Macromolecular Chemistry: Polymers, Dendrimers, and Surface Modification
Phys 225W	Introduction to Quantum Physics and Applications I
Phys 229a	Electricity, Magnetism and Electrodynamics
Phys 254	Physics of Condensed Matter

Course descriptions begin on page 330.

Mechanical Engineering

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THE vitality of our nation depends upon innovation in the design of new machines, devices to satisfy society's needs, engines to produce power efficiently, equipment to condition the environment of our buildings, and the systems to use and control these engineered products. Mechanical engineers are involved in solving problems by originating design concepts, developing products and processes of manufacture, and designing hardware and the systems needed to satisfy society's demands. Mechanical engineers work in virtually all industries.

The study of mechanical engineering requires a basic understanding of mathematics, chemistry, physics, and the engineering sciences. Mechanical engineering education emphasizes solid mechanics; dynamics of machines; aerodynamics; propulsion devices; material behavior; power producing and environmental conditioning processes; control of dynamics of machines; energy conversion; and the synthesis, development, evaluation, and optimization of designs of devices and systems.

Degree Programs. The Department of Mechanical Engineering offers the B.E., M.Eng., M.S., and Ph.D. in mechanical engineering.

The curriculum in mechanical engineering leading to a bachelor of engineering provides a broad-based engineering education with opportunities for the student to elect courses in areas of study related to any industry and, with careful planning of the elective courses, to achieve some specialization. The mechanical engineering program prepares an individual to become a practicing engineer who can participate fully in the engineering activities of design, building, operation, production, maintenance, safety, marketing, sales, research, and administration.

Undergraduate Honors Program. See the Special Programs chapter for general requirements of the professional Honors Program in mechanical engineering. In general, rising juniors are admitted, although seniors may be accepted in special cases. Honors candidates choose their technical elective courses with the advice and consent of the department chair. Each candidate is expected to take ME 209c and at least 6 hours of graduate courses, including one 300-level course. A formal written report on the candidate's research is required.

Honors candidates shall meet all Engineering School requirements in the nontechnical areas. The diploma designation is Honors in Mechanical Engineering.

Facilities. Facilities are available for studies in thermodynamics, combustion, heat power, refrigeration, air conditioning, fluid flow, heat transfer, design, mechanical vibrations, acoustics, robotics, instrumentation, and biomechanics. Subsonic and supersonic wind tunnels are used in general fluid dynamics studies. Laser diagnostic equipment is available for studies of the fundamental behavior of combustion processes. These are augmented by special equipment for investigations into the mechanism of fluid turbulence. Instrumentation for conducting experiments on mechanical systems is available to measure accurately a wide range of variables. The department also maintains various shops for fabrication of experimental equipment and for instruction.

Curriculum Requirements

The B.E. in mechanical engineering requires a minimum of 126 hours, distributed as follows.

1. Mathematics (17 hours). Required courses: 155A-B, 175, 198 (qualified students may substitute an honors mathematics sequence). Required elective: one from courses numbered 194 or above, except 252.
2. Basic Science (16 hours). Required courses: Chemistry 102A, 104A, MSE 150 (or Chemistry 102B and 104B), Physics 116A-B and 118A-B.
3. Engineering Science (25 hours). Required courses: ES 140A-C; CE 180, 182; CS 101 or CS 103; EECE 112; ME 190, 220A, 224, MSE 232.
4. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed in the Degree Programs in Engineering.
5. Open electives (6 hours).
6. ME core (26 hours). ME 160, 171, 202, 204, 213, 234, 242, 243, 248, and 297. Students who transfer into ME after the sophomore year will take a technical elective in place of ME 160.
7. Technical electives (9 hours). To be selected from any technical or scientific field; at least 3 hours must be above the sophomore level. The following courses will not be acceptable to satisfy a technical elective: Astronomy 115F and 130. Biological Sciences 105 and 115F. Chemistry 101A and 101B. Earth and Environmental Sciences 100, 102, and 115F. Engineering Management 150. Math 252. Physics 105, 110, 111, and 115F.
8. Professional (ME) depth (a minimum of 9 hours). Each student must choose at least 9 hours of ME elective courses.

No one-credit-hour ME course except 209A can be used as a mechanical engineering elective. A maximum of three one-credit-hour ME courses may be used as technical electives. Additional ME one-credit-hour courses can be open electives. At least one "W"-designated course in the English language must be included.

Specimen Curriculum for Mechanical Engineering

		Semester hours	
		FALL	SPRING
FRESHMAN YEAR			
ME 160	Introduction to Mechanical Engineering Design	-	3
	Other	14	12
		<hr/>	<hr/>
		14	15
SOPHOMORE YEAR			
Math 175	Multivariable Calculus	3	-
Math 198	Methods of Ordinary Differential Equations	-	3
Physics 116B	General Physics	3	-
Physics 118B	General Physics Laboratory	1	-
CE 180	Statics	3	-
ME 190	Dynamics	-	3
ME 171	Instrumentation Laboratory	-	2
ME 220A	Thermodynamics I	-	3
EECE 112	Circuits I	-	3
CS 101 or 103	Programming and Problem Solving	3	-
	Liberal Arts Core	3	3
		<hr/>	<hr/>
		16	17
JUNIOR YEAR			
ME 202	Machine Analysis and Design	3	-
ME 204	Mechatronics	-	3
ME 234	System Dynamics	4	-
ME 224	Fluid Mechanics	3	-
ME 248	Heat Transfer	-	3
CE 182	Mechanics of Materials	3	-
MSE 232	Strength and Structure of Engineering Materials	1	-
	Open Elective	-	3
	Mechanical Engineering Elective	-	3
	Liberal Arts Core	3	-
	Math Elective	-	3
		<hr/>	<hr/>
		17	15
SENIOR YEAR			
ME 242	Design Synthesis	2	-
ME 243	Design Projects	-	3
ME 213	Energetics Laboratory	2	-
ME 297	Senior Engineering Design Seminar	1	-
	Liberal Arts Core	3	3
	Technical Elective	6	3
	Mechanical Engineering Elective	3	3
	Open Elective	-	3
		<hr/>	<hr/>
		17	15

Course descriptions begin on page 331.

Scientific Computing

DIRECTORS Robert E. Bodenheimer, Thomas J. Palmeri, David A. Weintraub

Affiliated Faculty

PROFESSORS Peter T. Cummings (Chemical and Biomolecular Engineering), Mark N. Ellingham (Mathematics), David Furbish (Earth and Environmental Sciences), Gordon D. Logan (Psychology), Terry P. Lybrand (Chemistry and Pharmacology), Charles F. Maguire (Physics), Clare M. McCabe (Chemical and Biomolecular Engineering), Jeffrey D. Schall (Psychology and Neuroscience), Paul Sheldon (Physics), David A. Weintraub (Astronomy), Robert Weller (Electrical Engineering)

ASSOCIATE PROFESSORS Robert E. Bodenheimer (Computer Science), Michael I. Miga (Biomedical Engineering), Thomas J. Palmeri (Psychology and Neuroscience), Greg Walker (Mechanical Engineering)

ASSISTANT PROFESSORS Andreas A. Berlind (Astronomy), Kelly Holley-Bockelmann (Astronomy), Bennett Landman (Electrical Engineering), Haoxiang Luo (Mechanical Engineering), Jens Meiler (Chemistry), Sean Polyn (Psychology and Neuroscience), Antonis Rokas (Biological Sciences), Kalman Varga (Physics)

ASSOCIATE PROFESSOR OF THE PRACTICE Gerald H. Roth (Computer Science)

LECTURER Zhiao Shi (ACCRE)

FACULTY in the School of Engineering and the College of Arts and Science offer an interdisciplinary minor in scientific computing to help natural and social scientists and engineers acquire the ever-increasing computational skills that such careers demand. The minor is administered by the School of Engineering.

Computation is now an integral part of modern science and engineering. In science, computer simulation allows the study of natural phenomena impossible or intractable through experimental means. In engineering, computer simulation allows the analysis and synthesis of systems too expensive, dangerous, or complex to model and build directly. Astronomers studying the formation of massive black holes, neuroscientists studying neural networks for human memory, mechanical engineers studying the designs of turbines and compressors, and electrical engineers studying the reliability of electronics aboard spacecraft are united both in the computational challenges they face and the tools and techniques they use to solve these challenges.

Students in the program in scientific computing are taught techniques for understanding such complex physical, biological, and also social systems. Students are introduced to computational methods for simulating and analyzing models of complex systems, to scientific visualization and data mining techniques needed to detect structure in massively large multidimensional data sets, to high performance computing techniques for simulating models on computing clusters with hundreds or thousands of parallel, independent processors and for analyzing terabytes or more of data that may be distributed across a massive cloud or grid storage environment.

Scientific computing at Vanderbilt is supported by faculty and includes students from a wide range of scientific and engineering disciplines. While the content domain varies, these disciplines often require similar computational approaches, high-performance computing resources, and skills to simulate interactions, model real-life systems, and test competing hypotheses. Scientific computing embodies the computational tools and techniques for solving many of the grand challenges facing science and engineering today.

The minor in scientific computing prepares students for advanced coursework that combines computational approaches with a substantive area of science or engineering. It prepares students for directed or independent study with a faculty member on a research project. It prepares students for advanced study in graduate school. It provides skills that will be attractive to many employers after graduation.

The minor in scientific computing is distinct from the minor in computer science. Scientific computing uses computation as a tool to solve scientific and engineering problems in research and application. It is more focused on simulation, numerical techniques, high performance computing, and higher-level methods than the minor in computer science, which is focused on the algorithms, systems, and technologies that enable such methods to be developed and employed.

The minor in scientific computing requires 15 credit hours, distributed as follows:

1. Computer Science 101 or 103. (3 hours)
2. Computer Science 204 (CS 201 may be substituted for 204 with the approval of a Program Director). (3 hours)
3. Scientific Computing 250. (3 hours)
4. 6 hours of electives. Electives include courses in the Scientific Computing (SC) minor, courses approved for SC credit that are in another subject area, courses that meet the approval of a Director of the SC minor, and directed or independent study with a faculty member affiliated with the SC minor.

SC 250	Scientific Computing Toolbox
SC 291	Special Topics in Scientific Computing. [1-3 each semester]
SC 292	Special Topics in Scientific Computing. [1-3 each semester]
SC 293A	Directed Study in Scientific Computing
SC 293B	Directed Study in Scientific Computing
SC 293C	Directed Study in Scientific Computing
SC 295A	Independent Study in Scientific Computing
SC 295B	Independent Study in Scientific Computing
SC 295C	Independent Study in Scientific Computing

Approved courses by subject area are listed below. These courses either provide a detailed treatment of a core scientific computing tool and technique or combine scientific computing tools and techniques with a substantive area of science or engineering.

Astronomy 252, Stellar Astrophysics
 Astronomy 253, Galactic Astrophysics
 Biological Sciences 272, Computational Genomics
 Biomedical Engineering 279, Modeling Living Systems for Therapeutic Bioengineering
 Chemical and Biomolecular Engineering 285, Molecular Simulation
 Computer Science 274, Modeling and Simulation
 Mathematics 226, Introduction to Numerical Mathematics
 Mathematics 286, Numerical Analysis
 Mathematics 287, Nonlinear Optimization
 Mathematics 288, Linear Optimization
 Mechanical Engineering 263, Computational Fluid Dynamics and Multiphysics Modeling
 Physics 223C, Computational Thermodynamics and Statistical Physics
 Physics 257, Computational Physics

Engineering Courses

Biomedical Engineering

BME 101. Introductory Biomechanics. Structure and mechanics of the musculoskeletal system and to the properties and strength of biological materials. Application of Newtonian mechanics, statics, and strength of materials to bone, muscle, tendon, other biological material, and medical devices. Credit offered for only one of BME 101 or CE 180. Prerequisite: PHYS 116A, MATH 155B, and CS 103. FALL. [3]

BME 103. Biomedical Materials: Structure, Property, and Applications. Structure-property relationships in both natural and synthetic, hard and soft materials. Bio-inspired materials design, the role of self-assembly in achieving highly ordered structures, material design and properties for emerging biomedical applications, factors influencing biocompatibility, performance of biomaterials in both soft and hard tissues, and biological response to implants. Prerequisite: CHEM 102B, BME 101. SPRING. [3]

BME 201. Biomedical Engineering Ethics. Ethical principles in the practice of biomedical engineering: responsibility in professional practice, health care, research and mentoring. Development of skills in perceptiveness, discernment, competency and visualization of alternatives through case studies. Prerequisite: junior or senior standing. FALL. [3] (Only available for open elective credit for biomedical engineering majors.) (Not currently offered)

BME 210. Physiological Transport Phenomena. An introduction to the mechanics of fluids, heat transfer, and mass transfer in living systems. Basic theories of transport phenomena are presented and applied to mammalian and cellular physiology as well as to the design of medical devices. Prerequisite: BME 101, 103 or equivalent, MATH 196 or 198. [3]

BME 240A. Undergraduate Research. Independent research, either experimental or theoretical in nature or a combination of both, under the supervision of a biomedical engineering faculty member or another faculty member approved by the course director. Prerequisite: Consent of course director. [1-3 each semester; maximum of 6 hours total for all semesters of BME 240 and 241.]

BME 240B. Undergraduate Research. A continuation of the research in 240A or research in a different area of biomedical engineering. Prerequisite: Consent of course director. [1-3 each semester; maximum of 6 hours total for all semesters of BME 240 and 241.]

BME 241A. Undergraduate Project in Biomedical Engineering Education. An independent project, either developmental, experimental, or otherwise investigational in nature, that explores a selected topic in biomedical engineering education. The project is to be conducted under the supervision of a biomedical engineering faculty member or another faculty member approved by the course director. Prerequisite: Consent of course director [1-3 each semester; maximum of 6 hours total for all semesters of BME 240 and 241.]

BME 241B. Undergraduate Project in Biomedical Engineering Education. A continuation of the work in 241A or work in a different area of bioengineering education. Prerequisite: Consent of course director [1-3 each semester; maximum of 6 hours total for all semesters of BME 240 and 241.]

BME 249. Biomedical Engineering Service Learning and Leadership. Identification of local and global human needs, methods of need quantification, implementation of engineering solutions, sustainability, preparation of grant proposals, leadership principles. Independent service project required. Prerequisite: Junior standing. FALL [3]

BME 251. Systems Physiology. An introduction to quantitative physiology from the engineering point of view. Descriptive physiology of several organ systems (heart, lung, kidney, nerve, blood). Mathematical modeling and computer simulation of organ systems and physiologic

control mechanisms. Prerequisite: Differential equations or permission of instructor. [3]

BME 252. Systems Physiology. An introduction to quantitative physiology from the engineering point of view. Descriptive physiology of several organ systems (heart, lung, kidney, nerve, blood). Mathematical modeling and computer simulation of organ systems and physiologic control mechanisms. Prerequisite: Differential equations or permission of instructor. [3]

BME 253. Neuromuscular Mechanics and Physiology. Quantitative characterization of the physiological and mechanical properties of the neuromuscular system. Quantitative models of system components. Applications to fatigue, aging and development, injury and repair, and congenital and acquired diseases. Prerequisite: BME 251 and 101. SPRING. [3]

BME 255W. Biomedical Engineering Laboratory. Laboratory experiments in biomechanics, thermodynamics, biological transport, signal analysis, biological control, and biological imaging. Emphasis is placed on current methods, instrumentation, and equipment used in biomedical engineering; on oral presentation of results; and on the writing of comprehensive reports. One lecture and one three-hour laboratory per week. Prerequisite: BME 210, 251. [3]

BME 256. Bioelectricity. Cellular basis of the electrical activity of nerve and muscle cells; action potential propagation; voltage- and ligand-gated ion channels; space, voltage, and patch clamp; and electrical, optical, and magnetic measurements of bioelectric activity in cells, isolated tissues, intact animals, and humans. Prerequisite: MATH 196 or 198, BSCI 110A. FALL. [3]

BME 258. Foundations of Medical Imaging. Physics and engineering of image formation by different modalities used for medical applications. Concepts common to different imaging modalities and limits of physical phenomena. Mathematical concepts of image formation and analysis; techniques for recording images using ionizing radiation (including CT), ultrasound, magnetic resonance, and nuclear (including SPECT and PET). Methods of evaluating image quality. Prerequisite: PHYS 116B, 118B, MATH 196. Credit offered for only one of BME 258 and PHYS 228. SPRING. [3]

BME 260. Analysis of Biomedical Data. Application of modern computing methods to the statistical analysis of biomedical data. Sampling, estimation, analysis of variance, and the principles of experimental design and clinical trials are emphasized. Prerequisite: MATH 175. SPRING. [3]

BME 263. Signal Measurement and Analysis. Discrete time analysis of signals with deterministic and random properties and the effect of linear systems on these properties. Brief review of relevant topics in probability and statistics and introduction to random processes. Discrete Fourier transforms, harmonic and correlation analysis, and signal modeling. Implementation of these techniques on a computer is required. Prerequisite: Probability and Statistics. FALL. [3]

BME 271. Biomedical Instrumentation. Introduces methods used to determine physiological functions and variables from the point of view of optimization in the time and frequency domain and the relation to physiological variability. Laboratory exercises stress instrumentation usage and data analysis. Three lectures and one laboratory. Prerequisite: EECE 213 and 213L. FALL, SPRING. [4]

BME 272. Design of Biomedical Engineering Devices and Systems I. Integration of the engineering and life science backgrounds of senior biomedical engineering students through the presentation of design principles for medical devices and systems. Design principles and case examples for biomedical electronics, mechanical, chemical, and computing systems are presented. A full-semester design project is required. Evaluation is conducted through periodic oral and written presentations, and through a final written and poster report. Corequisite: BME 271; Prerequisite: BME 251, 252. [2]

BME 273. Design of Biomedical Engineering Devices and Systems II. Integration of the engineering and life science backgrounds of senior biomedical engineering students through the presentation of design principles for medical devices and systems. Design principles and case examples for biomedical electronics, mechanical, chemical, and computing systems are presented. A full-semester design project is required. Evaluation is conducted through periodic oral and written presentations, and through a final written and poster report. Prerequisite: BME 272. [3]

BME 274. Principles and Applications of BioMicroElectroMechanical Systems (BioMEMS). The principles, design, fabrication and application of micro- and nano-devices to instrument and control biological molecules, living cells, and small organisms, with a strong emphasis on development of microfabricated systems and micro- and nano-biosensors. Students will lead discussions from the research literature. Graduate students will prepare a research proposal or fabricate a functioning BioMEMS device. FALL. [3]

BME 274L. BioMicroElectroMechanical Systems Laboratory. Design, fabrication, and testing of BioMEMS devices for applications in the life sciences. Practical experience in photolithography, replica molding to fabricate microfluidic devices, and multilayer devices to assemble microfluidic devices with active valves. Corequisite: BME 274. FALL. [1]

BME 275. Therapeutic Bioengineering. Explores the engineering aspects of treating disease or disorders. Surgical mechanics, diffusion therapies including chemical and energy diffusion, image-guided therapies, and the role of discovery and design in the development of medical treatments. Prerequisite: EECE 213, BME 101, and BME 210. Corequisite: BME 271; an imaging course may be helpful. SPRING. [3]

BME 276. Biological Basis of Imaging. Physical and chemical relationships between biological characteristics of tissue and image contrast in major medical imaging modalities. Imaging modalities include x-ray, MRI, PET, and ultrasound. Applications include neurological disorders, neurological function, cardiac function and disease, cancer, and musculoskeletal physiology. Prerequisite: BME 258 or equivalent. SPRING. [3].

BME 277. Quantitative and Functional Imaging. Introduction to quantitative analysis of non-invasive imaging techniques to assess the structure and function of tissues in the body. Applications of computed tomography, positron emission tomography, ultrasound, and magnetic resonance imaging to tissue characterization. Measurement of lesion volume, cardiac output, organ perfusion, brain function, and receptor density. Prerequisite: BME 258 and CS 103 or equivalent. FALL. [3]

BME 279. Modeling Living Systems for Therapeutic Bioengineering. Introduction to computer modeling and simulation in therapeutic bioengineering processes. Building computer models and using modern modeling software tools. Introduction to numerical techniques to solve differential equations and origin of mathematical models for biotransport, biomechanics, tumor/virus growth dynamics, and model-based medical imaging techniques. Prerequisite: MATH 196 or MATH 198, CS 103 or equivalent, BME 101 or equivalent mechanics course. SPRING. [3]

BME 280. Introduction to Tissue Engineering. Basic principles, methods, and current topics in tissue engineering. Integration of biology, materials science, and biomechanics in the design and fabrication of engineered tissues. Biomaterials for scaffolding, stem cell applications, bioreactor design, and practical methods for testing. Case studies and guest lectures from experts in the field. Prerequisite: BSCI 110A-110B, CHEM 102B or equivalent. FALL. [3]

BME 281. Nanobiotechnology. Synthesis and characterization of nanostructured materials for use in living systems. Clinical applications of nanoscale biosensors. Methods for single molecule detection in biological specimens. Quantitative structure/function assessment of nanostructures in living systems. Prerequisite: one year of biology (BSCI 110A and 110B or equivalent) and transport phenomena (BME 210 or equivalent). SPRING. [3]

BME 281L. Nanobiotechnology Laboratory. Laboratory experiments in the characterization of nanomaterial interactions with living systems. Biological surface functionalization of inorganic nanoparticles. Measurement of cultured mammalian cell response to nanostructures. Quantitative structure/function assessment of nanostructures in living systems. Corequisite: BME 281. SPRING. [1]

BME 285. Introduction to Biomedical Optics. Fundamental concepts of optics, tissue optics and laser tissue interaction. Instrumentation for light and laser applications, and current uses for diagnosis and therapy in biomedicine. Prerequisite: Senior standing. FALL. [3]

BME 285L. Biomedical Optics Laboratory. Practical experience in basics of operating lasers, using optics, fiber optics and interferometry. Computer-aided design of optical systems and computer simulations of light tissue interaction. Application of optical concepts to biomedical problems. Prerequisite: Senior standing. Corequisite: BME 285. FALL. [1]

BME 290A. Special Topics. Different topics taught as A-D. [3] (Offered periodically)

BME 290B. Special Topics. [3] (Offered periodically)

BME 290C. Special Topics. [3] (Offered periodically)

BME 290D. Special Topics. [3] (Offered periodically)

BME 297. Senior Engineering Design Seminar. Elements of professional engineering practice. Professionalism, licensing, ethics and ethical issues, intellectual property, contracts, liability, risk, reliability and safety, interdisciplinary teams and team tools, codes, standards, professional organizations, careers, entrepreneurship, human factors, and industrial design. Prerequisite: Senior standing. Required, to be taken in conjunction with BME 272. FALL. [1]

BME 301A. Quantitative Methods in Biomedical Engineering (Part A). Mathematics, quantitative analysis and computation for biomedical engineering applications. The first in a three-unit sequence consisting of BME 301A, BME 301B and BME 301C (5 weeks each). Probability and statistics, hypothesis testing, sample size estimation, power analysis, multivariate analysis. FALL. [1]

BME 301B. Quantitative Methods in Biomedical Engineering (Part B). Mathematics, quantitative analysis and computation for biomedical engineering applications. The second in a three-unit sequence consisting of BME 301A, BME 301B and BME 301C (5 weeks each). Linear system models, continuous and discrete signals, Fourier transforms, application in signal analysis. FALL. [1]

BME 301C. Quantitative Methods in Biomedical Engineering (Part C). Mathematics, quantitative analysis and computation for biomedical engineering applications. The third in a three-unit sequence consisting of BME 301A, BME 301B and BME 301C (5 weeks each). Numerical differentiation, and integration, optimization, nonlinear ordinary and partial differential equations, applications in modeling and image analysis. FALL. [1]

BME 302A. Applied Physics for Biomedical Engineering (Part A). Applied physics essential for biomedical engineering. The first in a three-unit sequence consisting of BME 302A, BME 302B and BME 302C (5 weeks each). Electromagnetic, interaction of charges, currents and fields in biological systems, bioelectricity and biomagnetic fields. FALL. [1]

BME 302B. Applied Physics for Biomedical Engineering (Part B). Applied physics essential for biomedical engineering. The second in a three-unit sequence consisting of BME 302A, BME 302B and BME 302C (5 weeks each). Optics, wave and particle properties of light in tissue, coherence techniques and interferometry in tissue, laser tissue interaction. FALL. [1]

BME 302C. Applied Physics for Biomedical Engineering (Part C). Applied physics essential for biomedical engineering. The third in a three-unit sequence consisting of BME 302A, BME 302B and BME 302C (5 weeks each). Continuum mechanics, viscoelastic models of tissue, constitutive relationships for tissue and biological fluids, fluid mechanics with applications to biology, physiology and devices. FALL. [1]

BME 303A. Cellular and Molecular Biomedical Engineering (Part A). Techniques and applications of cellular and molecular biology in biomedical engineering. The first in a three-unit sequence consisting of BME 303A, BME 303B and BME 303C (5 weeks each). Cellular systems, DNA, RNA and proteins, control of gene expression, protein synthesis and trafficking, cell-cell interactions, biotechnology applications. SPRING. [1]

BME 303B. Cellular and Molecular Biomedical Engineering (Part B). Techniques and applications of cellular and molecular biology in biomedical engineering. The second in a three-unit sequence consisting of BME 303A, BME 303B and BME 303C (5 weeks each). Biomaterial properties, interfacial phenomena in vivo, nonmaterial applications. SPRING. [1]

BME 303C. Cellular and Molecular Biomedical Engineering (Part C). Techniques and applications of cellular and molecular biology in biomedical engineering. The third in a three-unit sequence consisting of BME 303A, BME 303B and BME 303C (5 weeks each). Biotransport, compartmental analysis, diffusion and active transport, convection applications. SPRING. [1]

BME 304A. Measurement Methods for Biomedical Engineers (Part A). Instrumentation and imaging for quantitative measurements in biomedical applications. The first in a three-unit sequence consisting of BME 304A, BME 304B and BME 304C (5 weeks each). Biomedical instrumentation, signal processing, measurement of electrical signals in the body, light, mechanical and chemical sensors. SPRING. [1]

BME 304B. Measurement Methods for Biomedical Engineers (Part B). Instrumentation and imaging for quantitative measurements in biomedical applications. The second in a three-unit sequence consisting of BME 304A, BME 304B and BME 304C (5 weeks each). Image properties, non-invasive imaging modalities, image reconstruction from projections and Fourier-encoded data. SPRING. [1]

BME 304C. Measurement Methods for Biomedical Engineers (Part C). Instrumentation and imaging for quantitative measurements in biomedical applications. The third in a three-unit sequence consisting of BME 304A, BME 304B and BME 304C (5 weeks each). Contrast mechanisms, interactions of electromagnetic radiation and acoustic waves with tissues, factors affecting nuclear magnetic resonance signals, imaging contrast agents. SPRING. [1]

BME 305. Research and Professional Development in Biomedical Engineering. Database search strategies, interpreting engineering and scientific literature, communication skills, engineering design, proposal writing, preparation of engineering publications, technology transfer/intellectual property, engineering laboratory documentation, regulatory oversight, ethics, funding. SPRING. [3].

BME 313. Advanced Biomechanics. Application of advanced concepts in statics, dynamics, continuum mechanics, and strength of materials to biological systems. Topics include measurement of mechanical properties of biological materials; rheological properties of blood; mechanics of cells, bone, skeletal muscle, and soft tissue; normal and abnormal dynamics of human movement; mechanics of articular joint movement; pulmonary mechanics; cardiac mechanics; arterial mechanics; mechanics of veins and collapsible vessels; and mechanics of flow in the microcirculation. Prerequisite: BME 101, BME 210 or equivalent. [3]

BME 317. Physiological Transport Phenomena. The quantitative description of momentum transport (viscous flow) and mass transport (convection and diffusion) in living systems. Prerequisite: BME 210 or equivalent courses in fluid dynamics and mass transfer. SPRING. [3]

BME 319. Engineering Models of Cellular Phenomena. Application of engineering methods to model and quantify aspects of cell physiology. Topics include receptor mediated cell processes, cell-cell signaling, cooperative barrier behavior, cell structural components, and cell motility. SPRING. [3] (Offered alternate years)

BME 320. Laser-Tissue Interaction and Therapeutic Use of Lasers. Optical and thermal aspects and models of the interaction between laser/light and biological tissue as it is used for therapeutic applications in

medicine and biology. Issues and objectives in therapeutic and surgical applications of lasers, overview of state-of-the-art topics and current research. FALL. [3]

BME 321. Optical Diagnosis: Principles and Applications. Applications of light and tissue optical properties for the diagnosis of tissue pathology. Basic scientific and engineering principles for developing techniques and devices that use light to probe cells and tissues. Recent applications of different optical diagnostic techniques. SPRING. [3]

BME 325. Physical Measurements on Biological Systems. A survey of the state-of-the-art in quantitative physical measurement techniques applied to cellular or molecular physiology. Topics include the basis for generation, measurement, and control of the transmembrane potential; electrochemical instrumentation; optical spectroscopy and imaging; x-ray diffraction for determination of macromolecular structure; magnetic resonance spectroscopy and imaging. Prerequisite: PHYS 225 (modern physics) or consent of instructor. SPRING. [3]

BME 329. Advanced Computational Modeling and Analysis in Biomedical Engineering. Survey of current topics within biomedical modeling: biotransport, biomechanics, tumor and virus growth dynamics, model-based medical imaging techniques, etc. Mathematical development and analysis of biomedical simulations using advanced numerical techniques for the solution of ordinary and partial differential equations. Emphasis will be on graduate research related topics. SPRING. [3]

BME 330. Cancer Imaging. Applications of noninvasive, in vivo imaging (i.e., MRI, optical, CT, SPECT, PET, and ultrasound) to cancer biology. Emphasis on assessing the response of tumors to treatment using emerging and quantitative imaging techniques. Prerequisite: BME 258 or BME 302B/304B/304C or PHYS 228. SPRING. (Offered alternate years) [3]

BME 331. Neuroimaging. Applications of noninvasive imaging techniques including MRI, fMRI, optical, EEG, and PET to the study of neural systems. Emphasis on the human brain, with a focus on current scientific literature. Prerequisite: BME 258 or BME 302B/304B/304C or PHYS 228. FALL. (Offered alternate years) [3]

BME 369. Master's Thesis Research.

BME 373. Design of Medical Products, Processes, and Services. Medical design projects involving teams of graduate-level engineering and management students. Projects are solicited from industry or universities and are undertaken from the initial phase of a design request to the end product, prototype, plan, or feasibility analysis. Prerequisite: BME 272 or equivalent. SPRING. [3]

BME 377. Advanced Quantitative and Functional Imaging. Analysis of non-invasive image data to assess tissue structure and function in the body. Modeling and parameter estimation based on medical imaging data. Measurements of tissue volume, fiber structure, blood flow, brain function, and receptor density. Prerequisite: BME 301B,C and BME 304B,C or equivalent. No credit for both BME 277 and 377. FALL. [3]

BME 378. Magnetic Resonance Imaging Methods. MR techniques to image tissue for clinical evaluation and research. RF pulses, k-space trajectories, chemical shift, motion, flow, and relaxation. Derivation of signal equations for pulse sequence design and analysis. Course includes hands-on experimental studies. Prerequisite: BME 304B,C or equivalent. SPRING. [3]

BME 379. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

BME 389. Master of Engineering Project.

BME 391. Biomedical Research Seminar. [1]

BME 392. Biomedical Research Seminar. [1]

BME 393. Biomedical Research Seminar. [1]

BME 394. Biomedical Research Seminar. [1]

BME 395A. Special Topics. Different topics taught as a-d graduate level. [1-3]

BME 395B. Special Topics. [1-3]

BME 395C. Special Topics. [1-3]

BME 395D. Special Topics. [1-3]

BME 399. Ph.D. Dissertation Research.

Chemical and Biomolecular Engineering

CHBE 161. Chemical Process Principles. A foundation for advanced work in chemical engineering. Process problems of a chemical and physico-chemical nature are considered. Emphasis is on stoichiometry, material balances, and energy balances required for design computation. FALL. [3]

CHBE 162. Chemical Engineering Thermodynamics. Application of the laws of thermodynamics to chemical engineering systems. Entropy balances and analysis of thermodynamic cycles. Methods of estimating thermodynamic properties of pure fluids and mixtures, including equations of state, to provide background for chemical process design and simulation. SPRING. [3]

CHBE 180. Modeling and Simulation in Chemical Engineering. Development of chemical engineering process models and their numerical solutions. The models include solution of linear and non-linear equations, eigenvalue problems, differentiation, and integration, ordinary differential equations, linear and nonlinear regression. Chemical process simulation using commercial simulators is introduced. A foundation for advanced work in chemical engineering. Prerequisite: CHBE 161; Corequisite: MATH 198; or consent of instructor. SPRING. [3]

CHBE 223. Phase Equilibria and Stage-Based Separations. Thermodynamic principles and calculations of mixture phase equilibrium. Development of correlations to design chemical separation processes. Applications to separation processes involving gases, liquids, and solids such as distillation, adsorption, and extraction. Simulation of separation processes. Prerequisite: CHBE 162, CHBE 180. FALL. [3]

CHBE 225. Chemical Reaction Engineering. Thermodynamic basis of chemical equilibrium. Analysis of chemical kinetic data and application to the design of chemical reactors. Batch, semibatch, and flow reactors are considered in both steady-state and transient operation. Brief treatments of catalysis and physical and chemical adsorption. Prerequisite: CHBE 223. FALL. [3]

CHBE 228W. Chemical Engineering Laboratory I. Laboratory experiments in momentum, energy, and mass transport, thermodynamics, kinetics, separations, and process dynamics. Interpretation of data for equipment and process design. Statistical treatment of data and error analysis. Writing and oral presentations are emphasized. CHBE 228W: Two lecture hours and one 5-hour laboratory. CHBE 229W: One lecture hour and one 5-hour laboratory. Prerequisite: CHBE 230. Sequence begins in SPRING. [4]

CHBE 229W. Chemical Engineering Laboratory II. Laboratory experiments in momentum, energy, and mass transport, thermodynamics, kinetics, separations, and process dynamics. Interpretation of data for equipment and process design. Statistical treatment of data and error analysis. Writing and oral presentations are emphasized. CHBE 228W: Two lecture hours and one 5-hour laboratory. CHBE 229W: One lecture hour and one 5-hour laboratory. Prerequisite: CHBE 230. Sequence begins in SPRING. [3]

CHBE 230. Fluid Mechanics and Heat Transfer. Principles of momentum and energy transport and their application to the analysis and design of chemical and biological engineering systems. Prerequisite: Junior standing. Corequisite: MATH 198. FALL. [3]

CHBE 231. Mass Transfer and Rate-Based Separations. Principles of mass transfer and their application to the analysis of chemical and biological engineering systems. Design of rate-based separation operations. Prerequisite: CHBE 230. SPRING. [3]

CHBE 233W. Chemical Engineering Process and Product Design. A systematic approach to design and safety practices for chemical process operations. Process and product design, economic evaluation of alternatives, ethics, and a cost and safety analysis of a typical chemical, biological, or petroleum process and products. Process simulations required. Prerequisite: CHBE 223, 225, and 231. FALL. [3]

CHBE 242. Chemical Process Control. Design of control systems for chemical processes. Principles of process dynamics and control of single and multivariable systems. Frequency and stability analyses and their effect on controller design. Prerequisite: MATH 198. FALL. [3]

CHBE 246. Chemical Engineering Projects. Opportunities for individual students to do research or design work under guidance of a faculty member. Requires faculty sponsorship of the project. [Variable credit: 1-3 each semester, not to exceed a total of 3]

CHBE 247. Chemical Engineering Projects. Opportunities for individual students to do research or design work under guidance of a faculty member. Requires faculty sponsorship of the project. [Variable credit: 1-3 each semester, not to exceed a total of 3]

CHBE 249. Seminar. SPRING. [1]

CHBE 280. Atmospheric Pollution. Fundamentals of atmospheric pollution and control. The sources and nature of gaseous and particulate air pollutants, the relation of meteorological conditions to their dispersal, and their effects on health and materials are discussed along with administration, standards, and control of air pollution. Prerequisite: Junior standing. SPRING. [3]

CHBE 282. Biochemical Engineering. A course in enzyme catalysis, microbial growth, bioreactor design and analysis and product recovery. Emphasis will be placed on enzyme kinetics and fermentation process modeling, applications to models of commercial fermentations, biomass plants, and enzyme engineering. For graduate students and advanced undergraduates. Prerequisite: consent of instructor. [3]

CHBE 283. Bioprocess Engineering. Application of cellular and molecular biology to process engineering to describe the manufacture of products derived from cell cultures. Design and scale-up of bioreactors and separation equipment. Metabolic and protein engineering utilizing genetically engineered organisms. Prerequisite: BSCI 110A, CHBE 225, CHBE 230. FALL [3].

CHBE 284. Semiconductor Materials Processing. Introduction to the materials processing unit operations of silicon device manufacturing. Topics include basic semiconductor physics and device theory, production of substrates, dopant diffusion, ion implantation, thermal oxidation and deposition processes, plasma deposition processes, photolithography, wet chemical and plasma etching, and analytical techniques. FALL. [3]

CHBE 285. Molecular Simulation. Introduction to the modern tools of statistical mechanics, such as Monte Carlo and molecular dynamics simulation, and variations. Understanding the methods, capabilities, and limitations of molecular simulation and applications to simple and complex fluids relevant to the chemical and related processing industries. Prerequisite: CHBE 162, CHBE 180, CHBE 223, or equivalents. [3]

CHBE 286. Molecular Aspects of Chemical Engineering. Integration of molecular chemistry, property-based thermodynamic descriptions, and a focus on intermolecular energetics for process analysis and product design. Case studies involve molecular, macromolecular, supramolecular, and biomolecular systems. Prerequisite: CHEM 220A and CHBE 162 or equivalents. [3]

CHBE 287. Polymer Science and Engineering. Macromolecular systems with emphasis on the interrelationship of chemical, physical, and engineering properties. Further relation of these properties to synthesis. Physicochemical and biological applications. Prerequisite: CHBE 162, a basic understanding of organic and physical chemistry. [3]

CHBE 290. Special Topics. Prerequisite: consent of instructor. [3] (Offered on demand)

CHBE 297. Senior Engineering Design Seminar. Elements of professional engineering practice. Professionalism, licensing, ethics and ethical issues, intellectual property, contracts, liability, risk, reliability and safety, interdisciplinary teams and team tools, codes, standards, professional organizations, careers, entrepreneurship, human factors, and industrial design. Prerequisite: Senior standing. FALL. [1]

CHBE 310. Applied Mathematics in Chemical Engineering. Chemical engineering applications of advanced mathematical methods. Analytical and numerical methods for ordinary and partial differential equations. Emphasis on recognizing the form of a mathematical model and possible solution methods. Applications in heat and mass transfer, chemical kinetics. FALL. [3]

CHBE 311. Advanced Chemical Engineering Thermodynamics. Application of the thermodynamics method to chemical engineering problems. Development of the first, second, and third laws of thermodynamics; estimation and correlation of thermodynamic properties; chemical and phase equilibria; irreversible thermodynamics. FALL. [3]

CHBE 312. Transport Phenomena. The theory of non-equilibrium processes. Development of the analogy between momentum, energy, and mass transport with applications to common engineering problems. SPRING. [3]

CHBE 313. Applied Chemical Kinetics. Experimental methods in kinetics. Kinetics of industrial reactions and reactor design. Absorption and catalytic systems are considered. FALL. [3]

CHBE 315. Systems Analysis for Process Design and Control. The design and control of chemical process plants, including economic optimization under steady state and transient conditions. [3]

CHBE 320. Surfaces and Adsorption. Surface energy, capillarity, contact angles and wetting, surface films, insoluble monolayers, solid surfaces, membranes, surface area determination, adsorption, adhesion, interface thermodynamics, friction and lubrication, interface in composites, relationships of surface to bulk properties of materials. FALL. [3]

CHBE 369. Master's Thesis Research.

CHBE 379. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

CHBE 389. Master of Engineering Project.

CHBE 395. Professional Communication Skills for Engineers. Introduction of graduate-level written and oral communication skills for engineers. Skills needed to produce peer-reviewed journal publications, research proposals, and research presentations are covered. SPRING. [1]

CHBE 397. Special Topics. [3]

CHBE 398. Seminar. [0]

CHBE 399. Ph.D. Dissertation Research.

Civil Engineering

CE 160. Civil and Environmental Engineering Information Systems I. Part I of a two-semester sequence course providing an introduction to information technologies utilized by civil and environmental engineers. Computer graphics and engineering drawings in civil and environmental engineering. Plans reading in civil engineering project development. Software tools to facilitate communication of engineering concepts and models via modern computer technology. FALL. [2]

CE 161. Civil and Environmental Engineering Information Systems II. Part II of a two-semester sequence providing an introduction to information technologies utilized by civil and environmental engineers. Project-oriented course focusing on developing skills in leveling, mapping, and GIS. Integration of CAD and surveying in hands-on, team-oriented projects addressing specific civil engineering information systems. Project work will include familiarization with, and use of, department information systems instrumentation. Computer applications. Prerequisite: CE 160. SPRING. [2]

CE 180. Statics. Application to systems of forces in two and three dimensions (particles and rigid bodies), resultants, equivalent systems, and equilibria. Vector notation, introduction to shear and moment diagrams, moments of inertia, friction, three-dimensional representation. Credit is offered for only one of CE 180 or BME 101. Corequisite: MATH 155B. FALL, SPRING, SUMMER. [3]

CE 182. Mechanics of Materials. Stress and strain; tension, compression, and shear; Hooke's law, Mohr's circle, combined stresses, strain-energy. Beams, columns, shafts, and continuous beams. Deflections, shear and moment diagrams. Prerequisite: CE 180. FALL, SPRING, SUMMER. [3]

CE 200A. Directed Study. Directed individual study of a pertinent topic in civil and environmental engineering. May include literature review and analysis, analytical investigations, and/or experimental work. Prerequisite: junior standing, completion of two CE courses, and one-page proposal approved by supervising faculty member and chair. FALL, SPRING, SUMMER. [Variable credit: 1-3 each semester]

CE 200B. Directed Study. Continuation of CE 200A in the same or another area of civil and environmental engineering. Prerequisite: CE 200A and one-page proposal approved by supervising faculty member and chair. FALL, SPRING, SUMMER. [Variable credit: 1-3 each semester]

CE 200C. Directed Study. Continuation of CE 200B in the same or another area of civil and environmental engineering. Prerequisite: CE 200B, and one-page proposal approved by supervising faculty member and chair. FALL, SPRING, SUMMER. [Variable credit: 1-3 each semester]

CE 203. Fluid Mechanics. Physical properties of fluids, fluid statics; integral and differential equations of conservation of mass, energy, and momentum; principles of real fluid flows: boundary layer effects, flow through pipes, flow in open channels, drag forces on bodies. Emphasis on civil and environmental engineering applications. Prerequisite: ME 190 and MATH 198. Graduate credit for students in earth and environmental sciences. Credit not awarded for both CE 203 and ME 224. FALL, SUMMER. [3]

CE 204. Fluid Mechanics Laboratory. Team project-oriented course. Practical applications of fluid mechanics principles through laboratory exercises and field trips. Corequisite: CE 203. FALL. [1]

CE 205W. Civil and Environmental Engineering Laboratory. A team project-oriented course that integrates principles of engineering design, simulation and experimentation as applied to civil engineering. Emphasis on experimental design, data analysis and technical communication. Prerequisite: CE 203, CE 232, CE 240. SPRING. [2]

CE 225. Transportation Systems Engineering. The planning, design, and implementation of transportation systems. Particular emphasis is placed upon the design process, traffic engineering, urban transportation planning, and the analysis of current transportation issues. FALL. [3]

CE 226. Introduction to Environmental Engineering. Introduction to the parameters affecting environmental quality, including air and water pollutants, and treatment techniques to achieve drinking water quality or to permit safe discharge to the environment. Contaminant transport and interactions of contaminants with the environment. Governmental regulations covering air, water, solid and hazardous wastes. Overview of residuals management including hazardous and solid wastes and sludge handling, treatment, and disposal. Prerequisite: CHEM 102A, PHYS 116A-B, MATH 198. CE 203 or CHBE 230 or ME 224. FALL. [3]

CE 227. Introduction to Water Resources Engineering. Introduction to engineering of water resources and sewerage systems that control the quantity, quality, timing, and distribution of water to support human habitation and the needs of the environment. Closed conduit flow, open channel flow, surface hydrology, groundwater hydrology, and contaminant transport. Prerequisite: CHEM 102A, PHYS 116AB, MATH 198. CE 203. SPRING. [3]

CE 232. Introduction to Structural Analysis. Analysis of statically determinate and indeterminate beams, trusses, and frames. Computer applications. Prerequisite: CE 182. FALL. [3]

CE 235. Introduction to Structural Design. Properties of steel and design philosophies. Load and resistance factor design of ties, struts,

beams, beam-columns, and very simple connections using bolts and welds as fasteners based on AISC Specifications. Properties of reinforced concrete and design philosophy. Design of beams in flexure and shear, one-way slabs, T-beams, columns, development length, and serviceability based on ACI Codes of Practice. Prerequisite: CE 232. SPRING. [3]

CE 240. Geotechnical Engineering. Origin, formation, identification, and engineering properties of soils. Discussion on index properties, soil moisture, soil structure, compressibility, shear strength, stress analysis, Rankine and Coulomb earth pressure theories and bearing capacity. Laboratory experiences. Graduate credit for earth and environmental sciences majors. Prerequisite: CE 182 or consent of instructor. FALL. [3]

CE 248. Civil Engineering Design I. A meaningful, major engineering design course for civil engineering students. Includes a response to request(s) for proposals, project conception, project design, design analysis, and economic evaluation of alternatives for typical civil engineering projects within selected areas of professional depth. Includes consideration of safety, reliability, aesthetics, ethics, social and environmental impact, and government regulations. Prerequisite: CE 205W, senior standing, or consent of instructor. FALL. [1]

CE 249. Civil Engineering Design II. A continuation of CE 248. The course involves an oral presentation and the submission of a final design report. Prerequisite: CE 248. SPRING. [2]

CE 251. Foundation Analysis and Design. Study of shallow and deep foundation elements and systems for civil engineering structures. Soil exploration and site investigation. Prerequisite: CE 240 or equivalent. SPRING. [3]

CE 252A. Civil and Environmental Engineering Seminar. Presentations of current technical and professional issues through literature discussions, seminars by faculty and practicing engineers, and participation in panel discussions. Prerequisite: Senior or graduate standing or consent of instructor. FALL, SPRING. [1]

CE 252B. Civil and Environmental Engineering Seminar. Continuation of CE 252A. Prerequisite: Senior or graduate standing or consent of instructor. FALL, SPRING. [1]

CE 255. Transportation System Design. Geometric analysis of transportation ways with particular emphasis on horizontal and vertical curve alignment. Design of highways, interchanges, intersections, and facilities for air, rail, and public transportation. Prerequisite: CE 225, junior standing. SPRING. [3]

CE 256. Urban Transportation Planning. Analytical methods and the decision-making process. Transportation studies, travel characteristic analysis, and land-use implications are applied to surface transportation systems. Emphasis is on trip generation, trip distribution, modal split, and traffic assignment. Computerized planning programs are used. Prerequisite: CE 225, junior standing. SPRING. [3]

CE 257. Traffic Engineering. Analysis of the characteristics of traffic, including the driver, vehicle, volumes, speeds, capacities, roadway conditions, and accidents. Traffic regulation, control, signing, signalization, and safety programs are also discussed. Prerequisite: CE 225. FALL. [3]

CE 259. Geographic Information Systems. Principles of computerized geographic information systems (GIS) and analytical use of spatial information. Integration with global positioning systems (GPS) and internet delivery. Includes GIS software utilization and individual projects. SPRING. [3]

CE 262. Intelligent Transportation Systems. Elements of intelligent transportation system (ITS) architecture. Survey of component systems. Analysis of potential impacts. Field operational tests, analysis methods, deployment initiatives and results. SPRING. [3]

CE 286. Construction Project Management. Introduction to the theory and application of the fundamentals of construction project management. The construction process and the roles of professionals in the process. Broad overview of the construction project from conception through completion. Application of management practices including

planning, directing, cost minimizing, resource allocation, and control of all aspects of construction operations and resources. Prerequisite: CE 235 or consent of instructor. FALL. [3]

CE 287. Construction Estimating. Fundamentals of construction estimating. Estimation of material, labor, and equipment quantities, including costing and pricing of projects. Application of estimating practices using real-world examples and project estimating software. Corequisite: CE 286. FALL. [3]

CE 288. Construction Planning and Scheduling. Fundamentals of construction planning and scheduling. Application of management practices including process planning; directing, costing; resource allocation; and controlling all aspects of construction operations and resources, from pre-construction through operation and maintenance. Use of real-world examples and project scheduling software. Prerequisite: CE 286 and CE 287. SPRING. [3]

CE 290. Reliability and Risk Case Studies. Review of case studies involving successes and failures in managing reliability and risk assessment of engineering systems from a wide range of perspectives, including design, production, operations, organizational culture, human factors and exogenous events. Analysis of event consequences in terms of public health and safety, the environment and business continuity, and the implications on regulation, legal liability and business practices. Evaluation of mitigation strategies based on achievable goals, technical and political feasibility and economic impact. Cases drawn from natural disasters, industrial accidents, and intentional acts. Prerequisite: Junior standing or consent of instructor. FALL [3]

CE 291. Construction Materials and Methods. Implications of design realities, material specifications, code limitations, and regulations on the construction process. Natural and man-made materials, construction techniques, and other issues that impact quality, constructability, and life-cycle assessment. Prerequisite: Senior standing. SUMMER. [3]

CE 292. Construction Law and Contracts. Review of case studies involving successes and failures in legal principles and landmark cases relevant to civil engineering and construction. Contracts, torts, agency and professional liability, labor laws, insurance, expert testimony, arbitration, patents and copyrights, sureties, and ethics. Prerequisite: CE 286. SPRING. [3]

CE 293. Advanced Structural Steel Design. Advanced topics in column and beam design including local buckling, composite beams, plate girders, and torsion design. Behavior and design of bolted and welded connections. Structural planning and design of structural systems such as multistory buildings including computer applications. Prerequisite: CE 235. FALL. [3]

CE 294. Advanced Reinforced Concrete Design. Design and behavior of two-way slab systems. Yield line theory. Shear and torsion analysis and design. Serviceability requirements and control of deflections of reinforced concrete systems. Introduction to prestressed concrete. Prerequisite: CE 235. SPRING. [3]

CE 295. Mechanics of Composite Materials. Review of constituent materials (reinforcements, matrices, and interfaces) and fabrication processes. Prediction of properties of unidirectional and short fiber materials (micromechanics). Anisotropic elasticity (derivation of Hooke's law for anisotropic materials, macromechanics of laminated composites). Analysis of laminated composites based on Classical Lamination Theory. Behavior of composite beams and plates. Special topics (creep, fracture, fatigue, impact, and environmental effects). Prerequisite: CE 182 and MSE 150. SPRING. [3]

CE 298. Building Systems and LEED. Design and construction of mechanical, electrical, plumbing, and telecommunications systems in buildings. Leadership in Energy and Environmental Design (LEED) green Building Rating System(TM) building approach to sustainability. Prerequisite: Senior standing. SPRING. [3]

CE 299. Special Topics. [3]

CE 301. Advanced Mechanics of Solids I. Stress and strain analysis: equilibrium, compatibility, and constitutive equations including linear

elastic and thermo-elastic relations; transformations; octahedral and deviatoric stresses. Applications to the torsion of bars, stress concentrations, and semi-infinite medium problems. Euler-Bernoulli and Timoshenko beam theories. Energy and related methods including applications. Kirchoff's bending of rectangular and circular plates. Prerequisite: CE 182 or equivalent, MATH 198 or equivalent, MATH 194 or equivalent, or consent of instructor. FALL. [3]

CE 302. Advanced Mechanics of Solids II. Modes of failure: creep and relaxation, plastic flow, fracture and fatigue. Stability of members, frames, and plates. Membrane and bending analyses of shells, including the beam on elastic foundation analogy for cylindrical shells. Inelastic behavior and plasticity including frame, planar, axi-symmetric, and slip line problems. Prerequisite: CE 301 or consent of instructor. SPRING. [3]

CE 307. Finite Element Analysis. Discrete modeling of problems of the continua. Mathematical basis of finite element method-weighted residual and variational concepts. Finite element formulations-displacement, force, and mixed methods. One-D problems of the continua and finite element solution-Co and C1 elements, eigenvalue and transient problems. Error checks and control. Mapping, shape functions, numerical quadrature, and solution of equations. Finite element formulation of two-dimensional problems (single- and multi-field), mapping and shape functions, triangular and quad elements with straight or curved boundaries. Application problems in 1-D, 2-D and 3-D. Three-D elements, singular problems, and elements of buckling and nonlinear problems. Error estimation and quality control. Computer implementation. Commercial packages. Prerequisite: MATH 194 and MATH 226 or equivalent, or consent of instructor. FALL. [3]

CE 308. Advanced Computational Mechanics. Basics of nonlinear mechanics—geometric and material nonlinearities. Discrete Lagrangian, Eulerian and other formulations. Nonlinear material models. Numerical solution algorithms in space and time. Solution of nonlinear (second-order and higher) problems. Multi-disciplinary problems. Error estimation and adaptive model improvement. Introduction to multi-scale modeling and atomistic/continuum coupling. Prerequisite: CE 307 or equivalent. SPRING. [3]

CE 309. Structural Dynamics and Control. Analysis of single- and multi-degree-of-freedom systems. Modal superposition method. Time and frequency domain analyses. Numerical methods and nonlinear dynamic analysis. Application to structures subject to earthquake and impact forces. Elements of feedback control systems. Control of lumped parameter systems. Active, passive, and hybrid mass dampers. Application to simple building and bridge structures. SPRING. [3]

CE 310. Probabilistic Methods in Engineering Design. Applications of probabilistic methods in the analysis and synthesis of engineering systems. Review of basic probability concepts, random variables and distributions, modeling and quantification of uncertainty, testing the validity of assumed models, linear regression and correlation analyses, Monte Carlo simulation, reliability analysis and reliability-based design. Prerequisite: MATH 194. FALL. [3]

CE 311. Engineering Design Optimization. Methods for optimal design of engineering systems. Optimization under uncertainty, reliability-based design optimization, robust design, multidisciplinary problems, multi-objective optimization. Discrete and continuous design variables, advanced numerical algorithms, and formulations and strategies for computational efficiency. Practical applications and term projects in the student's area of interest. Prerequisite: MATH 287, MATH 288 or CS 257 or CE 310. [3]

CE 313. Advanced Reliability Methods. Computational methods for probabilistic analysis and design of modern engineering systems. Emphasis on system reliability, nonlinear reliability methods, Weibull analysis, Bayesian methods, response surface modeling and design of experiments, advanced simulation and variance reduction concepts, sensitivity analysis and reliability-based design optimization. Practical applications using existing software. Prerequisite: CE 310. SPRING. [3]

CE 317. Stability of Structures. Buckling analysis of perfect and imperfect columns, mathematical treatment of various stability criteria, dynamic and static instability, energy methods. Buckling of frames, trusses, beam-columns, rings, and tubes. [3]

CE 318. Prestressed Concrete. Behavior and design of statically determinate prestressed concrete structures under bending moment, shear, torsion, and axial load effects. Design of statically determinate prestressed structures such as continuous beams, frames, slabs and shells. Creep and shrinkage effects and deflections of prestressed concrete structures. Applications to the design and construction of bridges and buildings. Prerequisite: CE 235 or equivalent. [3]

CE 325A. Individual Study of Civil Engineering Problems. Literature review and analysis of special problems under faculty supervision. FALL, SPRING, SUMMER. [1-4 each semester]

CE 325B. Individual Study of Civil Engineering Problems. Literature review and analysis of special problems under faculty supervision. FALL, SPRING, SUMMER. [1-4 each semester]

CE 325C. Individual Study of Civil Engineering Problems. Literature review and analysis of special problems under faculty supervision. FALL, SPRING, SUMMER. [1-4 each semester]

CE 351. Public Transportation Systems. Comprehensive study of public transportation, with emphasis on planning, management, and operations; paratransit, ridesharing, and rural public transportation systems. Prerequisite: CE 256. SPRING. [3]

CE 353. Airport Planning and Design. Integration and application of the principles of airport master planning from the beginning stages of site selection through actual design of an airport facility. Specific study topics address demand forecasting, aircraft characteristics, capacity analyses, and geometric design of runways, terminals, and support facilities. Prerequisite: CE 225 or consent of instructor. [3]

CE 355. Advanced Transportation Design. An in-depth view of the design process. Complex design problems and solutions, with the use of computer-based analytical and design tools. Comprehensive design projects. Prerequisite: CE 255. SPRING. [3]

CE 356. Advanced Transportation Planning. A continuation of the concepts from CE 256, with emphasis on analytical techniques used in forecasting travel. Use of computer-based models, transportation and energy contingency planning methods. Prerequisite: CE 256. SPRING. [3]

CE 357. Theory of Traffic Flow. A study of traffic flow from the perspective of probability as applied to highway, intersection and weaving capacities. Discrete and continuous flow, vehicle distributions, queuing, and simulation. Prerequisite: CE 257. [3]

CE 359. Emerging Information Systems Applications. An introduction to emerging information systems technologies and their role in improving productivity and efficiency in managing engineering operations. Design of integrated approaches to enhance the speed, accuracy, reliability, and quantity of information available for decision support. Emphasis on case studies of innovative applications in transportation and manufacturing, leading to individual and group projects requiring new product development. Prerequisite: background transportation or manufacturing operations or consent of instructor. FALL. [3]

CE 369. Master's Thesis Research.

CE 371A. Reliability and Risk Engineering Seminar. Seminars by expert speakers on reliability and risk assessment and management of multi-disciplinary engineering systems. Topics on infrastructure and environmental systems, mechanical, automotive, and aerospace systems; network systems (power distribution, water and sewage systems, transportation etc.); manufacturing and construction; and electronic and software systems. FALL, SPRING. [1]

CE 371B. Reliability and Risk Engineering Seminar. Continuation of CE 371A. FALL, SPRING. [1]

CE 379. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

CE 389. Master of Engineering Project.

CE 399. Ph.D. Dissertation Research.

Environmental Engineering

ENVE 220A. Sustainable Development. A Vanderbilt Initiative for Scholarship and Global Engagement course. Quantitative investigation of the role of adequate and renewable resources for continual economic development. Past and present resource challenges, influences of indigenous, national, and international cultures, land use practices, social policy, and economic strategies on infrastructure development. Future challenges posed by climate change, and how market- and government-based policies may be applied in conditions of uncertainty to encourage sustainable development. Intended to be followed by ENVE 220B. SPRING. [3]

ENVE 220B. Sustainable Development Field Experience. A Vanderbilt Initiative for Scholarship and Global Engagement course. Through lectures, research projects, and service-learning opportunities, students will reflect on themes from ENVE 220A and apply them to work in the field. Students will design and conduct quantitative-oriented research projects in collaboration with faculty mentors and international partners. Prerequisite: ENVE 220A. SUMMER. [1-3]

ENVE 220C. Sustainable Development Research. A Vanderbilt Initiative for Scholarship and Global Engagement course. A quantitative, project- and research-based seminar drawing on student experiences and learning in ENVE 220A and ENVE 220B. Prerequisite: ENVE 220B. FALL. [3]

ENVE 252. Physical Hydrology. Development of fundamental bases of hydrological processes. Land-atmosphere processes, surface-water flows, soil moisture dynamics, and groundwater flows. Exposition of physical principles, their embodiment in mathematical models, and their use in interpreting observations in the field and laboratory. Prerequisite: CE 203 or ME 224 or CHBE 230 or EES 255. FALL. [3]

ENVE 254. Energy and Water Resources. Scientific, technological, philosophical, and social issues surrounding approaches to carbon-based energy and alternative energy resources, management of carbon through sequestration, supplying and treating water for agriculture, communities, and industry, and changing climate impacts on regional distribution of water resources. SPRING. [3]

ENVE 260. Solid and Hazardous Waste Management. An introduction to solid municipal and hazardous waste management including generation, characterization, collection, treatment and disposal. Emphasis given to the legal requirements, risk assessment and management, costs and policy considerations including pollution prevention, recycling and substitution. SPRING. [3]

ENVE 262. Hydrology. The hydrologic cycle, study of precipitation, evapotranspiration, hydrometeorology, stream flow, flood flow, flood routing, storm sewer design, detention basin design, and water quality. Prerequisite: CE 203, CE 227. FALL. [3]

ENVE 264. Environmental Assessments. Design and conduct of environmental assessments to evaluate risks posed by infrastructure systems or environmental contamination. Impact analyses for sources, infrastructure modifications, due diligence environmental audits, and contaminated site remedial investigations. Prerequisite: senior standing or consent of instructor. FALL. [3]

ENVE 270. Environmental Thermodynamics, Kinetics, and Mass Transfer. Examination of fundamental environmental processes and phenomena which provide the analytical tools necessary to solve a broad range of environmental problems. These tools include equilibrium phenomena, process rate and mass transport phenomena. Prerequisite: CHEM 102A and 102B, MATH 198, CE 226 or equivalent, and senior standing or consent of instructor. FALL. [3]

ENVE 271. Environmental Chemistry. Theoretical aspects of physical, organic, and inorganic chemistry applied to environmental engineering. Estimation of chemical parameters based on thermodynamic and structural activity relationships, kinetics of chemical reactions, equilibrium processes in the environment, including the carbonate system, metal complexation and precipitation. Prerequisite: CHEM 102a and b and senior standing or consent of instructor. FALL. [3]

ENVE 272. Biological Unit Processes. Principles of biology and their application to wastewater treatment processes with emphasis on microbial ecology, bioenergetics, and the role of chemical structure in biodegradability. Utilization kinetics of inhibitory and non-inhibitory organic compounds. Biological process analysis and design (aerobic and anaerobic) for municipal and industrial wastewaters, using a mass balance approach. Prerequisite: senior standing or above. SPRING. [3]

ENVE 273. Environmental Characterization and Analysis. Introduction to the acquisition and interpretation of environmental data. Principles of chemical measurement, sample collection and sample program design; laboratory safety and good laboratory practices; analytical instrumentation and methods; quality assurance and quality control; and statistical interpretation of data. Hands-on experience is gained in combination with demonstrations featuring state-of-the-art analytical instrumentation. Prerequisite: Junior standing, CE 226, ENVE 271, or consent of instructor. SPRING. [3]

ENVE 274. Surface Water Quality Modeling. Analysis of physical, chemical, biological, and physiological contaminants in streams, lakes, and estuaries, and surface water/groundwater interfaces. Analytical and numerical modeling techniques. One- and two-dimension computer simulation of surface water quality. Prerequisite: ENVE 270 or equivalent. SPRING. [3]

ENVE 276. Groundwater Hydrology. The occurrence and flow of ground water. Basic concepts of the effects of varying permeability and capillarity on seepage flow. Flow toward wells, through dikes, and beneath dams. Students cannot receive credit for both ENVE 276 and EES 257. Prerequisite: MATH 198; CE 203. SPRING. [3]

ENVE 277. Physical/Chemical Unit Processes. Principles of mass transfer, chemistry, and chemical reactor technology applied to the design and operation of water and wastewater treatment processes. Unit processes such as coagulation/flocculation, sedimentation, filtration, carbon adsorption, ion exchange, air stripping, precipitation, chemical oxidation and chemical reduction will be evaluated as alternatives for the treatment of drinking water and industrial wastewaters. Prerequisite: CE 226 or equivalent and senior standing or above. SPRING. [3]

ENVE 285. Introduction to Nuclear Environmental Engineering. The nuclear fuel cycle and environmental and societal impacts associated with its traditional implementation. Technical and programmatic challenges associated with fuel production, and waste management including processing, storage, transportation, decontamination, decommissioning, and environmental restoration. Technologies and approaches for reducing impacts of the nuclear fuel cycle. Prerequisite: Senior or graduate standing. SPRING. [3]

ENVE 296. Operational Risk Management. Development of safety and security programs for protecting human health, the environment and business continuity. Focus on defining an all-hazards risk management process and program implementation, performing risk assessments, determining and selecting appropriate risk reduction strategies, and influencing risk management decisions internally and externally. Applications drawn from natural disasters, man-made accidents and intentional acts. Prerequisite: Senior standing or consent of instructor. SPRING. [3]

ENVE 312. Pollutant Transport in the Environment. An introduction to the mathematical foundations of fluid mechanics and transport of pollutants in the environment. Fundamental conservation of mass, momentum, and energy equations will be developed. Appropriate initial and boundary conditions and solution techniques will be discussed for a number of applications. Prerequisite: CE 203, MATH 198. FALL. [3]

ENVE 325A. Individual Study. Literature review and analysis, or laboratory investigation of special problems under faculty supervision. FALL, SPRING, SUMMER. [Variable credit: 1-4 each semester]

ENVE 325B. Individual Study. Literature review and analysis, or laboratory investigation of special problems under faculty supervision. FALL, SPRING, SUMMER. [Variable credit: 1-4 each semester]

ENVE 325C. Individual Study. Literature review and analysis, or laboratory investigation of special problems under faculty supervision. FALL, SPRING, SUMMER. [Variable credit: 1-4 each semester]

ENVE 330. Nuclear Facilities Life Cycle Engineering. The life cycle (including siting, licensing, construction, operations and decommissioning) of the nuclear facilities that comprise the nuclear fuel cycle—from mining uranium ore through the potential recycling of used nuclear fuel. FALL. [3]

ENVE 331. Nuclear Chemistry and Processes. Chemistry and chemical processing of the actinides and important fission products and by-products. Development of nuclear chemical engineering processes for these materials. SPRING. [3]

ENVE 332. Storage, Treatment and Disposal of Radioactive Waste. Evolution of current domestic and international approaches, including waste forms, classification, storage and disposal locations, and environmental and safety assessments. SPRING. [3]

ENVE 333. Nuclear Process Safety. Approaches for evaluating the safety of nuclear radiochemical processing systems. Safety analysis practices from the chemical industry, the nuclear power community, and the United States nuclear weapons complex, and other quantitative and qualitative risk assessment methods. SUMMER. [3]

ENVE 334. Nuclear Environmental Regulation, Law and Practice. Environmental laws and regulations governing radionuclides and radioactive waste, including those concerning hazardous chemicals and wastes and those impacting commercial nuclear fuel cycle facilities and former nuclear weapons and materials sites. Interplay between regulatory agencies such as the US Nuclear Regulatory Commission, the US Environmental Protection Agency, and the states. Self-regulation of activities by the U.S. Department of Energy. SUMMER. [3]

ENVE 369. Master's Thesis Research.

ENVE 379. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

ENVE 389. Master of Engineering Project.

ENVE 399. Ph.D. Dissertation Research.

Computer Engineering

CMPE 291. Special Topics. [Variable credit: 1-3 each semester]

CMPE 292. Special Topics. [Variable credit: 1-3 each semester]

Computer Science

CS 101. Programming and Problem Solving. An intensive introduction to algorithm development and problem solving on the computer. Structured problem definition, top down and modular algorithm design. Running, debugging, and testing programs. Program documentation. FALL, SPRING. [3]

CS 103. Introductory Programming for Engineers and Scientists. An introduction to problem solving on the computer. Intended for students other than computer science and computer engineering majors. Methods for designing programs to solve engineering and science problems. Generic programming concepts. FALL, SPRING. [3]

CS 151. Computers and Ethics. Analysis and discussion of problems created for society by computers, and how these problems pose ethical dilemmas to both computer professionals and computer users. Topics include: computer crime, viruses, software theft, ethical implications of life-critical systems. FALL, SPRING. [3]

CS 201. Program Design and Data Structures. Continuation of CS 101. The study of elementary data structures, their associated algorithms and their application in problems; rigorous development of

programming techniques and style; design and implementation of programs with multiple modules, using good data structures and good programming style. Prerequisite: CS 101. FALL, SPRING. [3]

CS 204. Program Design and Data Structures for Scientific Computing. Data Structures and their associated algorithms in application to computational problems in science and engineering. Time and memory complexity; dynamic memory structures; sorting and searching; advanced programming and program-solving strategies; efficient software library use. Prerequisite: CS 101 or 103. SPRING. [3]

CS 212. Discrete Structures. A broad survey of the mathematical tools necessary for an understanding of computer science. Topics covered include an introduction to sets, relations, functions, basic counting techniques, permutations, combinations, graphs, recurrence relations, simple analysis of algorithms, O-notation, Boolean algebra, propositional calculus, and numeric representation. Prerequisite: A course in computer science or two semesters of calculus. FALL, SPRING. [3]

CS 231. Computer Organization. The entire hierarchical structure of computer architecture, beginning at the lowest level with a simple machine model (e.g., a simple von Neumann machine). Processors, process handling, I/O handling, and assembler concepts. Graduate credit not given for computer science majors. Prerequisite: CS 201; corequisite: EECE 116/116L. FALL, SPRING. [3]

CS 240A. Undergraduate Research. Open to qualified majors with consent of instructor and adviser. No more than 6 hours may be counted towards the computer science major. Prerequisite: CS 231. FALL, SPRING. [Variable credit: 1-3 each semester, not to exceed a total of 6]

CS 240B. Undergraduate Research. Open to qualified majors with consent of instructor and adviser. No more than 6 hours may be counted towards the computer science major. Prerequisite: CS 231. FALL, SPRING. [Variable credit: 1-3 each semester, not to exceed a total of 6]

CS 242. Special Topics. [Variable credit: 1-3]

CS 250. Algorithms. Advanced data structures, systematic study and analysis of important algorithms for searching; sorting; string processing; mathematical, geometrical, and graph algorithms, classes of P and NP, NP-complete and intractable problems. Prerequisite: CS 201 and CS 212. FALL, SPRING. [3]

CS 251. Intermediate Software Design. High quality development and reuse of architectural patterns, design patterns, and software components. Theoretical and practical aspects of developing, documenting, testing, and applying reusable class libraries and object-oriented frameworks using object-oriented and component-based programming languages and tools. Prerequisite: CS 201. FALL, SPRING. [3]

CS 252. Theory of Automata, Formal Languages, and Computation. Finite-state machines and regular expressions. Context-free grammars and languages. Pushdown automata. Turing machines. Undecidability. The Chomsky hierarchy. Computational complexity. Prerequisite: CS 212. SPRING. [3]

CS 258. Introduction to Computer Graphics. Featuring 2D rendering and image-based techniques, 2D and 3D transformations, modeling, 3D rendering, graphics pipeline, ray-tracing, and texture-mapping. Prerequisite: Linear Algebra, CS 201, junior standing. FALL. [3]

CS 259. Introduction to Computer Animation. Introduction to the principles and techniques of computer animation. Students work in small groups on the design, modeling, animation, and rendering of a small animation project. Topics include storyboarding, camera control, skeletons, inverse kinematics, splines, keyframing, motion capture, dynamic simulation, particle systems, facial animation, and motion perception. Prerequisite: CS 201, Linear Algebra. SPRING. [3]

CS 260. Artificial Intelligence. Introduction to the principles and programming techniques of artificial intelligence. Strategies for searching, representation of knowledge and automatic deduction, learning, and adaptive systems. Survey of applications. Prerequisite: CS 250 and CS 270 or consent of instructor. FALL. [3]

CS 265. Introduction to Database Management Systems. Logical and physical organization of databases. Data models and query languages, with emphasis on the relational model and its semantics. Concepts of data independence, security, integrity, concurrency. Prerequisite: CS 201. FALL. [3]

CS 269. Project in Artificial Intelligence. Students work in small groups on the specification, design, implementation, and testing of a sizeable AI software project. Projects (e.g., an "intelligent" game player) require that students address a variety of AI subject areas, notably heuristic search, uncertain reasoning, planning, knowledge representation, and learning. Class discussion highlights student progress, elaborates topics under investigation, and identifies other relevant topics (e.g., vision) that the project does not explore in depth. Prerequisite: CS 260 or consent of instructor. SPRING. [3]

CS 270. Programming Languages. General criteria for design, implementation, and evaluation of programming languages. Historical perspective. Syntactic and semantic specification, compilations, and interpretation processes. Comparative studies of data types and data control, procedures and parameters, sequence control, nesting, scope and storage management, run-time representations. Non-standard languages, problem-solving assignments in a laboratory environment. Prerequisite: CS 231. FALL, SPRING. [3]

CS 274. Modeling and Simulation. General theory of modeling and simulation of a variety of systems: physical processes, computer systems, biological systems, and manufacturing processes. Principles of discrete-event, continuous, and hybrid system modeling, simulation algorithms for the different modeling paradigms, methodologies for constructing models of a number of realistic systems, and analysis of system behavior. Computational issues in modeling and analysis of systems. Stochastic simulations. Prerequisite: CS 201, MATH 194 or MATH 198, MATH 216 or MATH 218. SPRING. [3]

CS 276. Compiler Construction. Review of programming language structures, translation, loading, execution, and storage allocation. Compilation of simple expressions and statements. Organization of a compiler including compile-time and run-time symbol tables, lexical scan, syntax scan, object code generation, error diagnostics, object code optimization techniques, and overall design. Use of a high-level language to write a complete compiler. Prerequisite: CS 231. FALL. [3]

CS 278. Principles of Software Engineering. The nature of software. The object-oriented paradigm. Software life-cycle models. Requirements, specification, design, implementation, documentation, and testing of software. Object-oriented analysis and design. Software maintenance. Prerequisite: CS 270 or senior standing in Computer Science or Computer Engineering. FALL. [3]

CS 279. Software Engineering Project. Students work in teams to specify, design, implement, document, and test a nontrivial software project. The use of CASE (Computer-Assisted Software Engineering) tools is stressed. Prerequisite: CS 278. SPRING. [3]

CS 281. Principles of Operating Systems I. Overview of goals of operating systems. Introduction to the resource allocation and control functions of operating systems. Scheduling of processes and processors. Concurrent processes and primitives for their synchronization. Use of parallel processes in designing operating system subsystems. Methods of implementation of parallel processes on conventional computers. Introduction of notions of virtual memory, paging, protection of shared and non-shared information. Structures of files of data in secondary storage. Security issues. Case studies. Prerequisite: CS 231. FALL, SPRING. [3]

CS 282. Principles of Operating Systems II. Projects involving modification of a current operating system. Lectures on memory management policies, including virtual memory. Protection and sharing of information, including general models for implementation of various degrees of sharing. Resource allocation in general, including deadlock detection and prevention strategies. Introduction to operating system

performance measurement, for both efficiency and logical correctness. Two hours lecture and one hour laboratory. Prerequisite: CS 281. SPRING. [3]

CS 283. Computer Networks. Computer communications, network architectures, protocol hierarchies, and the open systems interconnection model. Modeling, analysis and specification of protocols. Wide area networks and local area networks including rings, buses, and contention networks. Prerequisite: CS 281. SPRING. [3]

CS 284. Computer Systems Analysis. Techniques for evaluating computer system performance with emphasis upon application. Topics include measurement and instrumentation techniques, benchmarking, simulation techniques, elementary queuing models, data analysis, operation analysis, performance criteria, case studies. Project involving a real computer system. Prerequisite: CS 281. SPRING. [3]

CS 285. Network Security. Principles and practice of network security. Security threats and mechanisms. Cryptography, key management, and message authentication. System security practices and recent research topics. Prerequisite: CS 283. FALL. [3]

CS 291. Special Topics. [Variable credit: 1-3 each semester] (Offered on demand)

CS 292. Special Topics. [Variable credit: 1-3 each semester] (Offered on demand)

CS 310. Design and Analysis of Algorithms. Set manipulation techniques, divide-and-conquer methods, the greedy method, dynamic programming, algorithms on graphs, backtracking, branch-and-bound, lower bound theory, NP-hard and NP-complete problems, approximation algorithms. Prerequisite: CS 250. SPRING. [3]

CS 311. Graph Algorithms. Algorithms for dealing with special classes of graphs. Particular emphasis is given to subclasses of perfect graphs and graphs that can be stored in a small amount of space. Interval, chordal, permutation, comparability, and circular-arc graphs; graph decomposition. Prerequisite: CS 310 or MATH 275. [3]

CS 315. Automated Verification. Systems verification and validation, industrial case studies, propositional and predicate logic, syntax and semantics of computational tree and linear time logics, binary decision diagrams, timed automata model and real-time verification, hands on experience with model checking using the SMV, SPIN and UPPAAL tools, and state reduction techniques. FALL. [3]

CS 320. Algorithms for Parallel Computing. Design and analysis of parallel algorithms for sorting, searching, matrix processing, FFT, optimization, and other problems. Existing and proposed parallel architectures, including SIMD machines, MIMD machines, and VLSI systolic arrays. Prerequisite: CS 310 or consent of instructor. [3]

CS 350. Artificial Neural Networks. Theory and practice of parallel distributed processing methods using networks of neuron-like computational devices. Neurobiological inspirations, attractor networks, correlation and error-correction learning, regularization, unsupervised learning, reinforcement learning, Bayesian and information theoretic approaches, hardware support, and engineering applications. SPRING. [3]

CS 351. Advanced Animation. Current research issues and problems in computer animation, with special focus on motion capture, dynamic simulation, and key-framing. Cloth, deformable bodies, natural phenomena, geometric algorithms, procedural techniques, facial animation, hair, autonomous characters, flocking, empirical evaluation, and interfaces for animation. Prerequisite: CS 259 or consent of instructor. FALL. [3]

CS 352. Human-Computer Interaction. An overview of human computer interaction and problems of current interest. Topics include: Human factors, GOMS, user interface design and evaluation, interaction modalities, distributed cognition, ubiquitous computing. A project involving design and evaluation will be performed. Prerequisite: consent of instructor. FALL. [3]

CS 358. Computer Vision. (Also listed as EECE 358) The fundamentals of computer vision and techniques for image understanding and high-level image processing. Includes image segmentation, geometric structures, relational structures, motion, matching, inference, and vision systems. Prerequisite: CS 357 or EECE 357. SPRING. [3]

CS 359. Medical Image Registration. Foundations of medical image registration. Mathematical methods and practical applications. Image-to-image registration, image-to-physical registration, applications to image-guided procedures and the most commonly used imaging modalities with an emphasis on tomographic images. FALL. [3]

CS 360. Advanced Artificial Intelligence. Discussion of state-of-the-art and current research issues in heuristic search, knowledge representation, deduction, and reasoning. Related application areas include: planning systems, qualitative reasoning, cognitive models of human memory, user modeling in ICAI, reasoning with uncertainty, knowledge-based system design, and language comprehension. Prerequisite: CS 260 or equivalent. FALL. [3]

CS 362. Machine Learning. An introduction to machine learning principles of artificial intelligence, stressing learning's role in constraining search by augmenting and/or reorganizing memory. Topics include connectionist systems; concept learning from examples; operator, episode, and plan learning; problem-solving architectures that support learning; conceptual clustering; computer models of scientific discovery; explanation-based learning; and analogical reasoning. Psychological as well as computational interests in learning are encouraged. Prerequisite: CS 260, CS 360, or equivalent. SPRING. [3]

CS 364. Intelligent Learning Environments. Theories and concepts from computer science, artificial intelligence, cognitive science, and education that facilitate designing, building, and evaluating computer-based instructional systems. Development and substantiation of the concept, architecture, and implementation of intelligent learning environments. Multimedia and web-based technology in teaching, learning, collaboration, and assessment. Prerequisite: CS 260, CS 360, or equivalent. SPRING. [3]

CS 366. Distributed Artificial Intelligence. Principles and practice of multiple agent systems for distributed artificial intelligence. Game theory, distributed negotiation and decision making, distributed problem solving, cooperation, coalition formation and distributed learning. Prerequisite: CS 260. SPRING. [3]

CS 369. Master's Thesis Research.

CS 375. Discrete-Event Systems: Supervisory Control and Diagnosis. Algebraic structures, automata and formal language theory, process modeling with finite-state automata, supervisory control theory, controllability and supervision, supervisory control under partial observation, modular and hierarchical supervisory control, supervisory control of real-time systems, fault diagnosis of discrete-event systems, and modular diagnosis approaches. SPRING. [3]

CS 376. Foundations of Hybrid and Embedded Systems. Modeling, analysis, and design of hybrid and embedded systems. Heterogeneous modeling and design of embedded systems using formal models of computation, modeling and simulation of hybrid systems, properties of hybrid systems, analysis methods based on abstractions, reachability, and verification of hybrid systems. FALL. [3]

CS 377. Topics in Embedded Software and Systems. Specification and composition of domain-specific modeling languages. Design methodologies for embedded systems. Platforms for embedded system design and implementation. Analysis of embedded systems. SPRING. [3]

CS 379. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit 0-12]

CS 381. Advanced Operating Systems Principles. Techniques for formally analyzing various issues in operating systems. Includes process synchronization, interprocess communication, deadlock, naming, memory management, objective capability-models, architectural support, protection, fault tolerance. Prerequisite: CS 281. FALL. [3]

CS 384. Performance Evaluation of Computer Systems. Techniques for computer systems modeling and analysis. Topics covered include analytical modeling with emphasis on queuing network models, efficient computational algorithms for exact and approximate solutions, parameter estimation and prediction, validation techniques, workload characterization, performance optimization, communication and distributed system modeling. Prerequisite: CS 281 or CS 381. SPRING. [3]

CS 385. Advanced Software Engineering. An intensive study of selected areas of software engineering. Topics may include CASE tools, formal methods, generative techniques, aspect-oriented programming, metrics, modeling, reuse, software architecture, testing, and open-source software. Prerequisite: CS 278. FALL. [3]

CS 386. System-Level Fault Diagnosis. An overview of the basic concepts of the theory of fault diagnosis and problems of current interest. Topics include the classical PMC and BGM models of fault diagnosis, hybrid (permanent and intermittent faults) models, diagnostic measures for one-step, sequential, and inexact diagnosis. Emphasis is on algorithmic techniques for solving the diagnosis and diagnosability problems in various models. Prerequisite: CS 381 or consent of instructor. SPRING. [3]

CS 387. Topics in Software Engineering. Topics may include empirical software engineering and open-source software engineering. Prerequisite: CS 278 or consent of instructor. SPRING. [3]

CS 388. Model-Integrated Computing. Model-Integrated Computing addresses the problems of designing, creating, and evolving information systems by providing rich, domain-specific modeling environments including model analysis and model-based program synthesis tools. Students are required to give a class presentation and prepare a project. FALL. [3]

CS 389. Master of Engineering Project.

CS 390. Individual Studies. Offered each term. [1-3]

CS 391. Seminar. [1-3 each semester]

CS 392. Seminar. [1-3 each semester]

CS 395. Special Topics. [3]

CS 396. Special Topics. [3]

CS 399. Ph.D. Dissertation Research.

Electrical Engineering

EECE 112. Circuits I. Development of basic electrical circuit element models, signal representations, and methods of circuit analysis. Matrix methods and computer techniques. Demonstrations of physical components, measurement techniques, and transient phenomena. Corequisite: PHYS 116B; MATH 175. FALL, SPRING. [3]

EECE 116. Digital Logic. Numbering systems. Boolean algebra and combinational logic, graphical simplification, sequential logic, registers, and state machines. Corequisite: EECE 116L. FALL, SPRING. [3]

EECE 116L. Digital Logic Laboratory. Laboratory for EECE 116. One three-hour laboratory per week. Corequisite: EECE 116. FALL, SPRING. [1]

EECE 203. Independent Study. Readings or projects on basic topics in electrical engineering or related fields under the supervision of the staff. Consent of instructor required. No more than 3 hours may be applied toward graduation. [Variable credit: 1-3 each semester]

EECE 204. Independent Study. Readings or projects on basic topics in electrical engineering or related fields under the supervision of the staff. Consent of instructor required. No more than 3 hours may be applied toward graduation. [Variable credit: 1-3 each semester]

EECE 213. Circuits II. Steady-state and transient analysis of electrical networks with emphasis on Laplace transform methods and pole-zero concepts. Prerequisite: EECE 112, PHYS 116B. Corequisite: EECE 213L, MATH 196. FALL, SPRING. [3]

EECE 213L. Circuits II Laboratory. Laboratory for EECE 213. One three-hour laboratory per week. Corequisite: EECE 213. FALL, SPRING. [1]

EECE 214. Signals and Systems. Fundamental signals, systems, and linear algebra concepts necessary for the study of communications and control systems. Includes continuous-time and discrete-time signal and system concepts, Fourier analysis in both continuous and discrete-time, Z-transform, and the FFT. Prerequisite: EECE 112. FALL, SPRING. [3]

EECE 218. Microcontrollers. Microprocessor and microcontroller architecture with emphasis on control applications. Usage of assembly language and interfacing with programs written in high-level languages. Interfacing and real-time I/O with 8-bit microprocessors, control algorithms, and networking with microcontrollers. Prerequisite: EECE 116 and CS 101 or CS 103. Corequisite: EECE 218L. SPRING. [3]

EECE 218L. Microcontrollers Laboratory. Laboratory for EECE 218. A small structured project is required. One three-hour laboratory per week. Corequisite: EECE 218. SPRING. [1]

EECE 233. Electromagnetics. Introduction to electromagnetic field theory. Maxwell's equations are developed from the historical approach. Electromagnetic waves are discussed with regard to various media and boundary conditions. Graduate credit except for electrical engineers. Prerequisite: Physics 116b. Corequisite: MATH 196. FALL. [3]

EECE 235. Electronics I. Introduction to semiconductor devices and electronic circuits. Diodes, BJT and MOS transistors. Device models, modes of operation, biasing. Small-signal models, low-frequency analysis of single- and multi-stage analog amplifiers, simple amplifier design. Large signal models, dc analysis of digital circuits. No graduate credit for electrical engineers. Prerequisite: EECE 112. Corequisite: EECE 235L. FALL. [3]

EECE 235L. Electronics I Laboratory. Laboratory for EECE 235. One three-hour laboratory per week. Corequisite: EECE 235. FALL. [1]

EECE 252. Signal Processing and Communications. AM and FM modulation. Also, advanced topics in signal processing are treated. Prerequisite: EECE 214. SPRING. [3]

EECE 253. Image Processing. The theory of signals and systems is extended to two dimensions. Coverage includes filtering, 2-D FFTs, edge detection, and image enhancement. Three lectures and one laboratory period. FALL. [4]

EECE 254. Computer Vision. Vision is presented as a computational problem. Coverage includes theories of vision, inverse optics, image representation, and solutions to ill-posed problems. Prerequisite: EECE 253. SPRING. [3]

EECE 256. Digital Signal Processing. Applications of Digital Signal Processing (DSP) chips to sampling, digital filtering, FFTs, etc. Three lectures and one laboratory period. Prerequisite: EECE 214. SPRING. [4]

EECE 257. Control Systems I. Introduction to the theory and design of feedback control systems, steady-state and transient analysis, stability considerations. Model representation. State-variable models. Prerequisite: EECE 213 or EECE 214. FALL. [3]

EECE 258. Control Systems II. Modern control design. Discrete-time analysis. Analysis and design of digital control systems. Introduction to nonlinear systems and optimum control systems. Fuzzy control systems. Two lectures and one laboratory. Prerequisite: EECE 257. SPRING. [3]

EECE 261. Introduction to Voice/Data Networks. Overview of voice/data wide area networking (WAN) technologies, including the implementation of WAN designs. Prerequisite: MATH 155 A/B, PHYS 116A/B or equivalent. FALL. [3]

EECE 262. Introduction to Local Area Networks and Internetworking. Overview of Local Area Network (LAN) technology, internetworking, and selected higher layer applications. Common local area networking protocols, internetworking (bridging and routing), common routing protocols, dynamic routing algorithms, selected layer 4 applications,

domain name system, and dynamic host configuration protocol. Prerequisite: EECE 261 or consent of instructor. SPRING. [3]

EECE 267. Power System Analysis. Analysis of large transmission and distribution networks. Analysis of power lines, load flow, short circuit studies, economic operation, and stability are introduced. Prerequisite: EECE 213. FALL. [3]

EECE 275. Microelectronic Systems. Active devices in the context of digital systems, with an emphasis on embedded systems integration. Characteristics and utilization of different digital integrated circuit families, common bus structures and protocols and real-world interfaces (comparators, A/D/A conversion). Prerequisite: EECE 112, 116. SPRING. [3]

EECE 276. Embedded Systems. Advanced course on the design and application of embedded microcontroller-based systems. Architecture and capabilities of advanced microcontrollers. Embedded system modeling, design, and implementation using real-time and event-driven techniques. A structured project is required. Prerequisite: EECE 218. Corequisite: EECE 276L. FALL. [3]

EECE 276L. Embedded Systems Laboratory. Laboratory for EECE 276. A team-oriented structured project is required. One three-hour laboratory per week. Corequisite: EECE 276. FALL. [1]

EECE 277. FPGA Design. Design and applications of field-programmable gate arrays, Electronic Design Automation (EDA) tools for design, placement, and routing. Hardware description languages. Implementation of designs on prototype FPGA board. A project is required. Prerequisite: EECE 116, EECE 218. SPRING. [3]

EECE 280. Electronics II. Integrated circuit analysis and design. High frequency operation of semiconductor devices. Frequency-response and feedback analysis of BJT and MOS analog amplifier circuits, multi-stage frequency-compensated amplifier design. Transient analysis of BJT and MOS digital circuit families. Digital-to-analog and analog-to-digital conversion circuits. Prerequisite: EECE 235. SPRING. [3]

EECE 283. Principles and Models of Semiconductor Devices. Physical principles of operation of the p-n junction, MOS field-effect transistor, and bipolar transistor. Fundamentals of charge transport, charge storage, and generation-recombination; application to the operation of MOSFET and BJT. Device modeling with emphasis on features and constraints of integrated circuit technologies. Prerequisite: EECE 235 or consent of instructor. SPRING. [3]

EECE 284. Integrated Circuit Technology and Fabrication. Introduction to monolithic integrated circuit technology. Understanding of basic semiconductor properties and processes that result in modern integrated circuit. Bipolar and MOSFET processes and structures. Elements of fabrication, design, layout, and applications as regards semiconductor microelectronic technologies. Prerequisite: EECE 235 or consent of instructor. SPRING. [3]

EECE 285. VLSI Design. Integrated circuit and fabrication techniques; CAD tools for design, layout, and verification; parasitic elements and their effects on circuit performance; system-level design experience is gained by completing design and layout phases of a project. Prerequisite: EECE 116, EECE 235 or consent of instructor. FALL. [3]

EECE 286. Audio Engineering. Engineering aspects of high fidelity sound reproduction, with emphasis on digital audio and loudspeakers. Analog-to-digital and digital-to-analog conversion, data storage, perceptual coding, loudspeaker design. Prerequisite: EECE 213 and EECE 235. SPRING. [3]

EECE 287. Engineering Reliability. Topics in engineering reliability with emphasis on electrical systems. Reliability concepts and models. Risk analysis. System examples. Prerequisite: Senior standing. FALL. [3]

EECE 288. Optoelectronics. Fundamentals and applications of light generation, propagation, and modulation in passive and active optoelectronic components. Waveguides, lasers, electro-optic modulators, and emerging optoelectronic technology for optical communication, computing, and sensing applications. Prerequisite: EECE 233 or equivalent. SPRING. [3]

EECE 291. Special Topics. [Variable credit: 1-3 each semester]

EECE 292. Special Topics. [Variable credit: 1-3 each semester]

EECE 295. Program and Project Management for EECE. Methods for planning programs and projects. Organization structures and information management for project teams. Communications between project teams and clients, government agencies, and others. Motivational factors and conflict resolution. Budget/schedule control. Similar to ENGM 274, but preparatory to the EECE senior design project course, EECE 296. Not for graduate credit. Credit given for only one of ENGM 274 and EECE 295. Prerequisite: Senior standing. Corequisite: EECE 297. FALL. [3]

EECE 296. Electrical and Computer Engineering Design. Based on product specifications typically supplied by industrial sponsors, teams of students responsible for the formulation, execution, qualification, and documentation of a culminating engineering design. The application of knowledge acquired from earlier coursework, both within and outside the major area, along with realistic technical, managerial, and budgetary constraints using standard systems engineering methodologies and practices. Not for graduate credit. Prerequisite: EECE 295, at least one DE course, senior standing. SPRING. [3]

EECE 297. Senior Engineering Design Seminar. Elements of professional engineering practice. Professionalism, licensing, ethics and ethical issues, intellectual property, contracts, liability, risk, reliability and safety, interdisciplinary teams and team tools, codes, standards, professional organizations, careers, entrepreneurship, human factors, and industrial design. Prerequisite: Senior standing. Corequisite: EECE 295. FALL. [1]

EECE 301. Introduction to Solid-State Materials. The properties of charged particles under the influence of an electric field, quantum mechanics, particle statistics, fundamental particle transport, and band theory of solids will be studied. FALL. [3]

EECE 302. Electric and Magnetic Properties of Solids. A review of electromagnetic theory of solids using advanced mathematical and computational techniques. Dielectric, magnetic, and optical properties. Fundamental interactions of electromagnetic radiation and charged particles in solids. Prerequisite: EECE 301 or equivalent. SPRING. [3]

EECE 304. Radiation Effects and Reliability of Microelectronics. The space radiation environment and effects on electronics, including basic mechanisms of radiation effects and testing issues. Total dose, single-event, high-dose-rate, and displacement damage radiation effects. Effects of defects and impurities on MOS long-term reliability. SPRING. [3]

EECE 305. Topics in Applied Magnetism. Selected topics in magnetism, magnetic properties of crystalline and non-crystalline materials; ferrite materials for electronics and microwave applications, resonance phenomena. Prerequisite: EECE 302 or consent of instructor. [3]

EECE 306. Solid-State Effects and Devices I. The semiconductor equations are examined and utilized to explain basic principles of operation of various state-of-the-art semiconductor devices including bipolar and MOSFET devices. FALL. [3]

EECE 307. Solid-State Effects and Devices II. The structure of solids, phonons, band theory, scattering phenomena, and theory of insulators. [3]

EECE 311. Systems Theory. Analysis and design of multivariable control systems using state space methods. Stability, controllability, and observability treated. Controllers designed using pole placement, optimal linear regulator, and the method of decoupling. State reconstruction via observers. SPRING. [3]

EECE 341. Advanced Analog Electronics. Analysis and design of analog electronics circuits with emphasis on integrated circuits. Topics include operational amplifiers, wideband amplifiers, multipliers, and phase-locked loops. FALL. [3]

EECE 342. Advanced Digital Electronics. Analysis and design of digital electronic circuits with emphasis on integrated circuits. Topics

include logic families, semiconductor memories, and the analog-digital interface. SPRING. [3]

EECE 343. Digital Systems Architecture. Architectural descriptions of various CPU designs, storage systems, IO systems, parallel and von Neumann processors and interconnection networks will be studied. [3]

EECE 354. Advanced Real-Time Systems. Fundamental problems in real-time systems, with focus on modeling, analysis, and design. Topics include: scheduling theory and techniques, time synchronization, time- and event-triggered systems, distributed architectures, advanced programming languages for real-time systems. Literature reviews and projects. SPRING. [3]

EECE 356. Intelligent Systems and Robotics. Concepts of intelligent systems, AI robotics, and machine intelligence, using research books and papers. Emphasis on how AI, brain research, soft computing, and simulations are advancing robotics. Class projects. SPRING. [3]

EECE 357. Advanced Image Processing. Techniques of image processing. Topics include image formation, digitization, linear shift-invariant processing, feature detection, and motion. Prerequisite: MATH 175; programming experience. FALL. [3]

EECE 361. Random Processes. An introduction to the concepts of random variables, functions of random variables and random processes. Study of the spectral properties of random processes and of the response of linear systems to random inputs. Introduction to linear mean square estimation. The emphasis is on engineering applications. FALL. [3]

EECE 362. Detection and Estimation Theory. Fundamental aspects of signal detection and estimation. Formulation of maximum likelihood, maximum a posteriori, and other criteria. Multidimensional probability theory, signal and noise problems, and Kalman filter structure are studied. SPRING. [3]

EECE 369. Master's Thesis Research.

EECE 379. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit 0-12]

EECE 389. Master of Engineering Project.

EECE 391. Seminar. [1]

EECE 392. Seminar. [1]

EECE 393. Advanced Seminar for Ph.D. Candidates. [1]

EECE 394. Advanced Seminar for Ph.D. Candidates. [1]

EECE 395. Special Topics. Based on research and current developments in electrical engineering of special interest to staff and students. [3]

EECE 396. Special Topics. Based on research and current developments in electrical engineering of special interest to staff and students. [3]

EECE 397. Independent Study. Readings and/or projects on advanced topics in electrical engineering under the supervision of the staff. Consent of instructor required. [Variable credit: 1-3 each semester]

EECE 399. Ph.D. Dissertation Research.

Engineering Management

ENGM 216. Engineering Economy. Economic evaluation and comparison of alternatives: interest, periodic payments, depreciation, criteria, and analytical procedures in investment decision-making, and cost-estimating. May be taken as an alternative to ENGM 251. Only one of these courses may be taken for the minor. FALL, SPRING. [3]

ENGM 221. Technology Strategy. A study of the problems encountered by managers in the planning, organizing, and allocating of resources and in directing, and controlling technical activities. Required for ENGM minor. Normally taken in the sophomore year. FALL, SPRING. [3]

ENGM 242. Technology Marketing. Marketing industrial and technologically-based products and services, marketing strategies, segmentation,

distribution, and personal selling, from inception of a product to end use. Prerequisite: ENGM 221 and junior standing. SPRING. [3]

ENGM 244. Applied Behavioral Science. Leadership styles, power team building, conflict resolution, management resolution, interviewing techniques. Required for ENGM minor. Prerequisite: Sophomore standing. FALL, SPRING, SUMMER. [3]

ENGM 251. Finance and Accounting for Engineers. Finance and accounting topics are studied from the perspective of engineering professionals working in business organizations. Areas covered include time value of money, capital budgeting, capital formation, financial accounting and reporting, performance measurements, and working capital management. Junior standing. FALL, SPRING, SUMMER. [3]

ENGM 253. Technology-Based Entrepreneurship. Identification and evaluation of opportunities: risks faced by entrepreneurs, market assessment, capital requirements, venture capital acquisition, legal structures, tax implications for sharing technology-based businesses. Prerequisite: ENGM 221 and junior standing. FALL. [3]

ENGM 254. Operations and Supply Chain Management. Manufacturing strategy, process analysis, product and process design, total quality management, capacity planning, inventory control, supply chain design, and advanced operations topics. Modeling and analysis using cases and spreadsheets. Prerequisite: ENGM 221 and junior standing; ENGM 273 strongly recommended. FALL. [3]

ENGM 273. Systems Engineering. Fundamental considerations associated with the engineering of large-scale systems. Models and methods for systems engineering and problem solving using a systems engineering approach. Prerequisite: ENGM 221, basics of probability and statistics and engineering systems. Required for the ENGM minor. Junior standing. FALL, SPRING. [3]

ENGM 274. Program and Project Management. Project planning and charting. Methods for planning budgets, schedule control, motivational factors, and conflict resolution. Credit given for only one of ENGM 274, CE 286 or EECE 295. Required for ENGM minor. Prerequisite: ENGM 221 and junior standing. FALL, SPRING. [3]

ENGM 275. Technology Assessment and Forecasting. Assess technological changes in social, political, economic, legal, and institutional environments. Intuitive thinking, exploratory techniques, trend exploration, normative techniques of relevance. Term project required. Prerequisite: Junior standing. SPRING. [3]

ENGM 289. Independent Study. Readings or projects on topics in engineering management under the supervision of the ENGM faculty. Consent of instructor required. FALL, SPRING. [1-3 each semester, not to exceed a total of 3].

ENGM 290. Independent Study. Readings or projects on topics in engineering management under the supervision of the ENGM faculty. Consent of instructor required. FALL, SPRING. [1-3 each semester, not to exceed a total of 3]

ENGM 291. Special Topics. [Variable credit 1-3 each semester]

ENGM 292. Special Topics. [Variable credit: 1-3 each semester]

Engineering Science

ES 101. Engineering Freshman Seminar. Engineering Freshman Seminar. [1]

ES 103. Preparatory Academics. To prepare students to enter an undergraduate engineering or science program. The content will vary from year to year and is usually offered in combination with other academic courses, English as a second language, and various PAVE programs. No credit toward a Vanderbilt degree. Prerequisite: Consent of instructor. SUMMER. [0]

ES 140A. Introduction to Engineering, Module 1. First of three required discipline-specific modules for Introduction to Engineering credit providing an introduction to engineering analysis and design. Discipline-specific modules selected based on individual choice. Students

choose three different disciplines for the three modules and all three must be completed in one semester for full course credit. Emphasis is on contemporary engineering problem solving in a discipline-specific context. FALL. [1]

ES 140B. Introduction to Engineering, Module 2. Continuation of ES 140A. ES 140A-C must be completed in one semester for full course credit. FALL. [1]

ES 140C. Introduction to Engineering, Module 3. Continuation of ES 140B. ES 140A-C must be completed in one semester for full course credit. FALL. [1]

ES 210W. Technical Communications. Instruction and practice in written and oral communication. Emphasis is on organization and presentation of information to a specific audience for a specific purpose. Course will include writing and editing reports of various lengths, preparing and using visual aids, and presenting oral reports. Required of all EE, CmpE, and ES students. FALL, SPRING. [3]

ES 248. Undergraduate Research. Offers students who have an independent study program the opportunity to pursue it under the direction of a faculty member with expertise in the area of study. FALL, SPRING. [1-3 each semester, not to exceed a total of 3]

ES 249. Undergraduate Research. Continuation of the research in ES 248 or research in another area of study. FALL, SPRING. [1-3 each semester, not to exceed a total of 3]

ES 290. Special Topics. Technical elective courses of special current interest. No more than six semester hours of these courses may be credited to the student's record. Prerequisite: Consent of instructor. FALL, SPRING. [1-3]

Materials Science and Engineering

MSE 150. Materials Science I. Concepts of materials science developed from an understanding of the atomic and molecular structure of materials and their relationship to the properties of matter. Mechanical, electrical, physical, chemical, and magnetic properties of metals, ceramics, organics, composites, and semiconductors are covered. Corequisite: MATH 155B and CHEM 102A or consent of instructor. Three lectures and one laboratory. SPRING. [4]

MSE 150L. Materials Science Laboratory.

MSE 209B. Materials Science and Engineering Seminar. Involving individual experimental, analytical, or design projects. A written final report is required. FALL. [Variable credit 1-3]

MSE 209C. Materials Science and Engineering Undergraduate Research. Open to selected senior engineering students wanting to do independent research. A formal written report is required. SPRING. [3]

MSE 210A. Special Topics. Technical elective courses of special current interest. No more than two semesters of this course may be credited to the student's record. Prerequisite: Consent of instructor. [Variable credit: 1-3 each semester] (Offered on demand)

MSE 210B. Special Topics. Technical elective courses of special current interest. No more than two semesters of this course may be credited to the student's record. Prerequisite: Consent of instructor. [Variable credit: 1-3 each semester] (Offered on demand)

MSE 232. Strength and Structure of Engineering Materials. A laboratory supplement to Mechanics of Materials, CE 182. Students conduct experiments on the strength behavior of materials and simple engineering structures. Includes: tension and bending, fasteners, photoelastic analysis of stress concentrators, strain gage instrumentation to determine principal stresses, bending and deflection curves for simple beams, loaded columns, and short struts. Corequisite: CE 182. FALL. [1]

MSE 250. Materials Science II. A study of engineering materials that includes microstructure and property characterization, materials selection, failure analysis, modern processing methods, and an introduction to nanostructured materials. Case studies and challenge based

learning will be used to develop structure-processing concepts for the practice of materials science and engineering. Prerequisite: MSE 150. FALL. Wittig.

MSE 310. Atomic Arrangements in Solids. A basic understanding of the atomic arrangements observed in metals, ceramics, semiconductors, glasses, and polymers. Lattice geometry and crystal symmetry are discussed in detail and these concepts are used to describe important crystal structures. Nanocrystalline materials are also covered. An introduction to scattering theory and diffraction phenomena provides insight into the analytical methods used by materials scientists for structural characterization. FALL. [3]

MSE 343. Introduction to Electron Microscopy. Principles and applications of transmission electron microscopy in the study of materials. Electron scattering, image contrast theory, operation of electron microscope, and specimen preparation. Use of the electron microscope in experimental investigations. Two lectures and one laboratory period. Prerequisite: Consent of instructor. FALL. [3]

MSE 369. Master's Thesis Research.

MSE 379. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

MSE 391. Special Topics. Based on faculty research projects and highly specialized areas of concentration. FALL, SPRING. [Variable credit: 1-3 each semester]

MSE 392. Special Topics. Based on faculty research projects and highly specialized areas of concentration. FALL, SPRING. [Variable credit: 1-3 each semester]

MSE 397. Seminar. A required noncredit course for all graduate students in the program. Topics of special interest consolidating the teachings of previous courses by considering topics which do not fit simply into a single course category. FALL, SPRING. [0] Staff.

MSE 398. Seminar. A required noncredit course for all graduate students in the program. Topics of special interest consolidating the teachings of previous courses by considering topics which do not fit simply into a single course category. FALL, SPRING. [0] Staff.

MSE 399. Ph.D. Dissertation Research.

Mechanical Engineering

ME 150. Automotive Components Seminar. General automotive knowledge for engineering and design considerations. Basic component function, terminology and design. Suspension (including suspension kinematics), steering (including steering geometry), driveline, transmission, engine and braking. Discussion and in-class participation. FALL. [1]

ME 151. Laboratory in Machining. Introduction to machining and fabrication of metals and plastics. Fabrication, design and manufacturability of parts or components. FALL, SPRING. [1]

ME 152. Laboratory in Welding. Introduction to theory of welding processes and welding of metals. Design, fabrication, and manufacturability of parts or components using welding processes. SPRING, FALL. [1]

ME 153. Computer Aided Design. Introduction to the use of computers for solid modeling of machine parts and assemblies. FALL, SPRING. [1]

ME 160. Introduction to Mechanical Engineering Design. A study of design, modeling, and graphical presentation for mechanical engineering components, processes, and systems, using computer-aided techniques and methods. Two lectures and one lab. No credit for juniors or seniors. Prerequisite ES 140. SPRING. [3]

ME 171. Instrumentation Laboratory. Techniques associated with engineering measurements, curve fitting, presentation, and analysis of data. Corequisite: MATH 175. SPRING. [2]

ME 190. Dynamics. The principles of dynamics (kinematics and kinetics) of particles and rigid bodies. Mechanical vibrations. Introduction

to continuous media. Prerequisite: CE 180, PHYS 116A. Corequisite: MATH 198. FALL, SPRING, SUMMER. [3]

ME 200. Kinematics. The kinematics of mechanisms using graphical and numerical methods. Computer applications and techniques. Prerequisite: ME 190; Corequisite: CS 101 or 103. SPRING. [3]

ME 201. Design of Machine Elements. Application of the principles of mechanics of materials to the analysis and synthesis of machine elements. Prerequisite: CE 182; recommended: ME 200. FALL. [3]

ME 202. Machine Analysis and Design. Application of the principles of mechanics of materials to the analysis and synthesis of machine elements. Prerequisite: CE 182. FALL. [3]

ME 204. Mechatronics. Design of analog and digital electromechanical sensors and actuators, signal and power electronics, and application of digital microcontrollers to mechatronic systems. Prerequisite: ME 234, EECE 112, and CS 101 or 103. SPRING. [3]

ME 209A. Mechanical Engineering Project. Each student selects a topic of interest, with approval of the faculty; conducts a literature search; and presents formal written and oral reports on the findings. Prerequisite: Junior standing. FALL, SPRING. [1]

ME 209B. Mechanical Engineering Project. Involving individual experimental, analytical, or design projects approved by the faculty. A written final report is required. Prerequisite: Junior standing. FALL, SPRING. [2]

ME 209C. Mechanical Engineering Undergraduate Research. Open to selected senior mechanical engineering students wanting to do independent research. A formal written report is required. Prerequisite: Senior standing. FALL, SPRING. [3]

ME 210. Special Topics. Technical elective courses of special current interest. No more than six semester hours of this course may be credited to the student's record. Prerequisite: Consent of instructor. FALL, SPRING, SUMMER. [Variable credit: 1-3 each semester] (Offered on demand)

ME 213. Energetics Laboratory. Experimental methods in heat transfer, fluid mechanics, and thermodynamics. Prerequisite: Junior standing. FALL. [2]

ME 220A. Thermodynamics I. Application of the first and second laws to energy transformation processes and properties of technologically important materials. Prerequisite: PHYS 116A; MATH 175. FALL, SPRING, SUMMER. [3]

ME 220B. Thermodynamics II. Application of principles of thermodynamics to vapor and gas cycles, mixtures, combustion, and compressible flow. Prerequisite: ME 220a; corequisite: MATH 198. FALL, SUMMER. [3]

ME 224. Fluid Mechanics. Physical properties of fluids, surface tension, viscosity; fluid statics and dynamics; control volume analysis of mass, momentum, and energy; dimensional analysis, similitude, and modeling; viscous flows in pipes; drag and lift on immersed bodies. Prerequisite: ME 190, MATH 198. Credit not awarded for both ME 224 and CE 203. FALL. [3]

ME 226. Introduction to Gas Dynamics. An introduction to the study of compressible flow from subsonic to supersonic flow regimes. Includes shock waves, expansion waves, shock tubes, and supersonic airfoils. Prerequisite: ME 224. SPRING. [3]

ME 234. Systems Dynamics. Energy-based modeling of dynamic mechanical, electrical, thermal, and fluid systems to formulate linear state equations, including system stability, time domain response, and frequency domain techniques. Three lectures and one three-hour laboratory. Prerequisite: ME 190, MATH 198. FALL. [4]

ME 236. Linear Control Theory. Classical and modern approaches to the analysis and design of single-input/single-output (SISO) and multiple-input/multiple-output (MIMO) linear time invariant control systems. Classical (frequency-domain) and modern (state-space) approaches to SISO and MIMO control, including optimal control methods. Credit is given for only one of ME 236 or ME 336. Prerequisite: ME 234. FALL. [3]

ME 242. Design Synthesis. Development of the design process: problem definition, design specifications, solution identification, idea synthesis, modeling and simulation, and design completion. Critical elements include problem selection, idea synthesis, and proposal writing. Individual design synthesis study projects required. Prerequisite: ME 202. FALL. [2]

ME 243. Engineering Design Projects. Each student participates in a major group design project. Lectures will cover case studies and topics of current interest in design. Prerequisite: ME 242. SPRING. [3]

ME 248. Heat Transfer. Steady-state and transient heat transfer by conduction, forced and free convection and radiation, including heat transfer by boiling and condensing vapors. Application is made to practical design problems. Prerequisite: ME 220A, ME 224. SPRING. [3]

ME 251. Modern Manufacturing Processes. Introduction to manufacturing science and processes. A quantitative approach dealing with metals, ceramics, polymers, composites, and nanofabrication and microfabrication technologies. SPRING. [3]

ME 259. Engineering Vibrations. Theory of vibrating systems and application to problems related to mechanical design. Topics include single degree of freedom systems subject to free, forced, and transient vibrations; systems with several degrees of freedom, methods of vibration suppression and isolation, and critical speed phenomena. Prerequisite: ME 190, MATH 198. SPRING. [3]

ME 260. Energy Conversion I. Energy resources, use, and conservation are studied. The fundamentals of positive displacement machinery, turbo-machinery, and reactive mixture are introduced and used to examine various forms of power-producing systems. Prerequisite: ME 220A, ME 224. FALL. [3]

ME 261. Basic Airplane Aerodynamics. Includes aerodynamic forces, airfoil characteristics from both theory and experiment, aircraft experiment, aircraft performance, longitudinal and lateral stability and control. Prerequisite: ME 224. FALL. [3]

ME 262. Environmental Control. A study of heating and cooling systems, energy conservation techniques, use of solar energy and heat pumps. Prerequisite: ME 220A; corequisite: ME 248. SPRING. [3]

ME 263. Computational Fluid Dynamics and Multiphysics Modeling. Computational modeling of viscous fluid flows and thermal-fluid-structure interaction. Computational techniques including finite-difference, finite-volume, and finite-element methods; accuracy, convergence, and stability of numerical methods; turbulence modeling; rotating machinery; multiphase flows; and multiphysics modeling. Prerequisite: ME 224. SPRING. [3]

ME 264. Internal Combustion Engines. A study of the thermodynamics of spark ignition and compression ignition engines; gas turbines and jet propulsion. Prerequisite: ME 220A. SPRING. [3]

ME 265. Direct Energy Conversion. The principles and devices involved in converting other forms of energy to electrical energy. Conversion devices: electro-mechanical, thermoelectric, thermionic, fluid dynamic, and fuel cell. Prerequisite: ME 220A. SPRING. [3]

ME 267. Aerospace Propulsion. Application of classical mechanics and thermodynamics principles to the study of rocket and aircraft propulsion. Design and performance analysis of air-breathing and chemical rocket engines. Advanced propulsion systems for interplanetary travel. Prerequisite: ME 224, ME 220A. SPRING. [3]

ME 271. Introduction to Robotics. History and application of robots. Robot configurations including mobile robots. Spatial descriptions and transformations of objects in three-dimensional space. Forward and inverse manipulator kinematics. Task and trajectory planning, simulation and off-line programming. Prerequisite: MATH 194. FALL. [3]

ME 275. Introduction to Finite Element Analysis. Development and solution of finite element equations for solid mechanics and heat transfer problems. Introduction to commercial finite element and pre- and post-processing software. Two lectures and one three-hour laboratory each week. Prerequisite: CE 182, MATH 198. SPRING. [3]

ME 280. Advanced Dynamics of Mechanical Systems. Development of methods for formulating differential equations to model mechanical systems, including formalisms of Newton-Euler, Lagrange, and virtual work methods to two- and three-dimensional systems. Prerequisite: ME 190 and MATH 198. FALL. [3]

ME 284. Modeling and Simulation of Dynamic Systems. Incorporates bond graph techniques for energy-based lumped-parameter systems. Includes modeling of electrical, mechanical, hydraulic, magnetic and thermal energy domains. Emphasis on multi-domain interaction. Prerequisite: ME 234. FALL. [3]

ME 297. Senior Engineering Design Seminar. Elements of professional engineering practice. Professionalism, licensing, ethics and ethical issues, intellectual property, contracts, liability, risk, reliability and safety, interdisciplinary teams and team tools, codes, standards, professional organizations, careers, entrepreneurship, human factors, and industrial design. Prerequisite: Senior standing. Corequisite: ME 242. FALL. [1]

ME 320. Statistical Thermodynamics. Old and modern quantum theory, including H atom, rigid rotor, and harmonic oscillator. Atomic and molecular structure and spectra. Maxwell-Boltzmann statistical model for ideal, chemically reacting, electron, or photon gas. Introduction to Gibbs method. Prerequisite: ME 220A. SPRING. [3]

ME 323. Introduction to Micro/NanoElectroMechanical Systems. Fabrication techniques and mechanical behavior of modern MEMS/NEMS structures. Application of NEMS/MEMS devices to sensing and actuation. FALL. [3]

ME 326. Gas Dynamics. Study of compressible fluid flow from subsonic to supersonic regimes in confined regions and past bodies of revolutions. Includes heat transfer, frictional effects, and real gas behavior. Prerequisite: ME 224. SPRING. [3]

ME 327. Energy Conversion Systems. An advanced study of energy conversion systems that include turbomachinery, positive displacement machinery, solar energy collection and combustion, with consideration for optimizing the systems. Prerequisite: Consent of instructor. FALL. [3]

ME 331. Robot Manipulators. Dynamics and control of robot manipulators. Includes material on Jacobian matrix relating velocities and static forces, linear and angular acceleration relationships, manipulator dynamics, manipulator mechanism design, linear and nonlinear control, and force control manipulators. Prerequisite: ME 271. SPRING. [3]

ME 333. Topics in Stress Analysis. An investigation of thermal stress, transient stress, and temperatures in idealized structures; consideration of plasticity at elevated temperatures; and some aspects of vibratory stresses. Prerequisite: Consent of instructor. FALL. [3]

ME 336. Linear Control Theory. Classical and modern approaches to the analysis and design of single-input/single-output (SISO) and multiple-input/multiple-output (MIMO) linear time invariant control systems. Classical (frequency-domain) and modern (state-space) approaches to SISO and MIMO control, including optimal control methods. Credit is given for only one of ME 236 or ME 336. Prerequisite: ME 234. FALL. [3]

ME 343. High-Performance Computing for Engineers. Introduction to high-performance computing. Engineering applications. Focus on high-speed cluster computing. Class project applying high-performance computing to various research topics. Prerequisite: Introductory programming class or consent of instructor. FALL. [3]

ME 348. Convection Heat Transfer. A wide range of topics in free and forced convection is discussed. Solutions are carried out using analytical, integral, and numerical methods. Internal and external flows are considered for both laminar and turbulent flow cases. Convection in high speed flow is also studied. Prerequisite: ME 248, ME 325. SPRING. [3]

ME 351. Adaptive Control. Introduction to adaptive control systems. Real-time parameter estimation methods. Self-tuning regulators. Model reference adaptive control. Adaptive control for nonlinear systems. A research project is required. Prerequisite: ME 336. SPRING. [3]

ME 352. Nonlinear Control Theory. Introduction to the concepts of nonlinear control theory. Topics include phase plane analysis, nonlinear transformations, Lyapunov stability, and controllability/observability calculations. A multidimensional geometric approach to these problems is emphasized. Prerequisite: MATH 194. SPRING. [3]

ME 353. Design of Electromechanical Systems. Analog electronic design for purposes of controlling electromechanical systems, including electromechanical sensors and actuators, analog electronic design of filters, state-space and classical controllers, and transistor-based servoamplifiers and high voltage amplifiers. Significant laboratory component with design and fabrication circuits to control electromechanical systems. Implementation of digital controllers. Prerequisite: ME 234. FALL. [3]

ME 359. Advanced Engineering Vibrations. The development and application of Lagrange's equations to the theory of vibrations. Nonlinear systems and variable spring characteristics are analyzed by classical methods and by digital computer techniques. Applications to the design of high speed machines are emphasized. Prerequisite: ME 259; MATH 234, MATH 294. SPRING. [3]

ME 363. Conduction and Radiation Heat Transfer. A comparative study of available methods for solution of single and multidimensional conduction heat transfer problems. Both steady and transient problems are considered. Mathematical and numerical methods are stressed. Radiant exchange between surfaces separated by non-participating media is studied. Numerical methods are developed and discussed for non-isothermal surfaces and combined radiation and conduction problems are solved. Prerequisite: ME 248. SPRING. [3]

ME 365. Micro/Nanoscale Energy Transport. Theoretical examination of energy transport by electrons and phonons and modeling of transport phenomena in crystalline solids at reduced length scales. Particle transport models and solution methods for energy carriers in the context of semiconductor electronics, direct energy conversion devices and nanostructure. FALL. [3]

ME 366. Combustion. Introduction to combustion processes. Topics include combustion thermodynamics, chemical kinetics, premixed flame theory, diffusion flame theory, ignition and detonation. Prerequisite: ME 220B, ME 224. SPRING. [3]

ME 369. Master's Thesis Research.

ME 379. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit 0-12]

ME 389. Master of Engineering Project.

ME 391. Special Topics. A course based on faculty research projects and highly specialized areas of concentration. [Variable credit: 1-3 each semester]

ME 392. Special Topics. A course based on faculty research projects and highly specialized areas of concentration. [Variable credit: 1-3 each semester]

ME 393. Independent Study. Readings and/or projects on advanced topics in mechanical engineering under the supervision of the faculty. Consent of instructor required. [Variable credit: 1-3 each semester]

ME 394. Independent Study. Readings and/or projects on advanced topics in mechanical engineering under the supervision of the faculty. Consent of instructor required. [Variable credit: 1-3 each semester]

ME 397. Seminar. [0]

ME 398. Seminar. [0]

ME 399. Ph.D. Dissertation Research.

Scientific Computing

SC 250. Scientific Computing Toolbox. Use of computational tools in multiple science and engineering domains. Simulations of complex physical, biological, social, and engineering systems, optimization and evaluation of simulation models, Monte Carlo methods, scientific visualization, high performance computing, or data mining. Prerequisite: CS 101 or 103; MATH 150A. Fall. [3]

SC 290. Special Topics in Scientific Computing. [1-3 each semester]

SC 291. Special Topics in Scientific Computing. [1-3 each semester]

SC 292. Special Topics in Scientific Computing. [1-3 each semester]

SC 293A. Directed Study in Scientific Computing. Participation in ongoing research projects under the direction of a faculty sponsor. Project must combine scientific computing tools and techniques with a substantive scientific or engineering problem. Consent of both the faculty sponsor and one Director of the SC minor is required. Prerequisite: SC 250. [1-3 each semester]

SC 293B. Directed Study in Scientific Computing. Participation in ongoing research projects under the direction of a faculty sponsor. Project must combine scientific computing tools and techniques with a substantive scientific or engineering problem. Consent of both the faculty sponsor and one Director of the SC minor is required. Prerequisite: SC 250. [1-3 each semester]

SC 293C. Directed Study in Scientific Computing. Participation in ongoing research projects under the direction of a faculty sponsor. Project must combine scientific computing tools and techniques with a substantive scientific or engineering problem. Consent of both the faculty sponsor and one Director of the SC minor is required. Prerequisite: SC 250. [1-3 each semester]

SC 295A. Independent Study in Scientific Computing. Development of a research project by the individual student under the direction of a faculty sponsor. Project must combine scientific computing tools and techniques with a substantive scientific or engineering problem. Consent of both the faculty sponsor and one Director of the SC minor is required. Prerequisite: SC 250. [1-3 each semester]

SC 295B. Independent Study in Scientific Computing. Development of a research project by the individual student under the direction of a faculty sponsor. Project must combine scientific computing tools and techniques with a substantive scientific or engineering problem. Consent of both the faculty sponsor and one Director of the SC minor is required. Prerequisite: SC 250. [1-3 each semester]

SC 295C. Independent Study in Scientific Computing. Development of a research project by the individual student under the direction of a faculty sponsor. Project must combine scientific computing tools and techniques with a substantive scientific or engineering problem. Consent of both the faculty sponsor and one Director of the SC minor is required. Prerequisite: SC 250. [1-3 each semester]

School of Engineering

KENNETH F. GALLOWAY, Ph.D., Dean
 K. ARTHUR OVERHOLSER, Ph.D., P.E., Senior Associate Dean
 DAVID M. BASS, M.Ed., Associate Dean for Development and Alumni Relations
 GEORGE E. COOK, Ph.D., Associate Dean for Research and Graduate Studies
 JOHN R. VEILLETTE, Ph.D., Associate Dean for Preparatory Academics
 JANIECE HARRISON, M.A., Associate Dean for Finance and Administration
 MARY LOU O'KELLY, B.A., Senior Executive Secretary to the Dean
 BRENDA S. JORDAN, Registrar
 BURGESS MITCHELL, B.S., Assistant Dean for Student Services
 CHRISTOPHER J. ROWE, Ed.D., Director of the First-Year Program;
 Senior Aide to the Dean
 STEPHEN H. WADLEY, M.A., Academic Counselor

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JAMES A. CADZOW, Centennial Professor of Electrical Engineering, Emeritus
 PETER T. CUMMINGS, John R. Hall Professor of Chemical Engineering
 BENOIT M. DAWANT, Cornelius Vanderbilt Chair in Engineering
 TOMLINSON FORT, Centennial Professor of Chemical Engineering, Emeritus
 MICHAEL GOLDFARB, H. Fort Flowers Professor of Mechanical Engineering
 JOHN C. GORE, Chancellor's University Professor of Radiology and Radiological Sciences and Biomedical Engineering
 THOMAS R. HARRIS, Orrin Henry Ingram Distinguished Professor of Engineering, Emeritus
 GEORGE M. HORNBERGER, Distinguished University Professor; Craig E. Philip Professor of Engineering
 ROBERT W. HOUSE, Orrin Henry Ingram Distinguished Professor of Engineering Management, Emeritus
 M. DOUGLAS LEVAN, J. Lawrence Wilson Professor of Engineering
 SANKARAN MAHADEVAN, John R. Murray Sr. Chair in Engineering
 ANITA MAHADEVAN-JANSEN, Orrin H. Ingram Chair in Biomedical Engineering
 ARTHUR M. MELLOR, Centennial Professor of Mechanical Engineering, Emeritus
 SOKRATES T. PANTELIDES, University Distinguished Professor of Physics and Engineering
 FRANK L. PARKER, Distinguished Professor of Environmental and Water Resources Engineering, Emeritus
 PETER N. PINTAURO, H. Eugene McBrayer Professor of Chemical Engineering
 RONALD D. SCHRIMPF, Orrin Henry Ingram Professor of Engineering
 RICHARD E. SPEECE, Centennial Professor of Civil and Environmental Engineering, Emeritus
 JANOS SZTIPANOVITS, E. Bronson Ingram Distinguished Professor of Engineering
 TAYLOR G. WANG, Centennial Professor of Materials Science and Engineering, Emeritus; Centennial Professor of Mechanical Engineering, Emeritus
 JOHN P. WIKSWO, JR., Gordon A. Cain University Professor; A. B. Learned Professor of Living State Physics

Department Chairs

TODD D. GIORGIO, Biomedical Engineering
 PETER N. PINTAURO, Chemical and Biomolecular Engineering
 DAVID S. KOSSON, Civil and Environmental Engineering
 DANIEL M. FLEETWOOD, Electrical Engineering and Computer Science
 ROBERT W. PITZ, Mechanical Engineering

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Faculty

MARK D. ABKOWITZ, Professor of Civil and Environmental Engineering; Professor of Engineering Management
 B.S., M.S., Ph.D. (Massachusetts Institute of Technology 1974, 1976, 1980) [1987]
 JULIE ADAMS, Associate Professor of Computer Science and Associate Professor of Computer Engineering
 B.S., B.B.A. (Siena 1989, 1990); M.S.E., Ph.D. (Pennsylvania 1993, 1995) [2002]
 MICHAEL L. ALLES, Research Associate Professor of Electrical Engineering; ISDE Staff Engineer of Electrical Engineering and Computer Science [2003]
 CARLOS ALONSO GONZALEZ, Visiting Professor of Electrical Engineering and Computer Science
 M.S., Ph.D. (Valladolid [Spain] 1987, 1990) [2011]
 ADAM W. ANDERSON, Associate Professor of Biomedical Engineering; Associate Professor of Radiology and Radiological Sciences; Director, Undergraduate Studies, Biomedical Engineering
 B.A. (Williams 1982); M.S., M.Phil., Ph.D. (Yale 1984, 1986, 1990) [2002]
 AMRUTUR V. ANILKUMAR, Professor of the Practice of Mechanical Engineering
 B.Tech. (Indian Institute of Technology, Mumbai [India] 1982); M.S., Ph.D. (California Institute of Technology 1983, 1988) [1988]
 THEODORE BAPTY, Research Associate Professor of Electrical Engineering
 B.S. (Pennsylvania 1985); M.S., Ph.D., B.E., M.S., Ph.D. (Vanderbilt 1995, 1995, 1970, 1978, 1993) [1995]
 ROBERT JOEL BARNETT, Associate Professor of the Practice of Mechanical Engineering
 B.E., M.S., Ph.D. (Vanderbilt 1970, 1978, 1993) [1993]

- J. ROBIN BARRICK, Adjunct Instructor in Civil and Environmental Engineering
B.E., M.B.A. (Vanderbilt 1974, 1983) [2008]
- ERIC J. BARTH, Associate Professor of Mechanical Engineering
B.S. (California 1994); M.S., Ph.D. (Georgia Institute of Technology 1996, 2000) [2000]
- PRODYOT K. BASU, Professor of Civil and Environmental Engineering; Director, Graduate Studies, Civil Engineering
B.S. (Lucknow [India] 1957); B.S. (Jadavpur [India] 1961); M.S. (Calcutta [India] 1963); D.Sc. (Washington University 1977) [1984]
- FRANZ J. BAUDENBACHER, Associate Professor of Biomedical Engineering
B.S. (Eberhard-Karls-Universität Tübingen [Germany] 1985); M.S., Ph.D. (Technische Universität München [Germany] 1990, 1994) [1997]
- ROBERT J. BAYUZICK, Professor of Chemical Engineering, Emeritus; Professor of Materials Science and Engineering, Emeritus
B.S. (Pittsburgh 1961); M.S. (Denver 1963); Ph.D. (Vanderbilt 1969) [1968]
- DAVID A. BEREZOV, Associate Professor of the Practice of Engineering Management
B.S. (Syracuse 1975); M.B.A. (Vanderbilt 1980) [2000]
- JOHN A. BERS, Associate Professor of the Practice of Engineering Management
B.S. (Yale 1968); Ed.D. (Harvard 1975); M.B.A. (Chicago 1984); Ph.D. (Vanderbilt 1998) [1996]
- BHARAT L. BHUVA, Professor of Electrical Engineering and Professor of Computer Engineering; Director, Graduate Studies, Electrical Engineering
B.S. (Maharaja Sayajirao [India] 1982); M.S., Ph.D. (North Carolina State 1984, 1987) [1987]
- XIAOHONG BI, Research Assistant Professor of Biomedical Engineering
B.S. (Nanjing [China] 1998); M.S., Ph.D. (Rutgers, Newark 2001, 2003) [2008]
- GAUTAM BISWAS, Professor of Computer Science and Professor of Computer Engineering; Professor of Engineering Management
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