School of Engineering

School of Engineering

PHILIPPE M. FAUCHET, Ph.D., Bruce and Bridgitt Evans Dean of Engineering
E. DUCO JANSEN, Ph.D., Senior Associate Dean for Graduate Education and Faculty Affairs
CYNTHIA B. PASCHAL, Ph.D., Senior Associate Dean for Undergraduate Education
PETER T. CUMMINGS, Ph.D., Associate Dean for Research
TERESA ROGERS, Associate Dean for Development and Alumni Relations
JULIANNE VERNON, Ph.D., Interim Associate Dean for Academic Success
CHRISTOPHER J. ROWE, Ed.D., Associate Dean for External Relations
HECTOR SILVA, M.B.A, Chief Business Officer
BURGESS MITCHELL, M.Ed., Assistant Dean for Student Services
THOMAS J. WITHROW, Ph.D., Assistant Dean for Design
ROBIN L. CARLSON, Assistant to the Dean
MADDIE FRENCH, M.A, Academic Counselor
ADAM MCKEEVER-BURGETT, M.Div., Director of Academic Services and Data Analytics

Named and Distinguished Professorships

DOUGLAS E. ADAMS, Distinguished Professor of Civil and Environmental Engineering; Daniel F. Flowers Chair
GAUTAM BISWAS, Cornelius Vanderbilt Chair
JAMES A. CADZOW, Centennial Professor of Electrical Engineering, Emeritus
THOMAS A. CRUSE, H. Fort Flowers Professor of Mechanical Engineering, Emeritus
PETER T. CUMMINGS, John R. Hall Professor of Chemical Engineering
BENOIT M. DAWANT, Cornelius Vanderbilt Chair in Engineering
CRAIG L. DUVALL, Cornelius Vanderbilt Professor of Engineering
PHILIPPE M. FAUCHET, Bruce and Bridgitt Evans Dean's Chair in Engineering
DANIEL M. FLEETWOOD, Olin H. Landreth Professor of Engineering
KENNETH F. GALLOWAY, Distinguished Professor of 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
DAVID S. KOSSON, Cornelius Vanderbilt Chair
MICHAEL R. KING, J. Lawrence Wilson Professor of Engineering
M. DOUGLAS LEVAN, J. Lawrence Wilson Professor of Engineering, Emeritus
SANKARAN MAHADEVAN, John R. Murray Sr. Chair in Engineering
ANITA MAHADEVAN-JANSEN, Orrin H. Ingram Chair in Biomedical Engineering
CLARE M. McCABE, Cornelius Vanderbilt Chair
ARTHUR M. MELLOR, Centennial Professor of Mechanical Engineering, Emeritus
W. DAVIS MERRYMAN, Walters Family Professor
MICHAEL I. MIGA, Harvie Branscomb Professor
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
CYNTHIA A. REINHART-KING, Cornelius Vanderbilt Chair
NILANJAN SARKAR, David K. Wilson Professor of Engineering
DOUGLAS C. SCHMIDT, Cornelius Vanderbilt Chair
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
ROBERT J. WEBSTER III, Richard A. Schroeder Chair in Mechanical Engineering
SHARON M. WEISS, Cornelius Vanderbilt Chair
JOHN P. WIKSWO, JR., Gordon A. Cain University Professor; A. B. Learned Professor of Living State Physics

Department Chairs and Division Director

MICHAEL R. KING, Biomedical Engineering
G. KANE JENNINGS, Chemical and Biomolecular Engineering
DOUGLAS E. ADAMS, Civil and Environmental Engineering
XENOFON KOUTSOUKOS, Electrical Engineering and Computer Science
YIORGOS KOSTOULAS, General Engineering
NILANJAN SARKAR, Mechanical Engineering

Faculty

For a list of current faculty, please visit *virg.vanderbilt.edu/webtools/registry*

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 lifelong 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 minor.

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 or the Computing Accreditation Commission of ABET *(abet.org)*.

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 are especially encouraged to 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 five main buildings with several satellite facilities. William W. Featheringill Hall houses 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. The new Engineering and Science Building is an eight-story state-of-the-art building that houses the Wond'ry at the Innovation Pavilion, numerous research labs, interactive classrooms, clean rooms, and space for students to work, study, and socialize. School administrative offices and several classrooms are located on the ground floor of the Science and Engineering Building in Stevenson Center, which also houses the Biomedical Engineering department on the 8th and 9th floors. Jacobs Hall, which flanks Featheringill Hall, contains laboratories, offices, and classrooms serving both the Civil and Environmental Engineering department and the Electrical Engineering and Computer Science department. Olin Hall houses Chemical and Biomolecular Engineering, Mechanical Engineering, and Materials Science. Several other satellite facilities that are part of the Engineering School include the W. M. Keck Free-Electron Laser Center building, housing the labs and offices of the Biomedical Photonics Center; the LASIR (Laboratory for Systems Integrity and Reliability), a hangar-style facility located off campus and dedicated to scaling up experiments to realistic and full size, including a wind tunnel and military aircraft; the MuMS facility (multiscale modeling and simulation); the Vanderbilt Institute of Software Integrated Systems; and the Institute for Space and Defense Electronics, providing office space, dry laboratories, and conference space.

In all its engineering programs, Vanderbilt recognizes the vital place of experimental and research laboratories in the learning experience. Laboratories are designed 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 *(abet.org)*. The bachelor of science program in computer science is accredited by the Computing Accreditation Commission of ABET *(abet.org)*.

Employment of Graduates

Of the recent Vanderbilt graduates with baccalaureate degrees in engineering, about 75 percent entered directly into professional practice. Twenty-five percent continued with graduate or professional education. 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 outside speakers, plant trips, and other subjects of interest to the membership.

First-year students 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 Nuclear Society (ANS)
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.)
Biomedical Engineering Society
Institute of Electrical and Electronics Engineers (I.E.E.E.)
International Society for Hybrid Microelectronics (I.S.H.M.)
International Society for Optics and Photonics (SPIE)
National Society of Black Engineers (N.S.B.E.)
Society of Asian Scientists and Engineers (S.A.S.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.)
Women in Computing
Women in Science and Engineering

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 outside of the School of Engineering. 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. and M.S. degrees 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		•		•	•
Cyber-Physical Systems			•		
Electrical Engineering	•		•	•	•
Engineering in Surgery and Intervention			•		
Engineering Management			•		
Engineering Science		•			
Environmental Engineering			•	•	•
Materials Science and Engineering				•	•
Mechanical Engineering	•		•	•	•
Risk, Reliability, and Resilience 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 125 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, requiring 120 and 121 semester hours, respectively. These programs have more flexibility in elective choice than the B.E. degree programs.

The First Year

Many courses normally scheduled for the first year are common to both the B.E. and B.S. degree programs. While the curriculum for the first 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 first year to plan 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 first year is the course Engineering Science 1401–1403 (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. 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 Math 2500-2501 sequence as a substitute for Math 2300. For more information, see the course descriptions under Mathematics in the Arts and Science section of this catalog. For majors requiring Math 2420 (Methods of Ordinary Differential Equations), students may select Math 2400 (Differential Equations with Linear Algebra) as a substitute.

Students with inadequate backgrounds in mathematics may be required to take Math 1005 (Pre-calculus Mathematics). Taking this course constitutes an additional requirement for graduation.

Math 1010-1011 (Probability and Statistical Inference) and Math 1100 (Survey of Calculus) cannot be credited toward a degree in the School of Engineering.

Students with greater interest in physics may enroll in Phys 1911, 1912, 1912L, and 2255L (Principles of Physics I and II and labs) as substitutes for Phys 1601, 1602, 1601L, and 1602L (General Physics I and II and labs), respectively.

Pre-calculus courses Phys 1010, 1010L, 2051, 2052, 2053, and 2054 cannot be credited toward a degree in the School of Engineering.

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 comprising:

1. At least 3 hours selected from courses classified in the AXLE Curriculum Course Distribution of the College of Arts and Science as Humanities and Creative Arts (HCA), with the exception of CMST 1500, 2100, 2110, and 2120, and
2. At least 3 hours selected from courses classified in the AXLE Curriculum Course Distribution of the College of Arts and Science as Social and Behavioral Sciences (SBS).

The remaining hours are to be selected from:

1. Courses classified in the AXLE Curriculum Course Distribution of the College of Arts and Science as Humanities and Creative Arts (HCA), International Cultures (INT), History and Culture of the United States (US), Social and Behavioral Sciences (SBS), and Perspectives (P)
2. CS 1151 and ENGM 2440
3. ARA, CHEB, CHIN, FREN, GER, GRK, HEBR, HNUR, ITA, JAPN, KICH, KOR, LAT, RUSS, SNSK, and SPAN courses numbered 1101; CHIN and JAPN courses numbered 1011 and 1012; and ENGL and SPAN courses numbered 1100.

4. Peabody College courses in Psychology and Human Development numbered 1205, 1207, 1250, 2200, 2250, 2300, 2400, 2500, 2550, 2600, and 3150, and in Human and Organizational Development numbered 1250, 1300, 2100, 2260, 2400, 2500, 2700, and 3232
5. All MUSC, MUSE, MUSO, COMP, MREP, MUTH, and performance courses in the Blair School of Music, except MUSO 1001

Open Electives

Courses taken beyond specified courses and restricted (such as program, technical, and liberal arts) electives for the major may be taken as open electives.

Officer Education

Course offerings in military science and naval science are described in the chapter on Special Programs for Undergraduates near the front of the catalog. All officer education courses designated as eligible for credit may be taken as open electives. In addition, officer education courses in history and political science that carry AXLE designations may be taken as part of the Liberal Arts Core. AFROTC students may count 6 hours of the 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 offered in biomedical engineering, chemical engineering, civil engineering, cyber-physical systems, electrical engineering, engineering in surgery and intervention, engineering management, environmental engineering, mechanical engineering, and risk, reliability, and resilience engineering.

Students must complete 30 hours of approved course work. A maximum of 6 hours of graduate-level course work may be transferred from another institution, 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 project adviser.

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. For information about admissions, application procedures, and application deadlines for the Master of Engineering programs, please visit engineering.vanderbilt.edu/gradschool.

For international students who did not graduate from an institution in a country where English is the official language, proficiency in English must be shown by a minimum score of 89 on the TOEFL or 7 on the IELTS test.

Digital Learning Programs

The School of Engineering offers two degree programs online: an M.S. in Computer Science, and an M.Eng. in Engineering Management. Courses in these digital learning programs are only available to students enrolled in these online degree programs. For information about admissions, application procedures, and application deadlines for the School of Engineering Digital Learning programs, please visit the website *engineeringonline.vanderbilt.edu*.

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.

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

Study Abroad

Vanderbilt's Global Education Office offers approximately thirty programs that allow students to take engineering or computer science courses in English abroad, in locations ranging from Dublin to Sydney, Madrid to Hong Kong. There are no language prerequisites for these programs. These programs also allow students to take a range of liberal arts core and elective courses abroad. In no case, after matriculating at Vanderbilt, may a student participate in a Vanderbilt-approved study abroad program through a different university or through an external agency and then seek to transfer that credit into Vanderbilt. Financial aid can be used for study abroad during the academic year, and scholarships are available to support Vanderbilt-approved summer study abroad options. Students are encouraged to discuss with their academic advisers how best to incorporate study abroad into their four-year plans of study. All students who study abroad must register their travel in advance with Vanderbilt's international security provider. Registration is completed on your behalf when enrolling in a program offered through the Global Education Office. Otherwise, information is available on the GlobalVU website: *vanderbilt.edu/global*.

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.

Second 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.

Both majors are 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. Minors are offered in engineering management, materials science and engineering, computer science, computer engineering, electrical engineering, environmental engi-neering, energy and environmental systems, nanoscience and nanotechnology, 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 Office of Academic Services 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.

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 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 by the end of the second year with at least a 3.0 grade point average may be accepted into an integrated Bachelor of Engineering–Master of Engineering program. This program is currently available in chemical, civil, environmental, and mechanical engineering. The last two years of a student's program are planned as a unit.

With the approval of the student's adviser, the director of graduate studies in the student's major department, and the senior associate dean for undergraduate education, students apply through the senior associate dean for graduate education for admission to this integrated dual degree program. Upon admission to this program, a second "career" will be set up for the student which will allow the student to start taking graduate courses (course numbers > 5000) during the junior and senior years. These courses will be credited toward the master of engineering. Note that no double counting of courses is allowed (i.e., the student must meet the degree requirements for each degree independent of the other degree). The student typically receives the bachelor's degree at the end of the fourth year and completes the master of engineering during the fifth year. Further information can be obtained from the director of graduate studies 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 a master of science in about the same time required for the bachelor's degree or slightly longer. 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 student's adviser, the director of graduate studies in the student's major department, and the senior associate dean for undergraduate education, students apply through the senior associate dean for graduate education for admission to this accelerated dual degree program. Upon admission to this program, a second "career" will be set up for the student which will allow the student to start taking graduate courses (course numbers > 5000) during the junior and senior years. These courses will be credited toward the master of science. Note that no double counting of courses is allowed (i.e., the student must meet the degree requirements for each degree independent of the other degree). The student receives the bachelor's degree at the end of the fourth year and typically spends the summer finishing a master's thesis to complete the master of science. Further information can be obtained from the director of graduate studies 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 three years' School of Engineering graduating seniors.

Magna Cum Laude. Students whose grade point average equals or exceeds that of the next 8 percent of the previous three years' School of Engineering graduating seniors.

Cum Laude. Students whose grade point average equals or exceeds that of the next 12 percent of the previous three years' School of Engineering 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

ALPHA ETA MU BETA, the National Biomedical Engineering Honor Society, was installed at Vanderbilt University in 1998 and re-established in 2019. AEMB was established in 1979 to recognize and encourage excellence in the field of biomedical engineering and bioengineering.

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 FIRST-YEAR STUDENTS. First-year students 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.

WILLIAM A. MA AWARD. Awarded to an outstanding senior majoring in chemical engineering on the basis of a demonstrated record of leadership and scholastic achievement.

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.

ROBERT D. TANNER UNDERGRADUATE RESEARCH AWARD. Awarded to a senior who, in the judgment of the chemical engineering faculty, has conducted at Vanderbilt University the best undergraduate research project.

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 who specializes in helping undeclared students explore different pathways and decide upon a major is assigned. 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.

Professional Registration and Accreditation

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 examination 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 *(abet.org)*. Students in these programs may take the Fundamentals of Engineering examination as seniors. In addition, proven professional experience is a requirement for registration. Other state boards may have different rules.

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 that 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 senior associate 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. A student must be enrolled in a minimum of 12 hours to be classified as a full-time student.

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+	= 2.3
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
		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, as designated by each program's curriculum.

Pass/Fail Electives Options by Program

	Open Elective	Liberal Arts Core	Technical Elective
BME	X	X	
CEE	X	X	
ChBE	X		
CMPE	X		
CS	X	X	X
EE	X		
ES	X	X	
ME	X	X	X (non-ME)

2. No more than two courses may be taken on a Pass/Fail basis in any one semester.
3. A minimum of 12 hours must be taken on a graded basis in any semester that a Pass/Fail course is taken. 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.
4. Students may register for grading on a Pass/Fail basis until the close of the Change Period at the end of the second week of classes. Students may change from Pass/Fail to graded status until the deadline date for withdrawing from 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 and is subject to approval 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 or credits earned, and 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 withdrawing from 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. 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. A course cannot be repeated through credit by examination.

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. 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.

Grade Point Average Requirements

To be eligible for graduation, a student must have successfully completed all degree requirements and shall have earned a minimum grade point average of 2.000 in (a) all courses taken, (b) courses taken within the School of Engineering, and (c) department courses of each major.

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.

Residence Requirements

A minimum of four semesters including the last two semesters must be spent in residence in the School of Engineering. A student in the School of Engineering is considered "in residence" if the student is (a) physically present at Vanderbilt and enrolled in Vanderbilt University classes offered on campus, or (b) enrolled in at least 12 credit hours in an approved Vanderbilt study abroad program. 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.

Immersion Vanderbilt Requirement

To fulfill the university requirement of Immersion Vanderbilt, a student must participate in an intensive learning experience that culminates in the creation of a tangible final project. This requirement applies to all students who enter Vanderbilt as first-year students in or after summer 2018, as second-year students in or after summer 2019, or as third-year students in or after summer 2020.

Immersion Vanderbilt (www.vanderbilt.edu/immersion/) allows students to pursue a multi-year pathway to engage in professional development, civic involvement, creative expression, international study, and/or research. The pathway may focus on one or more of these areas and should provide a structure upon which students can brainstorm, plan, and execute their immersive projects across multiple years. Most engineering students will take advantage of a four-year engineering design experience to satisfy the requirements of Immersion Vanderbilt. Each engineering major offers such a multi-year experience within its curriculum. Students whose plans include professional development may also pursue industrial internships. A research pathway can engage the student in discovery through research in engineering or other fields. Most engineering students will select an immersion experience associated with their major; however, students can pursue an Immersion plan outside their home program. For example, students interested in creative expression might develop a performance piece, exhibit, or artistic work, while those interested in international study may explore firsthand the culture, language, and history of other countries. Students interested in such immersion plans should consult the Office of Immersion Resources (OIR).

The Immersion Vanderbilt process is composed of three phases over the four-year experience. Phase one involves the creation of a plan that identifies the project, a pathway to completion, and its contribution to a student's overall education. Phase two is the experiential phase, consisting of the equivalent of at least 9 credit hours of work. It may be fulfilled through Vanderbilt courses and/or approved Immersion activities done during the academic year or summer. For most students in the School of Engineering, phase two can be satisfied by hands-on and team-based experiences within their required courses.

Finally, Immersion Vanderbilt culminates in the creation of a final project arising from the experience. Approval and assessment of the project is done by the supervising school or college. Senior design projects in the School of Engineering satisfy the final project requirement for Immersion Vanderbilt, with students presenting the results of their design project at the school's Design Day, held on the last day of classes each spring. For students completing other immersion projects, OIR coordinates a series of showcases open to the entire campus where students display their projects. Upon completion of phase three, OIR conveys that the requirements have been met by showing completion of the Immersion Vanderbilt graduation requirement on the student's degree audit and adding the Immersion project to the student's transcript.

Transfer Credit

Work that a student contemplates taking at a college or university other than Vanderbilt after matriculating to VU is treated as transfer work and must be approved in advance in writing through the YES Transfer Credit application. The institution must have appropriate regional accreditation. It is the student's responsibility to provide all information needed for an assessment of the program and course(s) for which transfer credit is requested. Students must upload a detailed syllabus, which then must be approved by the Office of the University Registrar, the relevant Vanderbilt University department, and the School of Engineering Dean's Office. Work transferred to Vanderbilt from another institution will not be included in the Vanderbilt grade point average. No transfer credit course in which a grade below C- was received will be credited toward a degree in offered by the School of Engineering. A course a student has taken at Vanderbilt may not be repeated in another institution to obtain a higher grade.. Students who have been dismissed from Vanderbilt and subsequently return to Vanderbilt are not eligible to receive transfer credit for any classes taken during the period of dismissal. Students cannot take courses for transfer credit at or through another institution while simultaneously enrolled in a semester at Vanderbilt unless authorized in advance by the School's Administrative Committee.

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 *yes.vanderbilt.edu*.

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 written consent of the instructor to attend the class and register to audit the course. Forms are available from the School of Engineering Office of Academic Services. No permanent record is kept of the audit. Regular students may audit one class each semester.

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 senior 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 second 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 (withdrawal) will be recorded.

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

Examinations

Examinations are usually given at the end of each semester in all undergraduate courses except for certain laboratory courses or seminars. Exams will be no longer than three hours in length and are given according to the schedule published in the *Final Examination Schedule*. The School of Engineering does not offer an alternate examination schedule. All examinations are conducted under the honor system.

Class Standing

School of Engineering students are promoted on the basis of cumulative GPA, hours earned, and regular semesters in residence. For the purposes of promotion, a regular semester is defined as any fall or spring term in which a student is enrolled at Vanderbilt University. Test credit and transfer credit can be used to satisfy the credit hour requirement.

VUSE Promotion Standards

Class Standing	GPA Requirement	Credit Hour Requirement	Minimum Residence Requirement
Sophomore	1.80	24 hours earned	2 regular semesters
Junior	1.90	54 hours earned	4 regular semesters
Senior	2.00	86 hours earned	6 regular semesters

Academic Standing

Good Standing

To remain in good academic standing, a student must pursue a program leading toward a degree in the School of Engineering and meet all GPA and hours earned requirements at the conclusion of each fall and spring semester. A first-year student must successfully complete at least 12 hours and earn at least a 1.8 semester GPA each semester to remain in good standing. A sophomore, junior, or senior must complete at least 12 hours and earn at least a 2.0 semester GPA each semester to remain in good standing. In addition, a student must also promote to the next academic class every two regular semesters according to the VUSE promotion standards (above) to remain in good standing.

Probation

Students who fail to meet the GPA, hours earned, or class standing promotion standards required to remain in good standing will be placed on academic probation. Students who fail to return to good standing after a semester on probation will be continued on probation or dismissed. Students who are on probation for three semesters risk dismissal.

A student authorized by the Administrative Committee to carry fewer than 12 hours because of illness or for some other approved reason may be placed on probation if the student's work is deemed unsatisfactory.

Required Leave of Absence

Under certain circumstances, a student may be required to take a semester-long leave of absence from the university. Such a leave may be required for students for whom one or more of the following conditions apply:

- Failing to pass 6 or more credit hours in a semester;
- Earning a semester grade point average of 1.4 or less; or
- Failing to improve academic achievement while on probation.

Dismissal

Any student who is deemed by the Administrative Committee not to be making satisfactory progress toward a degree in engineering will be dismissed from the School of Engineering and from Vanderbilt University. Satisfactory progress includes completing required courses in a timely manner and maintaining a 2.000 GPA in all courses, in the school, and in the student's major. Causes of dismissal include:

- Failure of all courses in any semester
- Three or more semesters on probation
- Failure to promote to the next class standing after three semesters
- Failure to progress toward a degree in the School of Engineering

Dismissed students are eligible to apply for reinstatement to the School of Engineering and to Vanderbilt University after one calendar year. The reinstatement process is outlined at *registrar.vanderbilt.edu/reinstatement*. Students who are dismissed and later apply for reinstatement are ineligible to receive transfer credit for courses taken while dismissed.

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. 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 each year will result in the cancellation of the scholarship.

Grade Reports

A grade report will be available to the student on Academic Record in YES 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 Office of Academic Services of the School of Engineering.

A grade reported and recorded in the Office of the University Registrar 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 in Graduate Courses

A qualified Vanderbilt junior or senior may enroll in courses approved for graduate credit by the graduate faculty. Credit from such courses may be applied to undergraduate degree requirements or, upon the student's admission to the Vanderbilt University Graduate School, toward a graduate degree. Vanderbilt cannot guarantee that another graduate school will grant credit for such courses. The principles governing this option are as follows:

1. Work taken under this option is limited to courses numbered 5000 and above and listed in the catalog of the Graduate School, excluding thesis and dissertation research courses and similar individual research and reading courses.
2. The student must, at the time of registration, have a 3.5 grade point average in the preceding two semesters.
3. The total course load, graduate and undergraduate courses, must not exceed 18 hours in that semester.
4. The student must obtain the written approval of their academic adviser and the instructor of the course on a form available in the Office of Academic Services.
5. 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.
6. An undergraduate student exercising this option will be treated as a graduate student with regard to class requirements and grading standards.

Reserving Credit for Graduate School

1. Undergraduate students who want to count credit earned in a course numbered 5000 and higher for graduate credit must at the time of registration declare their intention on a form available in the Office of Academic Services.
2. The work must be in excess of that required for the bachelor's degree.
3. All of the criteria detailed above regarding the enrollment by undergraduates in graduate courses apply 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 Office of Academic Services. 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 Office of Academic Services or the Office of the University Registrar. The university will consider notices or other information delivered if mailed to the address on file in YES.

Normal Program of Study

The normal program of study is 12 to 18 hours per semester. Students must be authorized by the Administrative Committee to register for fewer than 12 hours.

Withdrawal from the University

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

Courses of Study

1000–1999: Lower-level introductory courses. Generally no prerequisite.
2000–2999: Intermediate undergraduate courses. May have prerequisite courses.
3000–4999: Upper-level undergraduate course. Usually have prerequisite courses.
5000+: Courses for graduate credit.
Bracketed numbers indicate semester hours credit, e.g., [3].
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
NANO	Nanoscience and Nanotechnology
SC	Scientific Computing

The First Year

The first-year curriculum for all engineering disciplines is:

Specimen Curriculum

FALL SEMESTER		Semester hours
CHEM 1601, 1601L	General Chemistry and Laboratory	4
MATH 1300	Accelerated Single-Variable Calculus I	4
ES 1401–1403	Introduction to Engineering	3
	Elective (Liberal Arts Core Elective preferred)	3
ES 1115	First-year Engineering Seminar (optional)	1
VV 0700	Vanderbilt Visions	0
	Total	14–15

SPRING SEMESTER		Semester hours
Basic Science‡	Basic Science Course with Laboratory (requirements depend upon major)	4
MATH 1301	Accelerated Single-Variable Calculus II	4
PHYS 1601, 1601L	General Physics I and Laboratory	4
CS 1101, 1103, or 1104*	Computer Science Course	3
ES 1001	Engineering iCommons Seminar (optional)	1
	Total	15–16

‡ . Biomedical engineering and chemical engineering majors must take CHEM 1602 and 1602L; computer engineering, electrical engineering, and mechanical engineering majors must take MSE 1500 and 1500L or CHEM 1602 and 1602L; and civil engineering and engineering science majors should consult their program's basic science and technical elective requirements for approved courses.

* Computer science, computer engineering, and electrical engineering majors must take CS 1101 or 1104.

Biomedical Engineering

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ASSOCIATE CHAIR W. David Merryman
DIRECTOR OF UNDERGRADUATE STUDIES Craig Duvall
DIRECTOR OF GRADUATE STUDIES Cynthia Reinhart-King
DIRECTOR OF GRADUATE RECRUITING Mark D. Does
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ADJUNCT PROFESSOR Stacy Klein-Gardner
ADJOINT PROFESSOR Richard Mu
ASSOCIATE PROFESSORS Franz J. Baudenbacher, Leon Bellan, Audrey K. Bowden, Brett C. Byram, Edward Y. Chekmenev, Bruce M. Damon, Edwin Donnelly, William H. Fissell, William A. Grissom, Deborah Lannigan, Victoria L. Morgan, Jeffry S. Nyman, Cynthia B. Paschal, Wellington Pham, John J. Reese, James West
ASSOCIATE PROFESSORS OF THE PRACTICE Amanda Lowery, Christina C. Marasco
RESEARCH ASSOCIATE PROFESSORS Justin Baba, Rebecca Cook, Zhaohua Ding, Daniel J. France, Lisa McCrawley Baxter Rogers

ASSISTANT PROFESSORS Jonathan Brunger, James Cassat, Charles Caskey, Catie Chang, Dario Englot, Nicholas Ferell, Giresh Hiremath, Jacob Houghton, Clayton Kaiser, Ethan S. Lippmann, Gregor Neuert, Jack H. Noble, Ipek Oguz, Aron Parekh, Marjan Rafat, Mikail Rubinov, Seth A. Smith, Julie Sterling, Wesley Thayer, Yuankai Tao, Eric R. Tkaczyk, John T. Wilson, Lauren Woodard, Junzhong Xu, Karl Zelik, Cin Maizie Zhao

ASSISTANT PROFESSORS OF THE PRACTICE Romina Del Bosque, Joseph Schlesinger

RESEARCH ASSISTANT PROFESSORS Nick Adams, Charleson S. Bell, Zhipeng Cao, Logan Clements, Richard D'Arcy, Richard Dortch, Shannon Faley, Yurui Gao, Mukesh Gupta, Kevin Harkins, Nidhi Jyotsana, Dmitry Markov, Sinead E. Miller, Bryan Millis, Patricia K. Russ, Teresa K. Sanders, Veniamin Sidorov, Eric Spivey, Zhenjiang Zhang

ADJUNCT ASSISTANT PROFESSORS Valerie Guenst, Kalana Jayawardana

ADJOINT ASSISTANT PROFESSORS Frank Block, Brian C. Evans, Judy T. Lewis, Amber Simpson

INSTRUCTOR Amanda Buck

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, technical, and open electives. This allows students to design their own focus areas such as regenerative medicine and tissue engineering, wearables and point-of-care diagnostics, global health, surgery and engineering, robotics and prosthetics, lasers and medicine, medical imaging, biotechnology and nanomedicine, medical technology and entrepreneurship.

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, surgery and engineering, regenerative medicine, nanobiotechnology, 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 5000-level or above (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 3860 and 3861 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 curriculum information provided here is for students projected to graduate in class of '22 and forward. Students in the class of 2021 should refer to the additional BME curriculum guide posted at this website: engineering.vanderbilt.edu/bme/UndergraduateProgram/UndergraduateCurriculumGuide.php

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

1. Mathematics (15 hours): MATH 1300, 1301, 2300, 2400.
2. Basic Science (20 hours): CHEM 1601, 1601L, 1602, 1602L; PHYS 1601, 1601L, 1602, 1602L; BSCI 1510, 1510L.
3. Engineering Fundamentals (6 hours): ES 1401, 1402, 1403; CS 1101 or 1103 or 1104.
4. Electrical Engineering (3 hours): EECE 2112.
5. Biomedical Engineering (38 hours): BME 2001, 2002, 2100, 2400, 2900W, 3000, 3301, 3302, 3400, 3500, 3900W, 4901W, 4950, 4951, 4959.
6. Biomedical Engineering electives (12 hours) comprising:

   i) BME courses numbered 2210 and higher (except BME 2860 and designated sections of 3890–3893) to include up to 6 hours total of BME 3860, 3861.

   ii) Any one of the following: CHBE 4500, 4800, 4805, 4810, 4820, 4840, 4870; EECE 3214, 4353, 4354; ENVE 4610;
   ME 2220.
7. Technical electives (9 hours) comprising:

   i) Courses in the School of Engineering except BME 2201, 2860, CHBE 3300, CE 2200, CS 1000, 1151, ENGM 2160, 2440, 3100, 3350, ME 2171, and listings in Engineering Science. Up to 3 hours of independent study courses in the School of Engineering may be taken as technical electives.

   ii) Courses numbered 2000 or higher in the College of Arts and Science listed in the mathematics and natural sciences (MNS) AXLE distribution category except MATH 2610, 2810, 2820, and 3000.

   iii) BSCI 1511, 1511L; NURS 1500, 1600.
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	
SOPHOMORE YEAR		FALL	SPRING
BSCI 1510, 1510L	Introduction to Biological Sciences with Laboratory	4	–
BME 2001, 2002	Systems Physiology I, II	3	3
BME 2100	Biomechanics	–	3
BME 2400	Quantitative Methods I: Statistical Analysis	–	3
BME 2900W	Biomedical Engineering Laboratory I	–	1
EECE 2112	Circuits I	–	3
MATH 2300	Multivariable Calculus	3	–
MATH 2400	Differential Equations with Linear Algebra	–	4
PHYS 1602, 1602L	General Physics with Laboratory II	4	–
	Liberal Arts Core	3	–
		17	17
JUNIOR YEAR			
BME 3000	Physiological Transport Phenomena	3	-
BME 3301, 3302	Biomedical Instrumentation I, II	4	4
BME 3400	Quantitative Methods II: Signals and Modeling	3	–
BME 3500	Biomedical Materials	--	3
BME 3900W	Biomedical Engineering Laboratory II	1	–
	Biomedical Engineering and/or Technical Elective	3	6
	Liberal Arts Core	3	3
		17	16
SENIOR YEAR			
BME 4901W	Biomedical Engineering Laboratory III	1	–
BME 4950, 4951	Design of Biomedical Engineering Systems I, II	2	3
BME 4959	Senior Engineering Design Seminar	1	–
	Biomedical Engineering and/or Technical Elective	6	9
	Liberal Arts Core	3	3
	Open Elective	3	--
		16	15

Course descriptions can be found in the Engineering Courses section of this catalog.

Double Majors

I. The double major in biomedical and electrical engineering requires a minimum of 129 semester hours. The requirements include those numbered 1, 2, 3, and 8 for the B.E. in biomedical engineering and the following:

a. Biomedical engineering (32 hours): BME 2001, 2002, 2100, 2400, 2900W, 3000, 3302, 3500, 3900W, 4901W, 4950, 4951, 4959.

b. Biomedical engineering electives (3 hours): BME courses numbered 2210 and higher (except BME 3301, 3400 and designated sections of 3890–3893).

c. Electrical engineering (21 hours): EECE 2112, 2123, 2123L, 2213, 2213L, 3214, 3233, 3235, 3235L.

d. Electrical engineering electives (15 hours) selected as described by item 6 of the Curriculum Requirements in the electrical engineering section of the catalog, but totaling at least 15 hours. Students must complete at least two courses in each of two areas of concentration listed under electrical engineering in the Undergraduate Catalog. At least one course must be a domain expertise course as designated in the catalog. BME 3302 may be included toward satisfying the area of concentration requirement but cannot be counted as an electrical engineering elective.

A specimen curriculum for the double major with electrical engineering can be found on the biomedical engineering department's website.

II. The double major in biomedical and chemical engineering requires a minimum of 137 hours and is described in the chemical engineering section of the catalog under its curriculum requirements.

Chemical Engineering

CHAIR G. Kane Jennings
DIRECTOR OF GRADUATE PROGRAM Jamey D. Young
DIRECTOR OF UNDERGRADUATE STUDIES Paul E. Laibinis
PROFESSORS EMERITI Thomas R. Harris, M. Douglas LeVan, K. Arthur Overholser, Robert J. Roselli, John A. Roth, Robert D. Tanner
PROFESSORS Peter T. Cummings, Todd D. Giorgio, Scott A. Guelcher, G. Kane Jennings, David S. Kosson, Paul E. Laibinis, Matthew J. Lang, Clare M. McCabe, Peter N. Pintauro, Sandra J. Rosenthal, Florence Sanchez, Jamey D. Young
PROFESSOR OF THE PRACTICE Russell F. Dunn
ASSOCIATE PROFESSOR EMERITUS Kenneth A. Debelak
ASSOCIATE PROFESSOR Bridget R. Rogers
RESEARCH ASSOCIATE PROFESSOR Ryszard Wycisk
ADJOINT ASSOCIATE PROFESSOR Rizia Bardhan,
ASSISTANT PROFESSORS Kelsey B. Hatzell, Piran Kidambi, Shihong Lin, Ethan S. Lippmann, Marjan Rafat, Carlos A. Silvera Batista, John T. Wilson, Marija Zanic
RESEARCH ASSISTANT PROFESSORS Lihong Bishop, Christopher R. Iacovella, Julianne Vernon, Bo Wang
LECTURER Bryan R. Beyer

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 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 B.E. in chemical engineering and graduate study leading to the M.Eng., M.S., and Ph.D.

Undergraduate chemical 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. Specimen curricula with emphases in specific areas are available on the department website. 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 2112, CE 2200, and ME 2190.

Undergraduate Honors Program. The 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 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. Requirements include at least 6 hours of CHBE courses numbered 5000 or above, plus 6 hours of CHBE 3860 and 3861 taken in the junior and/or senior year under the direction of a faculty honors adviser. A formal written research report is submitted each semester CHBE 3860 or 3861 is taken with a final report and presentation given in the spring semester of the senior year to the CHBE faculty and students. 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; materials; energy and the environment.

Curriculum Requirements

The B.E. in chemical engineering requires a minimum of 125 hours, distributed as follows:

1. Mathematics (14 hours): MATH 1300, 1301, 2300, 2420.
2. Basic Science (24 hours): CHEM 1601, 1601L, 1602, 1602L, 2221, 2221L, 2222, 2222L; PHYS 1601, 1601L, 1602, 1602L.
3. Engineering Fundamentals (6 hours): ES 1401, 1402, 1403; CS 1101 or 1103 or 1104.
4. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed in the Degree Programs in Engineering.
5. Chemical and Biomolecular Engineering (39 hours): CHBE 2100, 2200, 2250, 2900W, 3200, 3250, 3300, 3350, 3600, 3900W, 4900W, 4950W, 4951W, 4959.
6. Science electives (6 hours): BSCI 1510 or CHBE 2150; CHEM 3300 (preferred) or BSCI 2201 or BSCI 2520.
7. Chemical and Biomolecular Engineering electives: 6 hours selected from CHBE courses numbered 4000 and above.
8. Technical electives (6 hours). To be selected from: a) courses numbered 2000 or above in BME, CHBE, CE, CS, EECE, ENVE, ME, MSE, NANO, and SC, except BME 2201, BME 2860, and ME 2220; b) courses numbered 1500 or above in the College of Arts and Science listed in the mathematics and natural sciences (MNS) AXLE distribution category; and c) ENGM 3000, 3010, 3300, 3650, 3700, 4500.
9. Open electives (6 hours).

Undergraduates in chemical engineering, including double majors with chemical engineering, may apply the pass/fail option only to courses taken as open electives, subject to the school requirements for pass/fail. No more than 6 total hours of CHBE 3860 and 3861 may be applied toward degree requirements.

Double Majors

I. The double major in chemical engineering and biomedical engineering requires a minimum of 137 semester hours. The requirements include those numbered 2, 3, and 4 for the B.E. in chemical engineering and the following:

a) Mathematics (15 hours): MATH 1300, 1301, 2300, 2400.

b) Biology (4 hours): BSCI 1510, 1510L.

c) Chemical and Biomolecular Engineering (29 hours): CHBE 2100, 2200, 2250, 3200, 3250, 3300, 3350, 4900W, 4950W, 4959.

d) Biomedical Engineering (32 hours): BME 2001, 2002, 2100, 2900W, 3301, 3302, 3400, 3500, 3900W, 4901W, 4950, 4951, 4959.

e) Electrical Engineering (3 hours): EECE 2112.

f) CHBE elective: 3 hours selected from CHBE 4500, 4800, 4805, 4810, 4820.

g) BME elective: 3 hours selected from BME courses numbered above 2000 except BME 2201, 2400, 2860, 3000, 3200, 6110.

II. The double major in chemical engineering and chemistry requires a minimum of 130 semester hours. The requirements include those numbered 1, 2, 3, 4, and 7 for the B.E. in chemical engineering and the following:

a) Chemical and Biomolecular Engineering (36 hours): CHBE 2100, 2200, 2250, 2900W, 3200, 3250, 3300, 3350, 4900W, 4950W, 4951W, 4959; CHBE 3600 or 4830.

b) Science (23 hours): CHEM 2100, 2100L, 3010, 3300, 3315; either CHEM 4965 and 4966 or CHEM 3980, 4980, and 4999; BSCI 1510 or CHBE 2150; BSCI 2520.

c) Engineering Elective: 3 hours selected from courses numbered 2000-3800 or 3890 and above in BME, CHBE, CE, EECE, ENVE, and ME, except BME 2201, 2860, and 3830.

Specimen Curriculum for Chemical Engineering

		Semester hours	
SOPHOMORE YEAR		FALL	SPRING
CHEM 2221, 2222	Organic Chemistry	3	3
CHEM 2221L, 2222L	Organic Chemistry Laboratory	1	1
MATH 2300	Multivariable Calculus	3	–
MATH 2420	Methods of Ordinary Differential Equations	–	3
PHYS 1602, 1602L	General Physics II and Laboratory	4	–
CHBE 2100	Chemical Process Principles	3	–
CHBE 2200	Chemical Engineering Thermodynamics	–	3
CHBE 2250	Modeling and Simulation in Chemical Engineering	–	3
CHBE 2900W	Technical Communications for Chemical Engineers	–	1
	Liberal Arts Core	3	3
		17	17

		Semester hours	
JUNIOR YEAR		FALL	SPRING
CHBE 2150	Molecular and Cell Biology for Engineers	3	–
CHBE 3200	Phase Equilibria and Stage-Based Separations	3	–
CHBE 3250	Chemical Reaction Engineering	–	3
CHBE 3300	Fluid Mechanics and Heat Transfer	3	–
CHBE 3350	Mass Transfer and Rate-Based Separations	–	3
CHBE 3900W	Chemical Engineering Laboratory I	–	3
	Chemical and Biomolecular Engineering Elective	–	3
	Science Elective: CHEM 3300 (preferred), BSCI 2201, or BSCI 2520	3	_
	Liberal Arts Core	3	3
		15	15

SENIOR YEAR		FALL	SPRING
CHBE 3600	Chemical Process Control	3	_
CHBE 4900W	Chemical Engineering Laboratory II	3	–
CHBE 4950W	Chemical Engineering Process and Product Design	4	–
CHBE 4951W	Chemical Engineering Design Projects	–	3
CHBE 4959	Professional Practice of Safety in Chemical Engineering Design	1	–
	Chemical and Biomolecular Engineering Elective	–	3
	Liberal Arts Core	–	3
	Technical Elective	3	3
	Open Elective	3	3
		17	15

Specimen curricula for the double majors with biomedical engineering and with chemistry can be found on the department's website.

Course descriptions can be found in the Engineering Courses section of this catalog.

Civil Engineering

CHAIR Douglas E. Adams
ASSOCIATE CHAIR Florence Sanchez
DIRECTORS OF GRADUATE STUDIES Daniel B. Work, interim (Civil Engineering), Florence Sanchez (Environmental Engineering)
DIRECTORS OF GRADUATE RECRUITING Hiba Baroud (Civil Engineering), Shihong Lin (Environmental Engineering)
DIRECTOR OF UNDERGRADUATE STUDIES Robert E. Stammer, Jr.
PROFESSORS EMERITI Prodyot K. Basu, Paul Harrawood, Peter G. Hoadley, Hugh F. Keedy, Frank L. Parker, John A. Roth, Richard E. Speece, Robert E. Stammer, Jr., Edward L. Thackston
PROFESSORS Mark D. Abkowitz, Douglas E. Adams, John Ayers, David J. Furbish, George M. Hornberger, David S. Kosson, Eugene J. Leboeuf, Sankaran Mahadevan, Caglar Oskay, Florence Sanchez, Matthew Weinger
PROFESSORS OF THE PRACTICE Curtis D. Byers, Sanjiv Gokhale, Steven L. Krahn, Robert E. Stammer, Jr., Lori A. Troxel
RESEARCH PROFESSOR Craig E. Philip
ASSOCIATE PROFESSORS Alan R. Bowers, Jonathan Gilligan, Daniel B. Work
RESEARCH ASSOCIATE PROFESSORS Kevin G. Brown, Janey S. Camp, Andrew G. Garrabrants
ASSISTANT PROFESSORS Hiba Baroud, Ravindra Duddu, Jesus Gomez-Velez, Shihong Lin
RESEARCH ASSISTANT PROFESSOR Pranav Karve
ADJUNCT PROFESSORS Gregory L. Cashion, Susan Cange, John Michael Corn, James H. Clarke, Allen G. Croff, James P. Dobbins, Boualem Hadjerioua, Ofra Klein-BenDavid, Vic L. McConnell L. Hampton Turner IV, Hans A. Van der Sloot, Raymond G. Wymer
ADJUNCT INSTRUCTORS Ghina Absi, James Barrick, Kenneth Church, David Livingston, Keith Loiseau, Ross Murihead, Said ElSaid

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 enhancement 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 in water resources, quality, and treatment; resilience and sustainability; nuclear environmental engineering; and environmental materials and materials durability. 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 five 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 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 125 hours, distributed as follows:

1. Mathematics (14 hours). Required courses: MATH 1300, 1301, 2300, 2420.
2. Basic science (12 hours). Required courses: CHEM 1601, 1601L; PHYS 1601, 1601L, 1602, 1602L.
3. Basic science elective (4 hours). To be selected from: Biological Sciences courses numbered 1510 and 1510L and above; and Earth and Environmental Sciences 1510 and 1510L, 3260, 3330, 3340
4. Computing (3 hours). Required course: CS 1101 or 1103 or 1104.
5. Engineering Fundamentals (26 hours). Required courses: ES 1401, 1402, 1403; CE 2101, 2200, 2205, 3700, 3700L; ENGM 2160; ME 2190; MSE 2205; ME 2220 or CHBE 2200 (students with interests in Environmental and Infrastructure Sustainability Engineering are encouraged to enroll in CHBE 2200).
6. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed under Degree Programs in Engineering.
7. Open electives (6 hours).
8. Technical electives (3 hours). To be selected from: (a) courses in BME, CHBE, CE, ENVE, EECE, ME, MSE, and ENGM 3000, 3010, 3200, 3650 (except BME 2201, 2860 and MSE 3860, 3889, 3890); (b) all courses acceptable as science electives as indicated above; (c) CHEM 1602 and above; (d) PHYS courses above 2000 (astronomy not accepted); and (e) MATH 2410 or 2600, and courses 2811 and above (except 3000). Students with an interest in Structural Engineering are encouraged to take MATH 2410 or 2600 as their technical elective.
9. Civil Engineering Core (27 hours). Required courses: CE 2120, 3100W, 3200, 3205, 3300, 3501, 3705, 4400, 4950, 4951, and 4959.
10. Civil Engineering Program Electives (6 hours). To be selected from: CE 3250, 3600, 4250, or ENVE 4615.
11. Civil Engineering Design Electives (6 hours). To be selected from: CE 4150, 4200, 4210, 4240, 4250, 4425, 4430, 4500, 4505, 4510; ENVE 4305, 4610, 4625, 4710.

Students may use CE program electives, CE design electives, technical electives, and open electives to gain additional depth and expertise. Students with interests in structural engineering are recommended to take electives such as CE 3250, 4200, 4210, 4211, 4250, 4300, ENVE 4305, and ME 4259, 4275. Students interested in environmental and infrastructure sustainability engineering are recommended to take electives such as CE 3600, 4100, 4150, 4240, 4300, ENVE 4305, 4600, 4605, 4610, 4615, 4620, 4700, 4705, 4707, 4710, 4715, 4716, and 4720. Specific courses selections should be discussed with their academic adviser. Students desiring advanced topic coverage should also consider 5000-level courses, with approval of their adviser.

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

Specimen Curriculum for Civil Engineering

		Semester hours	
SOPHOMORE YEAR		FALL	SPRING
MATH 2300	Multivariable Calculus	3	–
PHYS 1602, 1602L	General Physics II and Laboratory	4	–
CE 2101	Civil and Environmental Engineering Information Systems	3	–
CE 2120	Sustainable Design in Civil Engineering	3	–
CE 2200	Statics	3	–
MATH 2420	Methods of Ordinary Differential Equations	–	3
CE 2205	Mechanics of Materials	–	3
CE 3501	Transportation Systems Engineering	–	3
ME 2190	Dynamics	–	3
	Thermodynamics (ME 2220 or CHBE 2200)	–	3
	Liberal Arts Core	–	3
		16	18

JUNIOR YEAR

CE 3200	Structural Analysis	3	–
CE 3700, 3700L	Fluid Mechanics and Laboratory	4	–
MSE 2205	Strength and Structure of Engineering Materials	1	–
	CE Program Elective	3	–
	Elective*	3	–
	Liberal Arts Core	3	3
CE 3100W	Civil and Environmental Engineering Laboratory	–	2
CE 3205	Structural Design	–	3
CE 3300	Risk, Reliability, and Resilience Engineering	–	3
CE 3705	Water Resources Engineering	–	3
ENGM 2160	Engineering Economy	–	3
		17	17

SENIOR YEAR

CE 4400	Construction Project Management	3	–
CE 4950	Civil Engineering Design I	1	–
CE 4959	Senior Engineering Design Seminar	1	–
	CE Design Elective	3	3
	Elective*	3	3
	Liberal Arts Core	3	3
CE 4951	Civil Engineering Design II	–	2
	Open Elective	–	3
		14	14

***To be selected toward satisfying the following degree requirements: 6 hours of Program Electives, 3 hours of Technical Electives, and 6 hours of Open Electives.**

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. Further information is available from the pre-architecture advisers: Professor Vesna Pavlović, Department of Art, and Professor Kevin Murphy, Department of History of Art. 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 3600 – Environmental Engineering
ENVE 4600 – Environmental Chemistry

Elective Courses (9 hours)
CE 3705 – Water Resources Engineering
CE 4100 – Geographic Information Systems
ENVE 4305 – Enterprise Risk Management
ENVE 4605 – Environmental Thermodynamics, Kinetics, and Mass Transfer
ENVE 4610 – Biological Processes in Environmental Systems
ENVE 4615 – Environmental Assessments
ENVE 4620 – Environmental Characterization and Analysis
ENVE 4625 – Environmental Separations Processes
ENVE 4700 – Energy and Water Resources
ENVE 4705 – Physical Hydrology
ENVE 4710 – Hydrology
ENVE 4715 – Groundwater Hydrology
ENVE 4720 – Surface Water Quality Modeling
ENVE 4800 – Nuclear Environmental Engineering

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 4615 – Environmental Assessments
ENVE 4700 – Energy and Water Resources

Elective Courses (9 hours)
Area I: Energy Systems
EECE 4267 – Power System Analysis
ME 3890 – Special Topics: Nuclear Power
ME 4260 – Energy Conversion I
ME 4264 – Internal Combustion Engines
ME 4265 – Direct Energy Conversion

Area II: Environmental Engineering
CE 3600 – Environmental Engineering
CE 3705 – Water Resources Engineering
ENVE 4305 – Enterprise Risk Management
ENVE 4605 – Environmental Thermodynamics, Kinetics, and Mass Transfer
ENVE 4620 – Environmental Characterization and Analysis
ENVE 4710 – Hydrology
ENVE 4800 – Nuclear Environmental Engineering
ME 4262 – Environmental Control

Area III: Environmental Survey
ANTH 4154 – Energy, Environment, and Culture
CE 4100 – Geographic Information Systems
CE 4430 – High Performance and Green Buildings
EES 1080 – Earth and the Atmosphere
EES 2110 – Global Change and Global Issues
PHIL 3611 – Environmental Philosophy
SOC 3315 – Human Ecology and Society

Civil Engineering

Course descriptions can be found in the Engineering Courses section of this catalog.

Environmental Engineering

Course descriptions can be found in the Engineering Courses section of this catalog.

Computer Engineering

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ADJUNCT ASSISTANT PROFESSOR Andrew Sternberg

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. complete 3 hours of undergraduate research (EECE 3860, 3861 or CS 3860, 3861) with final written report.
3. complete 6 hours of EECE program elective credit from the following list:
   a. up to 3 additional hours of undergraduate research (EECE 3860, 3861 or CS 3860, 3861), or
   b. design domain expertise (DE) courses beyond the one course required by the program, or
   c. CS 3259, CS 3892, CS 4287, or
   d. 5000-level courses.

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: MATH 1300, 1301, 2300, 2400, 2810
2. Basic Science (16 hours). Required courses: CHEM 1601, 1601L; PHYS 1601, 1601L, 1602, 1602L; MSE 1500, 1500L (or CHEM 1602, 1602L).

3. Engineering Fundamentals (6 hours). Required courses:
   ES 1401, 1402, 1403, 2100W.
4. Culminating Design Experience (7 hours). Required courses: EECE 4950, 4951, 4959.
5. Computer Engineering Core (at least 23 hours). Required courses: EECE 2112, 2123, 2123L, 2218, 2218L; either EECE 2213 (and 2213L) or 3214; CS 1101 or 1104; CS 2201, 3251.
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 4376, Computing Systems and Networks (Area 2) must include CS 3281 and Intelligent Systems and Robotics (Area 3) must include EECE 4257. 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 CS or EECE courses numbered above 3000, or approved undergraduate research (CS 3860, 3861; EECE 3860, 3861) to total 18 hours.

Computer Engineering Areas of Concentration

Embedded Systems	**Computing Systems and Networks**	**Intelligent Systems and Robotics**
EECE 4257	**CS 3265**	**CS 4260**
EECE 4275	**CS 3274 (DE)**	**CS 4269 (DE)**
EECE 4356 (DE)	**CS 3281**	**EECE 4257**
EECE 4358 (DE)	**CS 3282 (DE)**	**EECE 4353 (DE)**
EECE 4376 (DE)	**CS 4266 (DE)**	**EECE 4354 (DE)**
EECE 4377 (DE)	**CS 4278 (DE)**	**EECE 4358 (DE)**
EECE 4385 (DE)	**CS 4279 (DE)**	**ME 4271**
CS 3274 (DE)	**CS 4283 (DE)**	
	CS 4284 (DE)	
	CS 4285	
	CS 4288 (DE)	
	EECE 4371 (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 (18 hours).

   a. (9-18 hours). At least 9 hours must be taken from this list of approved engineering technical electives.
      BME (except 2201, 2860)**
      CHBE (except 2150, 2900W)
      CE
      CS (except 1000, 1101, 1103, 1104, 1151)
      EECE (hours above basic requirement in sections 5 and 6 above)
      ENGM 3010
      ENVE
      ES 3300
      ME
      MSE (except 1500, 1500L)
      NANO 3000
      SC 3250, 3260
   b. (0-9 hours). Up to 9 hours may be taken from this list of optional technical electives.
      ENGM 2160, 2210, 3000, 3100, 3300, 3650, 4500
      MSE 1500, 1500L (if CHEM 1602, 1602L is used for basic science requirement)
      Astronomy (except 1010, 1111, 2130)
      Biological Sciences (except 1111)
      Chemistry (except 1010, 1020, 1601, 1602, 1111)
      Earth and Environmental Sciences (except 1080, 1111, 2150)
      Mathematics 2410 and above
      Neuroscience 2201, 3269, 4961
      Physics above 2000
      Psychology 2100, 3780

9. Open Elective (3 hours).

Undergraduates in computer engineering may apply the pass/fail option only to courses taken as open electives subject to the school requirements for pass/fail.

**Computer engineering majors may earn credit for only one of BME 3300 and BME 3302.

Specimen Curriculum for Computer Engineering

		Semester hours	
SOPHOMORE YEAR		FALL	SPRING
MATH 2300	Multivariable Calculus	3	–
MATH 2400	Differential Equations with Linear Algebra	–	4
PHYS 1602, 1602L	General Physics II and Laboratory	4	–
EECE 2112	Circuits I	3	–
EECE 2123, 2123L	Digital Systems and Laboratory	4	–
EECE 2218, 2218L	Microcontrollers and Laboratory	–	4
CS 2201	Program Design and Data Structures	3	–
CS 3251	Intermediate Software Design	–	3
	Liberal Arts Core	–	3
	Technical Elective	–	3
		17	17
JUNIOR YEAR			
MATH 2810	Probability and Statistics for Engineering	–	3
ES 2100W	Technical Communications	3	–
EECE 4376, 4376L	Embedded Systems and Laboratory	4/3	–
or CS 3281	Principles of Operating Systems I		
EECE 2213, 2213L	Circuits II and Laboratory	4/3	–
or EECE 3214	Signals and Systems		
	CMPE Program Electives ‡	3	6
	Liberal Arts Core	3	3
	Technical Electives	–	6
		15-17	18
SENIOR YEAR			
EECE 4950	Program and Project Management for EECE	3	–
EECE 4951	Electrical and Computer Engineering Design	–	3
EECE 4959	Senior Engineering Design Seminar	1	–
	CMPE Program Electives ‡	3	3
	Liberal Arts Core	3	3
	Technical Electives	6	3
	Open Electives	–	3
		16	15

‡ As described in "Computer Engineering Degree Requirements" subsection 6. At least one design domain expertise (DE) course required prior to EECE 4951.

Minor in Computer Engineering

The minor in computer engineering is available to all students except those majoring or minoring in electrical engineering or computer science. The computer engineering minor requires a minimum of 17 hours of EECS courses, including the completion of all laboratory corequisites for courses selected for the minor, distributed as follows:

1. Programming: CS 1101 or 1104	3 hours
2. Digital Systems: EECE 2123, 2123L	4 hours
3. Microcontrollers: EECE 2218, 2218L	4 hours
4. EECE 2112 or CS 2201 or CS 2204	3 hours
5. At least 3 hours of EECE or CS courses numbered 2000 or above (excluding EECE 3860, 3861 or CS 3860, 3861)	3 hours
Total:	17–18 hours

Computer Science

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ADJUNCT ASSISTANT PROFESSORS Daniel Balasubramanian, Zhiao Shi
LECTURERS Dominique Piot, Edward Stringfellow, Peter Volgyesi

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 back- ground 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 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 3860 and 3861) and 6000-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, distributed as follows:

1. Mathematics (20–22 hours). Required components:

   (a) Calculus/Linear algebra (14–16 hours). A sequence selected from the following:

   i MATH 1300, 1301, 2300, and one of 2410 or 2600, or
   ii. MATH 1300, 1301, 2500, 2501

   (b) Statistics/Probability (3 hours): MATH 2810, 2820, or 3640.

   (c) Elective course (3 hours).
   To be selected from MATH 2420 or courses numbered 2610 or higher.

2. Science (12 hours). To be selected from the following list and include at least one laboratory course: BSCI 1100, 1100L, 1510, 1510L, 1511, 1511L, 2218, 2219; CHEM 1601, 1601L, 1602, 1602L; Earth and Environmental Sciences 1510, 1510L; MSE 1500, 1500L; PHYS 1601, 1601L, 1602, 1602L. Recommended: CHEM 1601, 1601L; PHYS 1601, 1602.
3. Introduction to Engineering (3 hours): ES 1401, 1402,1403.
4. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed in the Degree Programs in Engineering.
5. Computer Science Core (25 hours).
   Software/Problem Solving: CS 1101 or 1104, and CS 2201, 3251, 3270.
   Hardware/Systems: EECE 2123, 2123L, CS 3281.
   Foundations: CS 2212, 3250.
6. Computer Science Depth (12 hours). To include at least one course selected from CS 4260, 4277, or 4278. Remaining hours to be selected from computer science courses numbered 3000 or higher; EECE 4353, 4354, 4376, and no more than two from MATH 3320, 3620, 4600, 4620. A maximum of 6 hours may come from CS 3860, 3861.
7. Computer Science Project (3 hours). To be selected from CS 3259, 3892, 4249, 4269, 4279, 4287.
8. Computer Science Seminar (1 hour). CS 4959.
9. Technical Electives (6 hours). To be selected from courses numbered 2000 or higher within the School of Engineering (except BME 2860, ENGM 2440, ENGM 4800, ES 2700,
   ES 3884, and CS courses numbered below 3000); or courses numbered 2000 or higher in the College of Arts and Science listed in the mathematics and natural science (MNS) AXLE distribution requirements. Students are encouraged to note the two-course sequence EECE 4950-4951.
10. Open Electives (18–20 hours).
11. Computers and Ethics (3 hours) CS 1151. May be used to satisfy three hours from the Liberal Arts Core (#4) or Open Electives (#10). May not be taken on a pass/fail grading basis by CS majors or minors.
12. Writing Component. At least one "W"-designated course or 1111 course in the English Language must be included from the Liberal Arts Core (#4), Technical Electives (#9), or Open Electives (#10).

Undergraduates in computer science may apply the pass/fail option only to courses taken as open electives, technical electives, or part of the liberal arts core, subject to the school requirements for pass/fail.

Specimen Curriculum for Computer Science

		Semester hours	
FIRST YEAR		FALL	SPRING
CHEM 1601, 1601L	General Chemistry and Laboratory	4	–
PHYS 1601, 1601L	General Physics I and Laboratory	–	4
MATH 1300	Accelerated Single-Variable Calculus I	4	–
MATH 1301	Accelerated Single-Variable Calculus II	–	4
ES 1401-1403	Introduction to Engineering	3	–
CS 1101	Programming and Problem Solving	–	3
	Liberal Arts Core	–	3
	Open Electives	3	–
		14	14
SOPHOMORE YEAR			
PHYS 1602, 1602L	General Physics II and Laboratory	4	–
MATH 2300	Multivariable Calculus	–	3
EECE 2123, 2123L	Digital Systems and Laboratory	4	–
CS 2201	Program Design and Data Structures	3	–
CS 2212	Discrete Structures	–	3
CS 3251	Intermediate Software Design	–	3
	Liberal Arts Core	–	3
	Open Electives	3	3
		14	15
JUNIOR YEAR			
MATH 2410	Methods of Linear Algebra	–	3
MATH 2820	Introduction to Probability and Mathematical Statistics	3	–
CS 3250	Algorithms	–	3
CS 3270	Programming Languages	3	–
CS 3281	Principles of Operating Systems I	3	–
	Computer Science Depth	–	3
	Liberal Arts Core	3	3
	Open Electives (ES 2100W recommended)	5	3
		17	15
SENIOR YEAR			
CS 4959	Computer Science Seminar	1	–
	Computer Science Project	–	3
	Computer Science Depth	6	3
	Mathematics Elective	3	–
	Technical Electives	3	3
	Liberal Arts Core	3	3
	Open Electives	–	3
		16	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 5, 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 is available to all students except those majoring in computer engineering. The minor in computer science requires 15–16 hours of computer science courses as follows:

1. Programming: CS 1101 or 1104 — 3 hours
2. Discrete Structures: CS 2212 — 3 hours
3. Intermediate Computer Concepts: CS 2201 — 3 hours
4. EECE 2123 (and 2123L), or CS 3250, or CS 3251 — 3–4 hours
5. One additional CS course numbered 3000 or above — 3 hours

Total: 15–16 hours

Course descriptions can be found in the Engineering Courses section of this catalog.

Electrical Engineering

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RESEARCH ASSISTANT PROFESSORS Jeffrey S. Kauppila, Brian D. Sierawski
ADJUNCT ASSISTANT PROFESSOR Andrew L. Sternberg
ADJUNCT INSTRUCTOR John Beck

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 tothe 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. complete 3 hours of undergraduate research (EECE 3860, 3861) with final written report.
3. complete 6 hours of EECE program elective credit from the following list:

a. up to 3 additional hours of undergraduate research (EECE 3860, 3861), or
b. design domain expertise (DE) courses beyond the one course required by the program, or
c. 5000-level courses.

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 Process- ing 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 sup- ported 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: MATH 1300, 1301, 2300, 2400, 2810.
2. Basic Science (16 hours). Required courses: CHEM 1601, 1601L; PHYS 1601, 1601L, 1602, 1602L; MSE 1500, 1500L or CHEM 1602, 1602L.
3. Engineering Fundamentals (6 hours). Required courses: ES 1401, 1402, 1403, ES 2100W.
4. Culminating Design Experience (7 hours). Required courses: EECE 4950, 4951, 4959.
5. Electrical Engineering Core (24 hours). Required courses: CS 1101 or 1104; EECE 2112, 2123, 2123L, 2213, 2213L, 3214, 3233, 3235, 3235L.
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. Stu- dents must complete at least one approved design domain expertise (DE) course as designated below. Other electives from any of the Areas of Concentration, or EECE courses numbered above 3000, or approved undergraduate research (EECE 3860, 3861) to total 18 hours.

Electrical Engineering Areas of Concentration

Computer Engr.	**Microelectronics**	**Signal/Image Processing**	**Robotics**	**Networking and Comm.**
EECE 2218	**EECE 4275**	**EECE 4252**	**EECE 4257**	**EECE 4252**
EECE 4275	**EECE 4283**	**EECE 4286**	**EECE 4354 (DE)**	**EECE 4334 (DE)**
EECE 4356 (DE)	**EECE 4284**	**EECE 4334 (DE)**	**EECE 4358 (DE)**	**EECE 4371 (DE)**
EECE 4376 (DE)	**EECE 4288**	**EECE 4353 (DE)**	**ME 4271**	
EECE 4377 (DE)	**EECE 4380 (DE)**	**EECE 4354 (DE)**		
EECE 4385 (DE)	**EECE 4385 (DE)**	**EECE 4356 (DE)**		
CS 3274 (DE)	**BME 3300 or 3302****	**CS 3258**		
ME 4271		**BME 3300 or 3302****		
		BME 3600		

(DE) designates a Design Domain Expertise course

**Electrical engineering majors may earn credit for only one of BME 3300 or 3302.

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 2201, 2860)
   CHBE (except 2150, 2900W)
   CE
   CS (except 1000, 1101, 1103, 1104, 1151)
   EECE (above basic requirement in sections 5 and 6 above)
   ENGM 3010
   ENVE
   ES 3300
   ME
   MSE (except 1500, 1500L)
   NANO 3000
   SC 3250, 3260

   b. (0–9 hours). Up to 9 hours may be taken from this list of optional technical electives.
   ENGM 2160, 2210, 3000, 3100, 3300, 3650, 4500
   MSE 1500, 1500L (if CHEM 1602, 1602L is used for basic science requirement)
   Astronomy (except 1010, 1111, 2130)
   Biological Sciences (except 1111)
   Chemistry (except 1010, 1020, 1601, 1602, 1111)
   Earth and Environmental Sciences (except 1080, 1111, 2150)
   Mathematics 2410 and above
   Neuroscience 2201, 3269, 4961
   Physics above 2000
   Psychology 2100, 3780

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.

A double major in electrical engineering and biomedical engineering is offered as a unitary BME-EE curriculum, which is described in the Biomedical Engineering section of the catalog under its curriculum requirements. It requires a minimum of 129 semester hours.

Undergraduates in electrical engineering, including double majors in electrical engineering, may apply the pass/fail option only to courses taken as open electives subject to the school requirements for pass/fail.

Specimen Curriculum for Electrical Engineering

		Semester hours	
		FALL	SPRING
SOPHOMORE YEAR			
MATH 2300	Multivariable Calculus	3	–
MATH 2400	Differential Equations with Linear Algebra	–	4
PHYS 1602, 1602L	General Physics II and Laboratory	4	–
EECE 2112	Circuits I	3	–
EECE 2123, 2123L	Digital Systems and Laboratory	4	–
EECE 2213, 2213L	Circuits II and Laboratory	–	4
	Liberal Arts Core	3	3
	Technical Electives	–	6
		17	17

JUNIOR YEAR

MATH 2810	Probability and Statistics for Engineering	–	3
ES 2100W	Technical Communications	–	3
EECE 3214	Signals and Systems	3	–
EECE 3233	Electromagnetics	3	–
EECE 3235, 3235L	Electronics I and Laboratory	4	–
	EE Program Electives‡	–	9
	Liberal Arts Core	3	3
	Technical Elective	3	–
		16	18

SENIOR YEAR

EECE 4950	Program and Project Management for EECE	3	–
EECE 4951	Electrical and Computer Engineering Design	–	3
EECE 4959	Senior Engineering Design Seminar	1	–
	EE Program Electives‡	6	3
	Liberal Arts Core	–	3
	Technical Electives	6	3
	Open Elective	–	3
		16	15

‡ As described in Electrical Engineering Degree Requirements subsection 6. At least one design domain expertise (DE) course required prior to EECE 4951.

Minor in Electrical Engineering

The minor in electrical engineering is available to all students except those majoring or minoring in computer engineering. The electrical engineering minor requires a minimum of 16 hours of EECS courses, including the completion of all laboratory corequisites for courses selected for the minor, distributed as follows:

1. Programming: CS 1101 or 1104	3 hours
2. Digital Systems: EECE 2123, 2123L	4 hours
3. Circuits: EECE 2112	3 hours
4. EECE 2213 (and 2213L), or EECE 3214, or EECE 3233, or EECE 3235 (and 3235L)	3–4 hours
5. At least 3 hours of EECE courses numbered 2000 or above (excluding EECE 3860, 3861)	3 hours
Total:	16–17 hours

Course descriptions can be found in the Engineering Courses section of this catalog.

General Engineering

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PROFESSORS OF THE PRACTICE Yiorgos Kostoulas, David A. Owens, Kenneth R. Pence, Christopher J. Rowe
ASSOCIATE PROFESSORS OF THE PRACTICE David A. Berezov, Graham S. Hemingway, Benjamin T. Jordan, Andrew Van Schaack
ASSISTANT PROFESSOR OF THE PRACTICE Courtney L. Johnson
LECTURER Julie S. Birdsong
ADJOINT PROFESSORS OF THE PRACTICE: John A. Bers, J. Caleb Clanton

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, 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.

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 engineering, electrical engineering, computer science, scientific computing, environmental engineering, energy and environmental systems, nanoscience and nanotechnology, 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 Academic Services of the School of Engineering.

Curriculum Requirements

The B.S. in engineering science requires a minimum of 121 hours, distributed as follows:

1. Basic Science (16 hours). CHEM 1601, 1601L plus 12 hours from BSCI 1510, 1510L, 1511, 1511L; CHEM 1602, 1602L; PHYS 1601, 1601L, 1602, 1602L; or MSE 1500, 1500L with two courses in a single discipline.
2. Mathematics (14 hours). MATH 1300, 1301, 2300 and 3 hours to be selected from mathematics courses numbered 2400 and above.
3. Engineering (43 hours).

   a) Engineering Fundamentals (12 hours): CS 1101 or 1103 or 1104; ES 1401, 1402, 1403, 2100W; ENGM 3700.

   b) Engineering Core (12 hours): To be selected from courses in any of the following disciplines: BME, CHBE, CE, CS, EECE, ENVE, MSE, ME, NANO, SC (except BME 1105, 2201, 2860; CS 1000, 1151).

   c) Engineering Electives (15 hours): To be selected from any Engineering School courses (including ES and ENGM), except BME 1105, 2201, 2860; CS 1000, 1151; ES 1115, 2700, 3884; ENGM 2440, 4800.

   d) Senior Capstone (4 hours): ES 4951, ES 4959.
4. Liberal Arts Core (18 hours). To be selected to fulfill the Liberal Arts Core requirements listed under Degree Programs in Engineering.

5. Open Electives (6 hours).
6. Program Concentration (24 hours). In consultation with the academic adviser, each student must identify a meaningful sequence of courses, not counting certain introductory-level courses, that directly contributes to meeting stated career goals. Program concentrations are approved by the academic adviser and the program director in advance and become part of the student's degree audit.

The preparation provided by this 24-hour package, together with a solid foundation in basic engineering courses, provides the engineering science student a strong and useful career base.

No more than 24 credit hours of business-related course work (BUS, ENGM, FNEC, MGRL) may be applied to the ES degree program. Only one business-related minor (BUS, ENGM, FNEC, MGRL, HOD) may count to a student's academic program. Credit for only one of CS 1101 or 1104 may be applied to the ES degree program.

Undergraduates in engineering science may apply the pass/ fail option only to courses taken as liberal arts core or open electives, subject to the school requirements for pass/fail. UNIV courses are eligible for open elective credit only. No more than 6 credit hours of courses numbered 3840 to 3879 in any program may be applied to the ES degree program.

Course descriptions can be found in the Engineering Courses section of this catalog.

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.

The engineering management minor is designed to provide a working knowledge of the fundamentals of management and innovation.

The minor program 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 2210	Technology Strategy
ENGM 2440	Applied Behavioral Science
ENGM 3000	Enterprise Systems Design OR
ENGM 3010	Systems Engineering
ENGM 3700*	Program and Project Management

The student must select one of the following courses:

ENGM 2160	Engineering Economy
ENGM 3100	Accounting and Finance for Engineers
ENGM 3200	Technology Marketing
ENGM 3300	Technology Assessment and Forecasting
ENGM 3350	Organizational Behavior
ENGM 3600	Technology-Based Entrepreneurship
ENGM 3650	Operations and Supply Chain Management
ENGM 4500	Product Development
CE 4300	Reliability and Risk Case Studies
ENVE 4305	Enterprise Risk Management
ES 2900	Engineering and Public Policy

* Students majoring in civil or electrical engineering may substitute CE 4400 or EECE 4950 for ENGM 3700.

Course descriptions can be found in the Engineering Courses section of this catalog.

Materials Science and Engineering

DIRECTOR OF UNDERGRADUATE STUDIES Bridget R. Rogers
DIRECTOR OF GRADUATE STUDIES Greg Walker

Affiliated Faculty

PROFESSORS David E. Cliffel (Chemistry), Peter T. Cummings (Chemical and Biomolecular Engineering), Craig L. Duvall (Biomedical Engineering), Philippe M. Fauchet (Electrical Engineering), Daniel M. Fleetwood (Electrical Engineering), Todd D. Giorgio (Biomedical Engineering), Scott A. Guelcher (Chemical and Biomolecular Engineering), Richard F. Haglund, Jr. (Physics), G. Kane Jennings (Chemical and Biomolecular Engineering), Weng P. Kang (Electrical Engineering), Paul E. Laibinis (Chemical and Biomolecular Engineering), Deyu Li (Mechanical Engineering), Peter N. Pintauro (Chemical and Biomolecular Engineering), Sandra J. Rosenthal (Chemistry), Florence Sanchez (Civil Engineering), Sharon M. Weiss (Electrical Engineering)
ASSOCIATE PROFESSORS Leon Bellan (Mechanical Engineering), Janet E. MacDonald (Chemistry), Bridget R. Rogers (Chemical and Biomolecular Engineering), Jason G. Valentine (Mechanical Engineering), Greg Walker (Mechanical Engineering), Yaqiong Xu (Physics)
RESEARCH ASSOCIATE PROFESSOR Enxia Zhang
ASSISTANT PROFESSORS Kelsey Hatzell (Mechanical Engineering), Piran Kidambi (Chemical and Biomolecular Engineering), Carlos Silvera Batista (Chemical and Biomolecular Engineering)

MATERIALS are now, and have often been, at the heart of the solutions to many of society's problems. Many of the barriers to widespread incorporation of alternate and renewable energy, from higher-capacity, more robust, less expensive batteries for energy storage, to high efficiency/low cost solar devices, involve the need for new materials. Materials will play a large role in the area of health care. New medical devices, drug delivery systems, and synthetic biological tissue are just a few of the health-related applications in need of new materials for their success. In addition, materials challenges are front and center in the ever-evolving areas of electronic devices. Engineers and scientists with knowledge of materials science and engineering concepts are needed to address these and many more materials challenges.

Materials science and engineering is an interdisciplinary program with affiliated faculty from all of the engineering disciplines, as well as faculty from chemistry, and physics. Two undergraduate options involving materials science and engineering are available. Students pursuing a B.S. in engineering science may choose a program concentration in materials science and engineering. This option requires the student to take MSE 1500, 1500L, and 2500, and other materials science and engineering elective courses to complete their 27 hours of engineering program electives. Students pursuing a B.E. in an engineering discipline can earn a minor in materials science and engineering.

Materials Science and Engineering Minor

The minor in materials science and engineering provides the student with an understanding of engineering materials. It complements and adds to the student's major in one of the engineering disciplines, exposing the student to 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 1500, 1500L and MSE 2500. No more than 10 hours below the 2500 level may be applied to the minor.

Program Requirements

MSE 1500, 1500L Materials Science I and Laboratory
MSE 2500 Materials Science II

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

MSE 3860 Undergraduate Research
MSE 3889-3890 Special Topics

BME 2100	Biomechanics
BME 3500	Biomedical Materials: Structure, Property, and Applications
BME 4200	Principles and Applications BioMicroElectro Mechanical Systems (BioMEMS)
BME 4500	Nanobiotechnology
CHBE 4840	Synthesis and Applications of 2D Nanomaterials
CHBE 4850	Semiconductor Materials Processing
CHBE 4860	Molecular Aspects of Chemical Engineering
CHBE 4870	Polymer Science and Engineering
CHBE 4880	Corrosion Science and Engineering
CE 2205	Mechanics of Materials
CE 3205	Structural Design
CE 4200	Advanced Structural Steel Design
CE 4210	Advanced Reinforced Concrete Design
CE 4211	Mechanics of Composite Materials
EECE 4283	Principles and Models of Semiconductor Devices
EECE 4284	Integrated Circuit Technology and Fabrication
ME 3202	Machine Analysis and Design
ME 4251	Modern Manufacturing Processes
ME 4275	Finite Element Analysis
CHEM 3010	Inorganic Chemistry
CHEM 3300	Physical Chemistry: Quantum Mechanics, Spectroscopy, and Kinetics
CHEM 3630	Macromolecular Chemistry: Polymers, Dendrimers, and Surface Modification
PHYS 2250W	Introduction to Quantum Physics and Applications I
PHYS 2290	Electricity, Magnetism, and Electrodynamics
PHYS 3640	Physics of Condensed Matter

Course descriptions can be found in the Engineering Courses section of this catalog.

Mechanical Engineering

CHAIR Nilanjan Sarkar
ASSOCIATE CHAIR Haoxiang Luo
DIRECTOR OF UNDERGRADUATE STUDIES Kenneth D. Frampton
DIRECTOR OF GRADUATE STUDIES Eric J. Barth
DIRECTOR OF GRADUATE RECRUITING Jason G. Valentine
PROFESSORS EMERITI Thomas A. Cruse, George T. Hahn, Donald L. Kinser, Robert L. Lott Jr., Arthur M. Mellor, Carol A. Rubin, Taylor G. Wang, James J. Wert, John W. Williamson
PROFESSORS Douglas E. Adams, Michael Goldfarb, S. Duke Herrell, Deyu Li, Sankaran Mahadevan, Caglar Oskay, Robert W. Pitz, Nilanjan Sarkar, Nabil Simaan Alvin M. Strauss, Robert J. Webster III
PROFESSORS OF THE PRACTICE Amrutur V. Anilkumar, Kenneth D. Frampton
ADJOINT PROFESSORS Pietro Valdastri, Peiyong Wang
ASSOCIATE PROFESSORS Eric J. Barth, Leon M. Bellan, Joshua D. Caldwell, Haoxiang Luo, Fabian Maldonado, Keith L. Obstein, Jason G. Valentine, Greg Walker
ASSOCIATE PROFESSORS OF THE PRACTICE Robert J. Barnett, Thomas J. Withrow
ADJOINT ASSOCIATE PROFESSORS Cary Pint, Joseph A. Wehrmeyer
ASSISTANT PROFESSORS David J. Braun, Kelsey B. Hatzell, Justus C. Ndukaife, Karl E. Zelik
RESEARCH ASSISTANT PROFESSORS Neal P. Dillon, Kevin C. Galloway, Richard J. Hendrick, Zheng Li, Jason Mitchell, Scott J. Webster
ADJOINT ASSISTANT PROFESSOR Carl A. Hall

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. Honors candidates choose their technical elective courses with the advice and consent of an honors adviser. Each candidate is expected to take 3 hours of ME 3860 in a single semester and at least 6 hours of graduate courses numbered 5000 or higher, including one course numbered 8000 or higher. A formal written honors thesis on the candidate's research must be approved by the honors adviser and the department chair. Honors candidates shall meet all Engineering School requirements in the nontechnical areas. The diploma designation is Honors in Mechanical Engineering.

Facilities. Undergraduate instructional laboratories are equipped for studies in heat and power, refrigeration and air-conditioning, fluid flow, heat transfer, design, controls, robotics, instrumentation, and biomechanics. Specialized facilities for robotic surgery, rehabilitation robotics, energy storage, medical microfluidics, thermal transport, combustion characterization, and photonics are used for both faculty-led research and instruction. The department also maintains various maker spaces including machine shops and design studios 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: MATH 1300, 1301, 2300, 2420. Required elective: one from courses numbered 2410 and above, except 3000.
2. Basic Science (16 hours). Required courses: CHEM 1601, 1601L; MSE 1500, 1500L (or CHEM 1602, 1602L); PHYS 1601, 1601L, 1602, 1602L.
3. Engineering Science (25 hours). Required courses: ES 1401, 1402, 1403; CE 2200, 2205; CS 1101 or 1103 or 1104;
   EECE 2112; ME 2190, 2220, 3224; MSE 2205.
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 2160, 2171, 3202, 3204, 3234, 3248, 4213, 4950, 4951, and 4959
7. Technical electives (9 hours). To be selected from the following approved courses. Courses selected from the College of Arts and Science must be designated a Mathematics and Natural Sciences (MNS) course in the AXLE curriculum.
   a) Engineering courses except BME 2201, 2860; CS 1000, 1151; ENGM 2440, 3350, 4800; ES 2700, 2900, 3884.
   b) Mathematics courses numbered 2420 or higher except MATH 3000
   c) Chemistry courses numbered 2000 or higher
   d) Physics courses numbered 2000 or higher
   e) Astronomy courses
   f) Biological Science courses
   g) Earth and Environmental Science courses
   h) Neuroscience courses

At least 3 hours must be numbered 2000 or above.

8. Professional (ME) depth (a minimum of 9 hours). Each student must choose at least 9 hours of ME elective courses. No more than 6 hours of 3850 and 3860 combined can be credited toward ME depth electives.

No one-credit-hour ME course except 3841 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 on a graded basis.

Undergraduates in mechanical engineering may apply the pass/fail option only to non-departmental courses taken as open electives, technical electives, or part of the liberal arts core, subject to the school requirements for pass/fail.

Specimen Curriculum for Mechanical Engineering

		Semester hours	
		FALL	SPRING
SOPHOMORE YEAR			
ME 2160	Introduction to Mechanical Engineering Design	3	–
MATH 2300	Multivariable Calculus	3	–
MATH 2420	Methods of Ordinary Differential Equations	–	3
PHYS 1602, 1602L	General Physics II and Laboratory	4	–
CE 2200	Statics	3	–
ME 2171	Instrumentation Laboratory	–	2
ME 2190	Dynamics	–	3
ME 2220	Thermodynamics	–	3
EECE 2112	Circuits I	–	3
	Liberal Arts Core	3	3
		16	17

		Semester hours	
JUNIOR YEAR		FALL	SPRING
ME 3202	Machine Analysis and Design	3	–
ME 3204	Mechatronics	–	3
ME 3224	Fluid Mechanics	3	–
ME 3234	System Dynamics	4	–
ME 3248	Heat Transfer	–	3
CE 2205	Mechanics of Materials	3	–
MSE 2205	Strength and Structure of Engineering Materials	1	–
	Mechanical Engineering Elective	–	3
	Open Elective	–	3
	Liberal Arts Core	3	–
	Mathematics Elective	–	3
		17	15
SENIOR YEAR			
ME 4213	Energetics Laboratory	2	–
ME 4950	Design Synthesis	2	–
ME 4951	Engineering Design Projects	–	3
ME 4959	Senior Engineering Design Seminar	1	–
	Mechanical Engineering Elective	3	3
	Liberal Arts Core	3	3
	Technical Elective	6	3
	Open Elective	–	3
		17	15

Course descriptions can be found in the Engineering Courses section of this catalog.

Nanoscience and Nanotechnology

DIRECTORS Paul E. Laibinis, Sandra J. Rosenthal

Affiliated Faculty

PROFESSORS David E. Cliffel (Chemistry), Peter T. Cummings (Chemical and Biomolecular Engineering), Craig L. Duvall (Biomedical Engineering), Philippe M. Fauchet (Electrical Engineering), Daniel M. Fleetwood (Electrical Engineering), Todd D. Giorgio (Biomedical Engineering), Scott A. Guelcher (Chemical and Biomolecular Engineering), Richard F. Haglund, Jr. (Physics), Timothy P. Hanusa (Chemistry), Frederick R. Haselton (Biomedical Engineering), G. Kane Jennings (Chemical and Biomolecular Engineering), Michael R. King (Biomedical Engineering), Paul E. Laibinis (Chemical and Biomolecular Engineering), Deyu Li (Mechanical Engineering), Clare M. McCabe (Chemical and Biomolecular Engineering), Sokrates T. Pantelides (Physics), Peter N. Pintauro (Chemical and Biomolecular Engineering), Cynthia A. Reinhart-King (Biomedical Engineering), Sandra J. Rosenthal (Chemistry), Florence Sanchez (Civil Engineering), Ronald D. Schrimpf (Electrical Engineering), Norman H. Tolk (Physics), Kalman Varga (Physics), Sharon M. Weiss (Electrical Engineering), John P. Wikswo, Jr. (Physics), David W. Wright (Chemistry)

ASSOCIATE PROFESSORS Leon Bellan (Mechanical Engineering), Joshua D. Caldwell (Mechanical Engineering), Janet E. MacDonald (Chemistry), Bridget R. Rogers (Chemical and Biomolecular Engineering), Jason G. Valentine (Mechanical Engineering), Greg Walker (Mechanical Engineering), Yaqiong Xu (Physics)

ASSISTANT PROFESSORS Kelsey B. Hatzell (Mechanical Engineering), Piran Kidambi (Chemical and Biomolecular Engineering), Justus C. Ndukaife (Electrical Engineering), Carlos A. Silvera Batista (Chemical and Biomolecular Engineering), John T. Wilson (Chemical and Biomolecular Engineering)

RESEARCH ASSOCIATE PROFESSOR James R. McBride (Chemistry)

RESEARCH ASSISTANT PROFESSORS Dmitry Koktysh (Chemistry), Alice Leach (Materials Science)

FACULTY in the School of Engineering and the College of Arts and Science offer an interdisciplinary minor in nanoscience and nanotechnology. The minor is administered by the School of Engineering.

Nanoscience and nanotechnology are based on the ability to synthesize, organize, characterize, and manipulate matter systematically at dimensions of ~1 to 100 nm, creating uniquely functional materials that differ in properties from those prepared by traditional approaches. At these length scales, materials can take on new properties that can be exploited in a wide range of applications such as for solar energy conversion, ultra-sensitive sensing, and new types of vaccines. These activities require the integration of expertise from various areas of science and engineering, often relying on methods of synthesis, fabrication, and characterization that are beyond those encountered in an individual course of study.

Students who minor in nanoscience and nanotechnology learn the principles and methods used in this rapidly growing field. Its core originates in the physical sciences by providing key approaches for describing the behavior of matter on the nanoscale. Synthetic approaches are used to manipulate matter systematically, for creating uniquely functional nanomaterials that can be inorganic, organic, biological, or a hybrid of these. With a third component of characterization, a process for designing systems to have particular properties as a result of their composition and nanoscale arrangement emerges. Students are introduced to these areas through foundational and elective courses for the minor that are specified below, the latter of which can be selected to fulfill the degree requirements for their major.

The minor in nanoscience and nanotechnology is supported by the Vanderbilt Institute of Nanoscale Science and Engineering (VINSE) that brings together faculty from the College of Arts and Science, the School of Engineering, and the Medical Center. A specialized laboratory facility maintained by VINSE provides students in the minor with capstone experiences that allow them to prepare and characterize a variety of nanostructured systems using in-house state-of-the-art instrumentation. This hands-on laboratory component enhances the attractiveness of students to both employers and graduate schools.

Nanoscience and Nanotechnology Minor

The minor in nanoscience and nanotechnology requires a total of 15 credit hours, distributed as follows:

1. Nano Core (9 hours). NANO 3000, PHYS 2660, and either CHEM 2610 or CHBE 4840.
2. Elective courses. 6 hours selected from the following list of approved subjects.
   BME 4200 Principles and Applications of BioMicro ElectroMechanical Systems (BioMEMS)
   BME 4500 Nanobiotechnology
   CHBE 4830 Molecular Simulation
   CHBE 4840 Synthesis and Applications of 2D Nanomaterials
   CHBE 4850 Semiconductor Materials Processing

CHBE 4860	Molecular Aspects of Chemical Engineering
CHBE 4870	Polymer Science and Engineering
CHBE 4880	Corrosion Science and Engineering
CHEM 2610	Introduction to Nanochemistry
CHEM 3300	Physical Chemistry: Quantum Mechanics, Spectroscopy, and Kinetics
CHEM 3630	Macromolecular Chemistry: Polymers, Dendrimers, and Surface Modification
CHEM 5610	Chemistry of Inorganic Materials
EECE 4283	Principles and Models of Semiconductor Devices
EECE 4284	Integrated Circuit Technology and Fabrication
EECE 4288	Optoelectronics
EECE 4385	VLSI Design
EECE 6306	Solid-State Effects and Devices I
IMS 5320	Nanoscale Science and Engineering
ME 8320	Statistical Thermodynamics
ME 8323	Micro/Nanoelectromechanical Systems
ME 8365	Micro/Nanoscale Energy Transport
MSE 6310	Atomic Arrangements in Solids
PHYS 2255	Modern Physics and the Quantum World
PHYS 3640	Physics of Condensed Matter

Courses taken to satisfy relevant degree requirements for majors in the College of Arts and Science and the School of Engineering may also be counted toward fulfilling the minor.

Scientific Computing

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

Affiliated Faculty

PROFESSORS Ralf Bennartz (Earth and Environmental Sciences), Gautam Biswas (Electrical Engineering and Computer Science), Robert E. Bodenheimer Jr. (Computer Science), Mario Crucini (Economics), Peter T. Cummings (Chemical and Biomolecular Engineering), Mark N. Ellingham (Mathematics), David Furbish (Earth and Environmental Sciences), Guilherme Gualda (Earth and Environmental Sciences), Kelly Holley-Bockelman (Astronomy), Shane Hutson (Physics), Bennett Landman (Electrical Engineering), Gordon D. Logan (Psychology), Terry P. Lybrand (Chemistry and Pharmacology), Clare M. McCabe (Chemical and Biomolecular Engineering), Michael I. Miga (Biomedical Engineering), Mark Neamtu (Mathematics), Thomas J. Palmeri (Psychology and Neuroscience), Antonis Rokas (Biological Sciences), Jeffrey D. Schall (Psychology and Neuroscience), Larry Schumaker (Mathematics), Paul Sheldon (Physics), Kalman Varga (Physics), David A. Weintraub (Astronomy)

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

ASSOCIATE PROFESSORS Andreas A. Berlind (Astronomy), Tony Capra (Biological Sciences and Biomedical Informatics), Haoxiang Luo (Mechanical Engineering), Sean Polyn (Psychology and Neuroscience), Jennifer Trueblood (Psychology), Greg Walker (Mechanical Engineering), Steve Wernke (Anthropology)

ASSISTANT PROFESSORS William Holmes (Physics and Astronomy), Carlos Lopez (Cancer Biology)

ADJUNCT ASSISTANT PROFESSORS William R. French (Chemical and Biomolecular Engineering), Davide Vanzo (Chemistry)

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. Students who complete this minor will have a toolkit that includes programming skills useful for simulating physical, biological, and social dynamics, as well as an understanding of how to take advantage of modern software tools to extract meaningful information from small and large datasets.

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 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.

Scientific Computing Minor

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

1. CS 1101 or 1103 or 1104. (3 hours)
2. CS 2204 (CS 2201 may be substituted for 2204 with the approval of a program director). (3 hours)
3. Elective courses (9 hours). Three hours must come from course list A (Mathematical, Quantitative, and Data Science Methods); three hours must come from course list B (Computational, Simulation, and Modeling Methods); and three hours can come from either course list A or B, or from independent study (SC 3850/3851) with a faculty member affiliated with the SC minor.

A. Mathematical, Quantitative, and Data Science Methods

SC 3250	Scientific Computing Toolbox
ANTH 3261	Introduction to Geographic Information Systems and Remote Sensing
BMIF 6310	Foundations of Bioinformatics
BMIF 7380	Data Privacy in Biomedicine
BSCI 3272	Genome Science
BME 3200	Analysis of Biomedical Data
CE 4320	Data Analytics for Engineers
ECON 3032	Applied Econometrics
ECON 3035	Econometric Methods
ECON 3750	Econometrics for Big Data
EECE 6358	Quantitative Medical Image Analysis
HOD 3200	Introduction to Data Science

MATH 3620	Introduction to Numerical Mathematics
MATH 3670	Mathematical Data Science
MATH 4600	Numerical Analysis
MATH 4620	Linear Optimization
MATH 4630	Nonlinear Optimization

B. Computational, Simulation, and Modeling Methods

SC 3260	High Performance Computing
ASTR 3600	Stellar Astrophysics
ASTR 3700	Galactic Astrophysics
ASTR 3800	Structure Formation in the Universe
BME 4310	Modeling Living Systems for Therapeutic Bioengineering
BME 7310	Advanced Computational Modeling and Analysis in Biomedical Engineering
BME 7410	Quantitative Methods in Biomedical Engineering
CHBE 4830	Molecular Simulation
CHEM 5410	Molecular Modeling Methods
CHEM 5420	Computational Structural Biochemistry
CS 3274	Modeling and Simulation
EES 4760	Agent and Individual Based Computational Modeling
MATH 3630	Mathematical Modeling in Biology
MATH 3660	Mathematical Modeling in Economics
ME 4263	Computational Fluid Dynamics and Multiphysics Modeling
ME 4275	Finite Element Analysis
NSC 3270	Computational Neuroscience
PHYS 3200	Statistical Physics
PHYS 3790	Computational Physics
PSY 4218	Computational Cognitive Modeling
PSY 4219	Scientific Computing for Psychological and Brain Sciences
PSY 4775	Models of Human Memory

Engineering Courses

BME 1015. Innovations in Biomedical Engineering. Review of areas within the field of BME. Topics include current research and industry trends in imaging, regenerative medicine, biophotonics, medical devices, technology and entrepreneurship, and low resource engineering. Open only to first-year and transfer students. Students in the School of Engineering receive open elective credit for BME 1015. SPRING. [1]

BME 2001. Systems Physiology I. Quantitative physiology from the engineering point of view. Descriptive physiology of several organ systems (nervous, musculoskeletal, cardiovascular, blood). Mathematical modeling and computer simulation of organ systems and physiologic control mechanisms. No credit for students who have earned credit for BME 3100. Prerequisite: CS 1101 or 1103 or 1104. Corequisite: BSCI 1510, PHYS 1602. [3]

BME 2002. Systems Physiology II. Quantitative physiology from the engineering point of view. Descriptive physiology of several organ systems (immune, endocrine, respiratory, renal, gastrointestinal, reproductive). Mathematical modeling and computer simulation of organ systems and physiologic control mechanisms. No credit for students who have earned credit for BME 3101. Prerequisite: CS 1101 or 1103 or 1104. Corequisite: BSCI 1510. [3]

BME 2100. Biomechanics. Structure and mechanics of the musculoskeletal system and 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 2100 or CE 2200. Prerequisite: PHYS 1601, MATH 1301, CS 1101 or 1103 or 1104. [3]

BME 2200. 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 1602. SPRING. [3]

BME 2201. 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 standing. FALL. [3] (Only available for open elective credit for biomedical engineering majors.) (Not currently offered)

BME 2210. Biomaterial Manipulation. Design and characterization of biomaterials. Assessment of tissue engineering scaffolds and nanoparticles. Manipulation of cell growth and expression. Application of mechanics and materials principles to medical and consumer products. Laboratory exercises in tissue culture, microscopy, mechanical testing, biochemical assays, and computer modeling. Prerequisite: BME 2100, BSCI 1510/1510L. Corequisite: BME 2200. SPRING. [3]

BME 2400. Quantitative Methods I: Statistical Analysis. Application of modern computing methods to the parametric and nonparametric statistical analysis of biomedical data.

Probability, sampling, estimation, analysis of variance, single and multivariable regression, and the principles of hypothesis testing, experimental design and clinical trials are emphasized. No credit for students who have earned credit for BME 3200. Prerequisite: MATH 2300. Corequisite: CS 1101 or 1103 or 1104. [3]

BME 2860. Introduction to Undergraduate Research. Introduction to Undergraduate Research. Introduction to 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. Students in the School of Engineering may only receive open elective credit for BME 2860. Prerequisites: Consent of course director (see BME undergraduate website for registration details). FALL, SPRING. [1-3]

BME 2900W. Biomedical Engineering Lab I. Introductory laboratory with guided reports. Experiment topics may cover systems physiology, biomechanics, and biomaterials. Emphasis on methods, instrumentation, and equipment used in biomedical engineering. One three-hour laboratory per week. No credit for students who have earned credit for BME 4900W. Prerequisite: CS 1101 or 1103 or 1104. Corequisite: BME 2001. [1]

BME 3000. Physiological Transport Phenomena. Mechanics of fluids, heat transfer, and mass transfer in living systems. Basic theories of transport phenomena, applications to mammalian and cellular physiology and the design of medical devices. Prerequisite: BME 2100; MATH 2400 or 2420. [3]

BME 3100. Systems Physiology. Quantitative physiology from the engineering point of view. Descriptive physiology of several organ systems (nervous, musculoskeletal, cardiovascular, blood). Mathematical modeling and computer simulation of organ systems and physiologic control mechanisms. Prerequisite: CS 1101 or 1103 or 1104. Corequisite: BSCI 1510. FALL. [3]

BME 3101. Systems Physiology. Quantitative physiology from the engineering point of view. Descriptive physiology of several organ systems (immune, endocrine, respiratory, renal, gastrointestinal, reproductive). Mathematical modeling and computer simulation of organ systems and physiologic control mechanisms. Prerequisite: CS 1101 or 1103 or 1104. Corequisite: BSCI 1510. SPRING. [3]

BME 3110. 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 2100, BME 3100. SPRING. [3]

BME 3200. 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 2300. SPRING. [3]

BME 3300. Biomedical Instrumentation. Methods 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 2213 and 2213L. FALL, SPRING. [4]

BME 3301. Biomedical Instrumentation I. Electronic circuits for measuring and processing physiological signals, analog front-end design, analog-to-digital conversion and digital signal processing. Physics and applications of clinically relevant biosensors. Laboratory exercises focus on construction, verification, and validation of biomedical instruments. Three lectures and one three-hour laboratory. No credit for students who have earned credit for BME 3300. Prerequisite: EECE 2112. Corequisite: BME 3400. [4]

BME 3302. Biomedical Instrumentation II. Systems-level approach to the design of devices that monitor clinically-relevant physiological functions and variables, driven by the needs of specific pathophysiological conditions. Laboratory exercises stress instrumentation design and integration of multiple modalities into an instrumentation platform. Three lectures and one three-hour laboratory. No credit for students who have earned credit for BME 3300. Prerequisite: BME 3301. [4]

BME 3400. Quantitative Methods II: Signals and Numerical Analysis. Quantitative analysis and computational methods for biomedical engineering applications. Signal and image processing, numerical analysis, and linear and nonlinear models. No credit for students who have earned credit for BME 3300. Prerequisite: CS 1101 or 1103 or 1104; MATH 2400. Corequisite: BME 2400. [3]

BME 3500. Biomedical Materials: Structure-Property Relationships 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. No credit for students who have earned credit for BME 2200. Prerequisite: CHEM 1602, BME 2100. [3]

BME 3600. 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. Corequisite: BME 3200 or MATH 2810. SPRING. [3]

BME 3830. 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 3860. 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. The class meets one hour per week to discuss research design, responsible conduct of research, laboratory documentation, literature review, and scientific writing. Prerequisite: Junior standing, consent of course director (see BME undergraduate website for registration details). [2-3; maximum of 6 hours total for all semesters of BME 3860 and 3861]

BME 3861. Undergraduate Research. A continuation of the research in 3860 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 3860 and 3861.]

BME 3890. Special Topics. [3]

BME 3891. Special Topics. [3]

BME 3892. Special Topics. [3]

BME 3893. Special Topics. [3]

BME 3900W. Biomedical Engineering Lab II. Intermediate laboratory with oral and written reports. Experiment topics may include thermodynamics, biological transport, signal analysis, biological control, and biological imaging. Emphasis on data analysis and communication. One three-hour laboratory per week. No credit for students who have earned credit for BME 4900W. Prerequisite: BME 2900W. Corequisite: BME 2001, 2002. [1]

BME 4000. 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 2400 or 2420, BSCI 1510. FALL. [3]

BME 4100. Lasers in Surgery and Medicine. Fundamentals of lasers, light-tissue interaction, problem-based design of optical instrumentation. Applications in laser surgery, disease detection, and surgical guidance. Includes hands-on experiences. Prerequisite: PHYS 1602. FALL. [3]

BME 4100L. 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 4100. FALL. [1]

BME 4200. 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 4200L. 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 values. Corequisite: BME 4200. FALL. [1]

BME 4300. 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 2213, BME 3000. Corequisite: BME 2100, BME 3300. SPRING. [3]

BME 4310. Modeling Living Systems for Therapeutic Bioengineering. Computer modeling and simulation in therapeutic bioengineering processes. Building computer models and using modern modeling software tools. 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 2400 or 2420; CS 1101 or 1103 or 1104; BME 2100. SPRING [3]

BME 4400. 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 1602, MATH 2400. SPRING. [3]

BME 4410. 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: PHYS 1602, MATH 2400. SPRING. [3]

BME 4420. Quantitative and Functional Imaging. 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: CS 1101 or 1103 or 1104; PHYS 1602; MATH 2400. FALL [3]

BME 4500. 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: BSCI 1510; BME 3000 or CHBE 3300 or ME 3224. SPRING. [3]

BME 4500L. 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 4500. SPRING. [1]

BME 4600. 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 1510, CHEM 1602. FALL. [3]

BME 4900W. Biomedical Engineering Laboratory. Laboratory experiments in biomechanics, thermodynamics, biological transport, signal analysis, biological control, and biological imaging. Emphasis is on current methods, instrumentation, and equipment used in biomedical engineering; on oral presentation of results; and on the writing of comprehensive reports. No credit for BME 4900W and BME 2900W, 3900W, or 4901W. One lecture and one three-hour laboratory per week. Prerequisite: BME 3100. Corequisite: BME 3000. [3]

BME 4901W. Biomedical Engineering Lab III. Advanced laboratory with comprehensive written reports. Students design experiments building on laboratory exercises conducted in BME 2900W and 3900W. Emphasis on experimental design, use of controls, and interpretation of data. One three-hour laboratory per week. No credit for students who have earned credit for BME 4900W. Prerequisite: BME 2400, 3900W. [1] (Not offered until 2021-2022.)

BME 4950. 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 3300. Prerequisite: BME 3100. [2]

BME 4951. 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 4950. [3]

BME 4959. 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: BME 4950. FALL. [1]

BME 5100. Lasers in Surgery and Medicine. (Also listed as BME 4100) Fundamentals of lasers, light-tissue interaction, problem-based design of optical instrumentation. Applications in laser surgery, disease detection, and surgical guidance. Includes hands-on experiences. No credit for students who have earned credit for 4100. FALL. [3]

BME 5110. Neuromuscular Mechanics and Physiology. (Also listed as BME 3110) 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. No credit for students who have earned credit for 3110. SPRING. [3]

BME 5130. Systems Physiology. (Also listed as BME 3100) Quantitative physiology from the engineering point of view. Descriptive physiology of several organ systems (nervous, musculoskeletal, cardiovascular, gastrointestinal). Mathematical modeling and computer simulation of organ systems and physiologic control mechanisms. No credit for students who have earned credit for 3100. FALL. [3]

BME 5131. Systems Physiology. (Also listed as BME 3101) Quantitative physiology from the engineering point of view. Descriptive physiology of several organ systems (blood, immune, endocrine, respiratory, renal, reproductive). Mathematical modeling and computer simulation of organ systems and physiologic control mechanisms. No credit for students who have earned credit for 3101. SPRING. [3]

BME 5200. Principles and Applications of BioMicroElectroMechanical Systems (BioMEMS). (Also listed as BME 4200) 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. No credit for students who have earned credit for 4200. FALL. [3]

BME 5210. Biomaterial Manipulation. (Also listed as BME 2210) Design and characterization of biomaterials. Assessment of tissue engineering scaffolds and nanoparticles. Manipulation of cell growth and expression. Application of mechanics and materials principles to medical and consumer products. Laboratory exercises in tissue culture, microscopy, mechanical testing, biochemical assays, and computer modeling. No credit for students who have earned credit for 3210. Corequisite: BME 2200. SPRING. [3]

BME 5300. Biomedical Instrumentation. (Also listed as BME 3300) Methods 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. No credit for students who have earned credit for 3300. FALL, SPRING. [4]

BME 5400. Foundations of Medical Imaging. (Also listed as BME 4400) 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. No credit for students who have earned credit for 4400. SPRING. [3]

BME 5410. Biological Basis of Imaging. (Also listed as BME 4410) 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. No credit for students who have earned credit for 4410. SPRING. [3].

BME 5500. Nanobiotechnology. (Also listed as BME 4500) 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. No credit for students who have earned credit for 4500. SPRING. [3]

BME 5600. Signal Measurement and Analysis. (Also listed as BME 3600) 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. No credit for students who have earned credit for 3600. SPRING. [3]

BME 5950. Design of Biomedical Engineering Devices and Systems I. (Also listed as BME 4950) 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 5300. No credit for students who have earned credit for 4950. [2]

BME 5951. Design of Biomedical Engineering Devices and Systems II. (Also listed as BME 4951) 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. No credit for students who have earned credit for 4951. [3]

BME 6110. 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. FALL. [3].

BME 6301. Engineering in Surgery and Intervention: Provocative Questions. Explores engineering and clinical aspects of treating disease or disorders by clinically-driven provocative questions. Surgical/Interventional mechanics, locoregional therapies such as convection-enhanced delivery, neuromodulation, and ablation. Image-guided therapies, and role of discovery and design in context of treatment. SPRING. [3].

BME 6302. Engineering in Surgery and Intervention: Clinical Interactions. Literature review coupled with clinical immersion experience. Literature review centers on clinical translation of engineering research in surgical/interventional applications. Clinical immersion involves observing surgical/interventional procedures and attending clinical conferences. Prerequisite: Permission of Instructor. FALL. [3].

BME 7110. 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 7120. 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 7310. 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 7410. Quantitative Methods in Biomedical Engineering. Mathematics, quantitative analysis, and computational methods for biomedical engineering applications. Topics include applied probability and statistics, signal analysis and experiment design, linear systems, Fourier transforms, and numerical modeling and analysis. FALL. [3]

BME 7413. 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 2100, BME 3000 or equivalent. [3]

BME 7419. 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 7420. 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. SPRING. [3]

BME 7425. 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 2250. SPRING. [3]

BME 7430. 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. Prerequisites: BME 4400 or PHYS 2805. SPRING. (Offered alternate years) [3]

BME 7440. 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. Prerequisites: BME 4400 or PHYS 2805. FALL. (Offered alternate years) [3]

BME 7450. Advanced Quantitative and Functional Imaging. 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, including measurement of tissue volume, microstructure, organ perfusion, blood flow, brain function, and receptor density. Prerequisite: working knowledge of MATLAB. FALL. [3]

BME 7473. 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 4950 or equivalent. SPRING. [3]

BME 7500. Independent Study in Biomedical Engineering. Study of advanced biomedical engineering topics not regularly offered in the curriculum. Consent of instructor is required. FALL, SPRING. [3]

BME 7899. Master of Engineering Project.

BME 7999. Master's Thesis Research.

BME 8900. Special Topics. [1-3]

BME 8901. Special Topics. [1-3]

BME 8902. Special Topics. [1-3]

BME 8903. Special Topics. [1-3]

BME 8991. Biomedical Research Seminar. [1]

BME 8992. Biomedical Research Seminar. [1]

BME 8993. Biomedical Research Seminar. [1]

BME 8994. Biomedical Research Seminar. [1]

BME 8999. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

BME 9999. Ph.D. Dissertation Research. [0-12]

CHBE 2100. Chemical Process Principles. A foundation for advanced work in chemical engineering. Process problems of a chemical and physico-chemical nature. Emphasis on stoichiometry, material balances, and energy balances required for design computation. Prerequisites: CHEM 1602, MATH 1301. FALL, SPRING. [3]

CHBE 2150. Molecular and Cell Biology for Engineers. Basic molecular and cellular biology principles and concepts. Application of engineering principles to further the understanding of biological systems. Protein structure and function, transcription, translation, post-translational processing, cellular organization, molecular transport and trafficking, and cellular models. Not open to students who have earned credit for BSCI 1100 or 1510 without permission. Total credit for this course and BSCI 1100 or BSCI 1510 will not exceed 3 credit hours. Credit reduced from second course taken (or from test or transfer credit as appropriate). Prerequisite: Chem 1602. FALL. [3]

CHBE 2200. 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. Prerequisite: MATH 2300. SPRING. [3]

CHBE 2250. 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. Prerequisite: CHBE 2100. Corequisite: CHBE 2200; MATH 2420; CS 1101 or 1103 or 1104. SPRING. [3]

CHBE 2900W. Technical Communications for Chemical Engineers. Preparation for academic and professional communication tasks. Principles of effective communication, information design, and audience awareness. Development of written reports, oral presentations, posters, visuals, emails, letters, and memos for communicating technical details. Corequisite: CHBE 2200. SPRING [1]

CHBE 3200. 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 2100, CHBE 2200, and either CHBE 2250 or BME 2100. FALL. [3]

CHBE 3250. 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: CHEM 2211 or 2221; CHBE 3200. SPRING. [3]

CHBE 3300. 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: MATH 2420. FALL. [3]

CHBE 3350. 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 3300. SPRING. [3]

CHBE 3600. 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: CHBE 2250 and MATH 2400 or MATH 2420. FALL. [3]

CHBE 3860. Undergraduate Research. Opportunities for individual students to do research under the guidance of a faculty member. Requires faculty sponsorship of the project. [1-3 each semester]

CHBE 3861. Undergraduate Research. Opportunities for individual students to do research under the guidance of a faculty member. Requires faculty sponsorship of the project. [1-3 each semester]

CHBE 3890. Special Topics. [Variable credit: 0-3 each semester]

CHBE 3900W. Chemical Engineering Laboratory I. Laboratory experiments in momentum, energy and mass transport, focusing on chemical engineering fundamentals, instrumentation, and unit operations. Statistical treatment of data, error analysis, and experimental design. Written reports, oral presentations, and laboratory safety are emphasized. One 5-hour laboratory per week. Prerequisite: CHBE 2100, CHBE 2200, CHBE 2900W, CHBE 3300, and either CHBE 2250 or BME 2100. Corequisite: CHBE 3350. SPRING. [3]

CHBE 4500. 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 1510 or CHBE 2150; CHBE 3250, CHBE 3300. [3]

CHBE 4800. The Molecular and Cellular Mechanome. Applications of molecular and cellular biophysics and mechanics over various lengths, energy and timescales to describe biological phenomena through an 'omics' systems level perspective to molecular motors, cell machinery, mechanotransduction, cell migration, cell division, and nonequilibrium receptor ligand interactions. Physical and engineering based descriptions of molecular and cellular machinery incorporating biophysics and statistical and continuum mechanics perspectives. Modern and historical results, instrumentation, and measurement techniques. Prerequisite: Junior standing. FALL. [3]

CHBE 4805. Biomolecular Engineering and Design. Approaches for interrogating and controlling biological function on a molecular and cellular level. Applications to biotechnology fields such as diagnostics, therapeutics, and regenerative medicine. Focus areas include concepts of molecular recognition, extracellular and intracellular signal transduction, protein engineering, genome engineering, cellular engineering, and tissue engineering. Prerequisites: ChBE 2150 or BSCI 1510. [3]

CHBE 4810. Metabolic Engineering. Analysis and synthesis of metabolic networks using principles of thermodynamics, kinetics, and transport phenomena. Computational approaches for predicting metabolic phenotypes. Experimental techniques to measure and manipulate key metabolic variables including pathway fluxes, protein/gene expression, enzyme regulation, and intracellular metabolite concentrations. Prerequisite: BSCI 1510 or CHBE 2150; junior standing. [3]

CHBE 4820. Immunoengineering. Approaches and technologies for manipulating and studying the immune system. Topics include fundamentals of immunology, immunology tools and methods, vaccines and immunotherapies, drug delivery principles, and materials engineering for immunomodulation. Prerequisite: ChBE 2150 or BSCI 1510. [3]

CHBE 4830. Molecular Simulation. Modern tools of statistical mechanics, such as Monte Carlo and molecular dynamics simulation, and variations. Methods, capabilities, and limitations of molecular simulation and applications to simple and complex fluids relevant to the chemical and related processing industries. Prerequisite: CHBE 3200, CHEM 3300. [3]

CHBE 4840. Synthesis and Applications of 2D Nanomaterials. Structure-property relationships and applications of atomically thin, two-dimensional materials and 2D/layered systems. Preparation by mechanical exfoliation, solution processing, and bottom-up synthesis. Nucleation/growth of 2D materials via gas/solid, liquid/solid, and catalytic/phase transformation reactions. Kinetic vs. thermodynamic processing, stabilizing meta-stable intermediates, interface engineering, and scale-up. Prerequisite: CHEM 1602 or MSE 1500; junior standing. [3]

CHBE 4850. Semiconductor Materials Processing. Materials processing unit operations of silicon device manufacturing. 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. Lectures alternate with one two-hour laboratory on a weekly basis. FALL. [3]

CHBE 4860. 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 2211 or 2221; CHBE 2200. [3]

CHBE 4870. 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 2200, a basic understanding of organic and physical chemistry. [3]

CHBE 4875. Colloid Science and Engineering. Fundamental concepts (surface forces, self-assembly, electrokinetics) and experimental techniques (microscopy, scattering, measurement of charge) in colloid science. Applications to personal care products, energy devices, and drug delivery. Prerequisite: ChBE 2200, ChBE 3300. [3]

CHBE 4880. Corrosion Science and Engineering. Aqueous-phase metal and alloy corrosion phenomena. Fundamental chemistry and electrochemistry theories, as applied to corroding systems. Specific forms of corrosion including pitting, crevice corrosion, and galvanic corrosion. Methods for corrosion control based on electrochemical fundamentals. Prerequisite: CHBE 3300. SPRING. [3]

CHBE 4900W. Chemical Engineering Laboratory II. Laboratory experiments in unit operations covering reactions and separations. Interpretation of data for equipment and process design. Methods of hazard analysis, their application to lab-scale unit operations, and the scale-up of chemical processes from laboratory data. Written reports and oral presentations are emphasized. One 5-hour laboratory per week. Prerequisite: CHBE 3900W or BME 3300 or CHEM 3315. Corequisite: ChBE 4950W. FALL. [3]

CHBE 4950W. Chemical Engineering Process and Product Design. A systematic approach to design and safety practices for chemical process operations leading to the identification of a team-based capstone design project. Design, economic evaluation of alternatives, ethics, and cost and safety analysis of chemical, biological, and petroleum process and products. Systems-based process integration design methodologies. Steady-state simulation using chemical engineering design software. Three lecture hours and one two-hour laboratory each week. Prerequisite: CHBE 3200, CHBE 3250, CHBE 3350. Corequisite: ChBE 4900W, ChBE 4959. FALL. [4]

CHBE 4951W. Chemical Engineering Design Projects. Continuation of a team-based design project from ChBE 4950W. Evaluations through periodic oral and written presentations, a final written report, and a poster report. Emphasis on design tools and methodologies, economic assessment, and hazard analysis leading to a recommended chemical product or process design that meets key safety and economic criteria. Prerequisite: CHBE 4950W. SPRING. [3]

CHBE 4959. Professional Practice of Safety in Chemical Engineering Design. Elements of professional engineering practice. Hazard analysis methodologies applied to chemical products and processes are emphasized and applied to lab-scale unit operations. Professional practice of the design of safe chemical products and processes is examined through case studies. Corequisite: ChBE 4950W. FALL. [1]

CHBE 5200. Phase Equilibria and Stage-Based Separations. (Also listed as CHBE 3200) 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. No credit for students who have earned credit for 3200. FALL. [3]

CHBE 5250. Chemical Reaction Engineering. (Also listed as CHBE 3250) 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. No credit for students who have earned credit for 3250. SPRING. [3]

CHBE 5300. Fluid Mechanics and Heat Transfer. (Also listed as CHBE 3300) Principles of momentum and energy transport and their application to the analysis and design of chemical and biological engineering systems. No credit for students who have earned credit for 3300. FALL. [3]

CHBE 5350. Mass Transfer and Rate-Based Separations. (Also listed as CHBE 3350) Principles of mass transfer and their application to the analysis of chemical and biological engineering systems. Design of rate-based separation operations. No credit for students who have earned credit for 3350. SPRING. [3]

CHBE 5500. Bioprocess Engineering. (Also listed as CHBE 4500) 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. No credit for students who have earned credit for 4500. [3]

CHBE 5600. Chemical Process Control. (Also listed as CHBE 3600) 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. No credit for students who have earned credit for 3600. [3]

CHBE 5800. The Molecular and Cellular Mechanome. (Also listed as CHBE 4800) Applications of molecular and cellular biophysics and mechanics over various lengths, energy and timescales to describe biological phenomena through an 'omics' systems level perspective to molecular motors, cell machinery, mechanotransduction, cell migration, cell division, and nonequilibrium receptor ligand interactions. Physical and engineering based descriptions of molecular and cellular machinery incorporating biophysics and statistical and continuum mechanics perspectives. Modern and historical results, instrumentation, and measurement techniques. No credit for students who have earned credit for 4800. FALL. [3]

CHBE 5805. Biomolecular Engineering and Design. Approaches for interrogating and controlling biological function on a molecular and cellular level. Applications to biotechnology fields such as diagnostics, therapeutics, and regenerative medicine. Focus areas include concepts of molecular recognition, extracellular and intracellular signal transduction, protein engineering, genome engineering, cellular engineering, and tissue engineering. [3]

CHBE 5810. Metabolic Engineering. (Also listed as CHBE 4810) Analysis and synthesis of metabolic networks using principles of thermodynamics, kinetics, and transport phenomena. Computational approaches for predicting metabolic phenotypes. Experimental techniques to measure and manipulate key metabolic variables including pathway fluxes, protein/gene expression, enzyme regulation, and intracellular metabolite concentrations. No credit for students who have earned credit for 4810. [3]

CHBE 5820. Immunoengineering. (Also listed as CHBE 4820) Approaches and technologies for manipulating and studying the immune system. Topics include fundamentals of immunology, immunology tools and methods, vaccines and immunotherapies, drug delivery principles, and materials engineering for immunomodulation. No credit for students who have earned credit for 4820. [3]

CHBE 5830. Molecular Simulation. (Also listed as CHBE 4830) Modern tools of statistical mechanics, such as Monte Carlo and molecular dynamics simulation, and variations. Methods, capabilities, and limitations of molecular simulation and applications to simple and complex fluids relevant to the chemical and related processing industries. No credit for students who have earned credit for 4830. [3]

CHBE 5840. Synthesis and Applications of 2D Nanomaterials. (Also listed as CHBE 4840) Structure-property relationships and applications of atomically thin, two-dimensional materials and 2D/layered systems. Preparation by mechanical exfoliation, solution processing, and bottom-up synthesis. Nucleation/growth of 2D materials via gas/solid, liquid/solid, and catalytic/phase transformation reactions. Kinetic vs. thermodynamic processing, stabilizing meta-stable intermediates, interface engineering, and scale-up. No credit for students who have earned credit for 4840. [3]

CHBE 5850. Semiconductor Materials Processing. (Also listed as CHBE 4850) Materials processing unit operations of silicon device manufacturing. 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. Lectures alternate with one two-hour laboratory on a weekly basis. No credit for students who have earned credit for 4850. FALL. [3]

CHBE 5860. Molecular Aspects of Chemical Engineering. (Also listed as CHBE 4860) 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. No credit for students who have earned credit for 4860. [3]

CHBE 5870. Polymer Science and Engineering. (Also listed as CHBE 4870) Macromolecular systems with emphasis on the interrelationship of chemical, physical, and engineering properties. Further relation of these properties to synthesis. Physicochemical and biological applications. No credit for students who have earned credit for 4870. [3]

CHBE 5875. Colloid Science and Engineering. (Also listed as CHBE 4875) Fundamental concepts (surface forces, self-assembly, electrokinetics) and experimental techniques (microscopy, scattering, measurement of charge) in colloid science. Applications to personal care products, energy devices, and drug delivery. No credit for students who have earned credit for 4875. [3]

CHBE 5880. Corrosion Science and Engineering. (Also listed as CHBE 4880) Aqueous-phase metal and alloy corrosion phenomena. Fundamental chemistry and electrochemistry theories, as applied to corroding systems. Specific forms of corrosion including pitting, crevice corrosion, and galvanic corrosion. Methods for corrosion control based on electrochemical fundamentals. No credit for students who have earned credit for 4880. SPRING [3]

CHBE 5890. Special Topics. (Also listed as CHBE 3890) No credit for students who have earned credit for 3890. [Variable credit: 1-3 each semester]

CHBE 6100. 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 6110. 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 6120. Applied Chemical Kinetics. Experimental methods in kinetics. Kinetics of industrial reactions and reactor design. Absorption and catalytic systems are considered. FALL. [3]

CHBE 6200. 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 6250. Professional Communication Skills for Engineers. Written and oral communication skills for engineers to produce peer-reviewed journal publications, research proposals, and research presentations. SPRING. [1]

CHBE 7899. Master of Engineering Project. [0-6]

CHBE 7999. Master's Thesis Research. [0-6]

CHBE 8900. Special Topics. [Variable credit: 1-3 each semester]

CHBE 8991. Seminar. [0]

CHBE 8999. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

CHBE 9999. Ph.D. Dissertation Research. [0-12]

CE 2101. Civil and Environmental Engineering Information Systems. Information technologies used by civil and environmental engineers. Lab and project-oriented course focusing on developing skills in engineering drawings, computer graphics, plans reading, leveling, mapping, and GIS. Integration of CAD and surveying with team-based projects. FALL [3]

CE 2120. Sustainable Design in Civil Engineering. Concepts and methods of sustainability; resilience in civil engineering design. Best practices. Economic, social, and environmental analysis. Ratings, indices, and measurements. Local, regional, and federal policy. Challenges posed by climate change. Sustainability and resilience rating systems. Applications to development and design. FALL. [3]

CE 2200. Statics. Vector analysis of two- and three-dimensional equilibrium of particles, rigid bodies, trusses, frames, and machines. Internal forces, shear and moment diagrams, cables, centroids, moments of inertia, and friction. Credit offered for only one of CE 2200 or BME 2100. Corequisites: MATH 1301, PHYS 1601. FALL, SPRING, SUMMER [3]

CE 2205. 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 2200. FALL, SPRING, SUMMER. [3]

CE 3100W. 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 2205. SPRING. [2]

CE 3200. Structural Analysis. Classification; nature of loads and their calculation; analysis of statically determinate and indeterminate beams, trusses, and frames using classical methods (integration, moment area, energy) and matrix methods; basics of nonlinear behavior; structural analysis software. Prerequisite: CE 2205. FALL. [3]

CE 3205. Structural Design. Loads and their identification; issues of safety and uncertainties; steel and concrete behavior and design of components in compression, tension, bending, shear; application to simple structural systems; use of the AISC Steel Specifications; sustainability issues. Prerequisite: CE 3200. SPRING [3]

CE 3250. 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 2205. FALL. [3]

CE 3300. Risk, Reliability, and Resilience Engineering. Fundamental concepts in probability and statistical inference. Counting methods, discrete and continuous random variables, and their associated distributions. Sampling distributions, point estimation, confidence intervals, and hypothesis testing. Applications of probability and statistics to risk, reliability, and resilience of engineering systems. Prerequisite: MATH 2300. SPRING. [3]

CE 3501. Transportation Systems Engineering. Planning, design, and operations of transportation systems. Particular emphasis on the design process, traffic engineering, urban transportation planning, the analysis of current transportation issues, and the ethics of transportation safety. SPRING. [3]

CE 3600. Environmental Engineering. Parameters affecting environmental quality, including air and water pollutants; treatment techniques to achieve drinking water quality or permit safe discharge to the environment. Sustainability. Contaminant transport and interactions of contaminants with the environment. Risk assessment and governmental regulations covering air, water, solid and hazardous wastes. Residuals management including hazardous and solid waste. Prerequisite: CHEM 1601, PHYS 1601, MATH 2420. FALL. [3]

CE 3700. 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. Credit not awarded for both CE 3700 and ME 3224. Prerequisite: ME 2190, MATH 2420. FALL, SUMMER. [3]

CE 3700L. Fluid Mechanics Laboratory. Team project-oriented course. Practical applications of fluid mechanics principles through laboratory exercises and field trips. Corequisite: CE 3700. FALL. [1]

CE 3705. Water Resources Engineering. 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: CE 3700 or CHBE 3300 or ME 3224. SPRING. [3]

CE 3841. 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. [1-3 each semester]

CE 3842. Directed Study. Continuation of CE 3841 in the same or another area of civil and environmental engineering. Prerequisite: CE 3841 and one-page proposal approved by supervising faculty member and chair. [1-3 each semester]

CE 3843. Directed Study. Continuation of CE 3842 in the same or another area of civil and environmental engineering. Prerequisite: CE 3842 and one-page proposal approved by supervising faculty member and chair. [1-3 each semester]

CE 3890. Special Topics. [3]

CE 4100. Geographic Information Systems (GIS). 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 4150. Energy Systems Engineering. Physical principles of energy conversion. Energy sources and usage. Sustainability and carrying capacity. Systems tools and economics for energy systems. Energy distribution and storage. Future energy system design. Prerequisite: MATH 2300. SPRING. [3]

CE 4200. Advanced Structural Steel Design. Advanced topics in column and beam design: elastic and inelastic analysis and design of continuous beams, composite beams, torsion design, behavior and design of bolted and welded connections, structural planning and design of structural systems such as multistory buildings. Prerequisite: CE 3205. FALL. [3]

CE 4205. 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 4210. 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. Prestressed concrete. Prerequisite: CE 3205. SPRING. [3]

CE 4211. 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 2205, MSE 1500, MSE 1500L. SPRING. [3]

CE 4240. Infrastructure Systems Engineering. Systems-level approach to the infrastructure of the built environment. Elements of systems engineering. Case studies of infrastructure under duress. Smart infrastructure. Transportation, building, and water and wastewater supply and distribution systems. Infrastructure interdependencies and concepts of smart cities. Applications to infrastructure system design. FALL. [3]

CE 4250. Foundation Analysis and Design. Study of shallow and deep foundation elements and systems for civil engineering structures considering geotechnical, structural, and construction aspects. Corequisite: CE 3205. Prerequisite: CE 3250. SPRING. [3]

CE 4300. Reliability and Risk Case Studies. Review of historical events involving successes and failures in managing system reliability and risk from a wide range of perspectives, including design, production, operations, organizational culture, human factors and exogenous events. Analysis of risk factors leading to event occurrence, as well as event consequences in terms of impacts to public health, safety, security and environmental protection. Evaluation of risk 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. FALL. [3]

CE 4320. Data Analytics for Engineers. Programming, analysis, and visualization of real data for the purposes of informing decision making in engineering problems. Statistical modeling in a practical and applied perspective; application of data analytics to bridge the gap between data and decisions; fundamentals of design of experiments. Prerequisite: CE 3300 or MATH 2810 or MATH 2820. FALL. [3]

CE 4340. Risk and Decision Analysis. Risk quantification, risk perception, decision-making under uncertainty, risk communication. Model risk and decisions using analytical and simulation approaches. Focus on theory and methodology, applications in engineering, environmental systems, business, and healthcare. Prerequisite: CE 3300 or MATH 2810 or MATH 2820. FALL. [3]

CE 4400. Construction Project Management. Theory and application of the fundamentals of construction project management. The construction process and the roles of professionals in the process. 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. Credit given for only one of ENGM 3700, CE 4400, or EECE 4950. Prerequisite: CE 3205. FALL. [3]

CE 4401. Advanced Construction Project Management. Current and critical issues in the construction industry, including best practices developed at the Construction Industry Institute (CII). Guest lecturers include representatives of the CII and visiting industry leaders. Prerequisite: CE 4400. FALL. [3]

CE 4405. Construction Estimating. Estimation of material, labor, and equipment quantities, including costing and pricing of construction projects. Application of estimating practices using real-world examples and project estimating software. Corequisite: CE 4400. FALL. [3]

CE 4410. 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 4400. SPRING. [3]

CE 4415. 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. SUMMER. [3]

CE 4420. 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 4400. SPRING. [3]

CE 4425. Building Information Modeling. Generation and management of building data during its life cycle. Three-dimensional, real-time, dynamic modeling to increase productivity in building design and construction. Considerations of building geometry, spatial relationships, geographic information, and building components. Corequisite: CE 4400. FALL. [3]

CE 4430. High Performance and Green Buildings. Design and construction of high performance buildings and related systems in buildings. Leadership in Energy and Environmental Design (LEED) green Building Rating System (TM) building approach to sustainability. Prerequisite: CE 4400. SPRING. [3]

CE 4500. Transportation Systems Design. Geometric analysis of transportation ways with particular emphasis on horizontal and vertical curve alignment and superelevation. Design of highways, interchanges, intersections, and facilities for pedestrians, and air, rail, and public transportation. Prerequisite: CE 3501 or 3601. SPRING. [3]

CE 4505. 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. Planning processes in non-urban settings are also presented. Prerequisite: CE 3501 or CE 3601. SPRING [3]

CE 4510. Traffic Engineering. Analysis of the characteristics of traffic, including the driver, vehicle, volumes, capacities, congestion, roadway conditions, complete streets and accidents.

Traffic regulations, markings, signing, signalization, and safety programs are also discussed. Prerequisite: CE 3501 or CE 3601. FALL. [3]

CE 4950. Civil Engineering Design I. A capstone design course for civil engineering students. Includes project conception, design, economic evaluations, safety, reliability, ethics, social and environmental impact, licensure, and government regulations. Projects may be interdisciplinary, competition-oriented, or traditional civil engineering projects. Prerequisite: CE 3100W. FALL [1].

CE 4951. Civil Engineering Design II. Continuation of CE 4950. The course involves an oral presentation and the submission of a final design report. Prerequisite: CE 4950. SPRING. [2]

CE 4959. 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: CE 4950. FALL. [1]

CE 5100. Geographic Information Systems (GIS). (Also listed as CE 4100) 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. No credit for students who have earned credit for 4100. SPRING. [3]

CE 5150. Energy Systems Engineering. (Also listed as CE 4150) Physical principles of energy conversion. Energy sources and usage. Sustainability and carrying capacity. Systems tools and economics for energy systems. Energy distribution and storage. Future energy system design. SPRING. [3]

CE 5200. Advanced Structural Steel Design. (Also listed as CE 4200) 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. No credit for students who have earned credit for 4200. FALL. [3]

CE 5210. Advanced Reinforced Concrete Design. (Also listed as CE 4210) 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. Prestressed concrete. No credit for students who have earned credit for 4210. SPRING. [3]

CE 5240. Infrastructure Systems Engineering. (Also listed as CE 4240) Systems-level approach to the infrastructure of the built environment. Elements of systems engineering. Case studies of infrastructure under duress. Smart infrastructure. Transportation, building, and water and wastewater supply and distribution systems. Infrastructure interdependencies and concepts of smart cities. Applications to infrastructure system design. FALL. [3]

CE 5250. Foundation Analysis and Design. (Also listed as CE 4250) Study of shallow and deep foundation elements and systems for civil engineering structures. Soil exploration and site investigation. No credit for students who have earned credit for 4250. SPRING. [3]

CE 5300. Reliability and Risk Case Studies. (Also listed as CE 4300) Review of historical events involving successes and failures in managing system reliability and risk from a wide range of perspectives, including design, production, operations, organizational culture, human factors and exogenous events. Analysis of risk factors leading to event occurrence, as well as event consequences in terms of impacts to public health, safety, security and environmental protection. Evaluation of risk mitigation strategies based on achievable goals, technical and political feasibility, and economic impact. Cases drawn from natural disasters, industrial accidents, and intentional acts. No credit for students who have earned credit for CE 4300. FALL. [3]

CE 5320. Data Analytics for Engineers. (Also listed as CE 4320) Programming, analysis, and visualization of real data for the purposes of informing decision making in engineering problems. Statistical modeling in a practical and applied perspective; application of data analytics to bridge the gap between data and decisions; fundamentals of design of experiments. No credit for students who have earned credit for CE 4320. FALL. [3]

CE 5340. Risk and Decision Analysis. (Also listed as CE 4340) Risk quantification, risk perception, decision-making under uncertainty, risk communication. Model risk and decisions using analytical and simulation approaches. Focus on theory and methodology, applications in engineering, environmental systems, business, and healthcare. No credit for students who have earned credit for CE 4340. FALL. [3]

CE 5400. Construction Project Management. (Also listed as CE 4400) Theory and application of the fundamentals of construction project management. The construction process and the roles of professionals in the process. 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. No credit for students who have earned credit for 4400. FALL. [3]

CE 5401. Advanced Construction Project Management. (Also listed as CE 4401) Current and critical issues in the construction industry, including best practices developed at the Construction Industry Institute (CII). Guest lecturers include representatives of the CII and visiting industry leaders. No credit for students who have earned credit for 4401. FALL. [3]

CE 5405. Construction Estimating. (Also listed as CE 4405) Estimation of material, labor, and equipment quantities, including costing and pricing of construction projects. Application of estimating practices using real-world examples and project estimating software. Corequisite: CE 5400. No credit for students who have earned credit for 4405. FALL. [3]

CE 5410. Construction Planning and Scheduling. (Also listed as CE 4410) 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. No credit for students who have earned credit for 4410. SPRING. [3]

CE 5415. Construction Materials and Methods. (Also listed as CE 4415) 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. No credit for students who have earned credit for 4415. SUMMER. [3]

CE 5420. Construction Law and Contracts. (Also listed as CE 4420) 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. No credit for students who have earned credit for 4420. SPRING. [3]

CE 5425. Building Information Modeling. (Also listed as CE 4425) Generation and management of building data during its life cycle. Three-dimensional, real-time, dynamic modeling to increase productivity in building design and construction. Considerations of building geometry, spatial relationships, geographic information, and building components. No credit for students who have completed 4425. FALL. [3]

CE 5430. High Performance and Green Buildings. (Also listed as CE 4430) Design and construction of high performance buildings and related systems in buildings. Leadership in Energy and Environmental Design (LEED) green Building Rating System (TM) building approach to sustainability No credit for students who have earned credit for 4430. SPRING. [3]

CE 5500. Transportation System Design. (Also listed as CE 4500) 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. No credit for students who have earned credit for 4500. SPRING. [3]

CE 5505. Urban Transportation Planning. (Also listed as CE 4505) 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. No credit for students who have earned credit for 4505. SPRING. [3]

CE 5510. Traffic Engineering. (Also listed as CE 4510) 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. No credit for students who have earned credit for 4510. FALL. [3]

CE 5884. Internship. Internship working in a professional setting. Intended for M.Eng. students in the area of construction management. Coreq: CE 5400. [0]

CE 5999. Special Topics. (Also listed as CE 3890) No credit for students who have earned credit for 3890. [3]

CE 6200. Continuum Mechanics. Mathematical preliminaries: tensor algebra, tensor calculus, coordinate transformation, principal values and directions. Kinematics of continuum: motion and deformation, infinitesimal and finite strain theory, balance of mass. Stress and integral formulations: traction on planes, stress invariants and failure theories, Piola-Kirchhoff stress tensors, balance of momentum, stress power. Elastic solid: linear isotropic and anisotropic elasticity, engineering material constants, plane elastic waves, non-linear isotropic elasticity. FALL. [3].

CE 6205. Theory of Inelasticity. Physical mechanisms of deformation and failure. Modern theories of plasticity, viscoplasticity and continuum damage mechanics. Thermodynamics of plasticity and damage processes. Numerical and computational aspects of inelastic deformation mechanisms in solids and structures. SPRING. [3]

CE 6210. 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. 1-D problems of the continua and finite element solution-C0 and C1 elements, eigenvalue and transient problems. Error checks and control. Mapping, shape functions, numerical quadrature, and solution of equations. Formulation of 2-D problems (single and multi-field)-mapping and shape functions, triangular and quad elements with straight or curved boundaries. 3-D elements, singular problems, buckling, and nonlinear problems. Error estimation and quality control. Computer implementation. Commercial packages. Prerequisite: MATH 2410, MATH 3620. FALL. [3]

CE 6212. Advanced Computational Mechanics. 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. Multi-scale modeling and atomistic/continuum coupling. Prerequisite: CE 6210. SPRING. [3]

CE 6215. 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 6300. 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 2410. FALL. [3]

CE 6305. 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 4630, MATH 4620 or CE 6300. [3]

CE 6310. Uncertainty Quantification. Computational methods for analysis and design of modern engineering systems under uncertainty. Emphasis on epistemic uncertainty due to data and models. Topics include stochastic finite elements; time-dependent reliability; Bayesian methods and networks; surrogate modeling; advanced simulation; global sensitivity analysis; model verification, validation, and calibration; and optimization under uncertainty. Applications to practical engineering systems. Prerequisite: CE 6300. SPRING. [3]

CE 6313. Multiscale Modeling. State-of-the-art and emerging multiscale computational methods for modeling of mechanics, transport, and materials phenomena. Principles of information transfer between multiple spatial and temporal scales, including atomistic-to-continuum coupling, continuum-to-continuum coupling, and bridging of time scales. Enrichment methods including generalized finite elements, partition of unity, variational multiscale methods. FALL. [3]

CE 6318. 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. Application to the design and construction of bridges and buildings. Prerequisite: CE 3205. [3]

CE 6351. Public Transportation Systems. Comprehensive study of public transportation, with emphasis on planning, management, and operations; paratransit, ridesharing, and rural public transportation systems. Prerequisite: CE 4505. SPRING. [3]

CE 6353. 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 3601. [3]

CE 6355. Advanced Transportation Design. In-depth view of the transportation design process. Complex transportation design problems and solutions, with the use of computer-based analytical design tools. Comprehensive design projects. Prerequisite: CE 4500. SPRING [3]

CE 6356. Advanced Transportation Planning. A continuation of the concepts from CE 4505, with emphasis on analytical techniques used in forecasting travel. Use of computer-based models, along with transportation and energy contingency planning methods. Prerequisite: CE 4505. SPRING [3]

CE 6357. 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 4510. [3]

CE 6359. Emerging Information Systems Applications. Role of emerging information systems technologies in improving productivity and efficiency and 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 in transportation or manufacturing operations. FALL. [3]

CE 7899. Master of Engineering Project.

CE 7999. Master's Thesis Research. [0-6]

CE 8000. Individual Study of Civil Engineering Problems. Literature review and analysis of special problems under faculty supervision. FALL, SPRING, SUMMER. [1-4 each semester]

CE 8001. Individual Study of Civil Engineering Problems. Literature review and analysis of special problems under faculty supervision. FALL, SPRING, SUMMER. [1-4 each semester]

CE 8002. Individual Study of Civil Engineering Problems. Literature review and analysis of special problems under faculty supervision. FALL, SPRING, SUMMER. [1-4 each semester]

CE 8300. Reliability and Risk Engineering Seminar. Perspectives 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 8301. Reliability and Risk Engineering Seminar. Seminars by expert speakers provide a wide range of perspectives on reliability and risk assessment and management of multidisciplinary 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 8999. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

CE 9999. Ph.D. Dissertation Research. [0-12]

CS 1000. The Beauty and Joy of Computing. Fundamental concepts of computing including abstraction, algorithms, design, and distributed computation. Hands-on curriculum focusing on translating ideas into working computer programs and developing a mastery of practical computational literacy. The relevance and societal impact of computer science are emphasized. Students in the School of Engineering may only receive open elective credit for CS 1000. FALL, SPRING. [3]

CS 1101. 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. Not open to students who have earned credit for CS 1104 without permission. Total credit for this course and CS 1104 will not exceed 3 credit hours. Credit hours reduced from second course taken (or from test or transfer credit) as appropriate. FALL, SPRING. [3]

CS 1103. Introductory Programming for Engineers and Scientists. 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 using MATLAB. Generic programming concepts. FALL, SPRING. [3]

CS 1104. Programming and Problem Solving with Python. An intensive introduction to algorithm development and problem solving using the Python programming language. Structured problem definition, top down and modular algorithm design. Running, debugging, and testing programs. Program documentation. Not open to students who have earned credit for CS 1101 without permission. Total credit for this course and CS 1101 will not exceed 3 credit hours. Credit hours reduced from second course taken (or from test or transfer credit) as appropriate. FALL, SPRING. [3]

CS 1151. 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 2201. Program Design and Data Structures. Continuation of CS 1101. 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 1101 or 1104. FALL, SPRING. [3]

CS 2204. 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 1104. SPRING. [3]

CS 2212. Discrete Structures. Survey of the mathematical tools necessary for an understanding of computer science. 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 2231. 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, IO handling, and assembler concepts. Graduate credit not given for computer science majors. Prerequisite: CS 2201. Corequisite: EECE 2116, EECE 2116L. FALL, SPRING. [3]

CS 3250. 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 2201, CS 2212. FALL, SPRING. [3]

CS 3251. 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 2201. FALL, SPRING [3]

CS 3252. Theory of Automata, Formal Languages, and Computation. Finite-state machines and regular expressions. Context-free grammars and languages. Pushdown automata. Turing machines. Undecideability. The Chomsky hierarchy. Computational complexity. Prerequisite: CS 2212. SPRING. [3]

CS 3253. Parallel Functional Programming. Conceptual and practical aspects of designing, implementing, and debugging parallel software programs using functional programming language features and frameworks. Systematic reuse of scalable and robust software patterns and architectures for parallel programs. Prerequisite: CS 3251. FALL. [3]

CS 3254. Concurrent Object-Oriented Programming. Conceptual and practical aspects of designing, implementing, and debugging concurrent software programs using object-oriented programming language features and frameworks. Systematic reuse of scalable and robust software patterns and architectures for concurrent programs. SPRING. [3]

CS 3258. Introduction to Computer Graphics. 2D rendering and image-based techniques, 2D and 3D transformations, modeling, 3D rendering, graphics pipeline, ray-tracing, and texture-mapping. Prerequisite: MATH 2400, 2410, 2501 or 2600; CS 3251. SPRING. [3]

CS 3259. Project in Computer Animation Design and Technology. Principles and techniques of computer animation. Topics include storyboarding, camera control, skeletons, inverse kinematics, splines, keyframing, motion capture, dynamic simulation, particle systems, facial animation, and motion perception. Students work in groups on the design, modeling, animation, and rendering of a computer animation project. Prerequisite: MATH 2400, 2410, 2501, or 2600; CS 2201. FALL. [3]

CS 3265. Database Management Systems. Logical and physical organization of databases. Data models and query languages, with emphasis on the relational model and its semantics. Data independence, security, integrity, concurrency. Prerequisite: CS 2201. [3]

CS 3270. 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. Problem solving using non-standard languages. Prerequisite: CS 2201, CS 2231 or EECE 2123. FALL, SPRING. [3]

CS 3274. 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 2201. [3]

CS 3276. 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 3270. [3]

CS 3281. Principles of Operating Systems I. 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 implementing parallel processes on conventional computers. Virtual memory, paging, protection of shared and non-shared information. Structures of data files in secondary storage. Security issues. Case studies. Prerequisite: CS 2231 or EECE 2123, CS 3251. FALL, SPRING. [3]

CS 3282. 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. Operating system performance measurement, for both efficiency and logical correctness. Two hours lecture and one hour laboratory. Prerequisite: CS 3281. [3]

CS 3860. 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 2201. [1-3 each semester]

CS 3861. 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 2201. [1-3 each semester]

CS 3891. Special Topics. [Variable credit: 1-3 each semester]

CS 3892. Special Topics. Fulfills project course requirement in CS major. [3]

CS 4249. Projects in Virtual Reality Design. Students work in groups on specification, design, and construction of complex immersive 3D virtual environments. Includes modeling, interaction, usability, rendering, perception, and tracking. Prerequisite: CS 3251. FALL. [3].

CS 4260. Artificial Intelligence. 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 3250, CS 3251; MATH 2810 or 2820 or 3640. FALL. [3]

CS 4262. Foundations of Machine Learning. Theoretical and algorithmic foundations of supervised learning, unsupervised learning, and reinforcement learning. Linear and nonlinear regression, kernel methods, support vector machines, neural networks and deep learning methods, instance-based methods, ensemble classifiers, clustering and dimensionality reduction, value and policy iteration. Explainable AI, ethics, and data privacy. Prerequisite: CS 3251; one of MATH 2810, 2820, or 3640; one of MATH 2410, 2500, 2501, or 2600. SPRING. [3]

CS 4266. Topics in Big Data. Principles and practices of big data processing and analytics. Data storage databases and data modeling techniques, data processing and querying, data analytics and applications of machine learning using these systems. Prerequisite: CS 3251. SPRING. [3]

CS 4269. 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 4260. SPRING. [3]

CS 4277. Cyber Security. Software issues, secure software design, attacks and detection, identity, sessions, human security mistakes, and security auditing. Prerequisite: CS 3251. FALL. [3]

CS 4278. 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 3251. FALL. [3]

CS 4279. 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 4278. SPRING. [3]

CS 4283. Computer Networks. Computer communications. Network (Internet) architecture. Algorithms and protocol design at each layer of the network stack. Cross-layer interactions and performance analysis. Network simulation tools. Lab and programming assignments. Course not open to students who have earned credit for EECE 4371 without permission. Serves as repeat credit for EECE 4371. Prerequisite: CS 3281 or EECE 4376. [3]

CS 4284. 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 3281. [3]

CS 4285. 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 4283. [3]

CS 4287. Principles of Cloud Computing. Fundamental concepts of cloud computing, different service models, techniques for resource virtualization, programming models, management, mobile cloud computing, recent advances, and hands-on experimentation. Prereq: CS 3281. [3]

CS 4288. Web-based System Architecture. Core concepts necessary to architect, build, test, and deploy complex web-based systems; analysis of key domain requirements in security, robustness, performance, and scalability. Prerequisite: CS 3251. FALL. [3]

CS 4959. Computer Science Seminar. Elements of professional engineering practice, professional education and lifelong learning, intellectual property and software patents, open source and crowd source software development, liability, soft risk safety and security, privacy issues, interdisciplinary teams and team tools, professional organization, careers, entrepreneurship, human computer interaction. Prerequisite: CS 3251. FALL [1]

CS 5249. Projects in Virtual Reality Design. Students work in groups on specification, design, and construction of complex immersive 3D virtual environments. Includes modeling, interaction, usability, rendering, perception, and tracking. No credit for students who have earned credit for 4249. FALL. [3].

CS 5250. Algorithms. (Also listed as CS 3250) 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. No credit for students who have earned credit for 3250. FALL, SPRING. [3]

CS 5251. Intermediate Software Design. (Also listed as CS 3251) 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. No credit for students who have earned credit for 3251. FALL, SPRING [3]

CS 5252. Theory of Automata, Formal Languages, and Computation. (Also listed as CS 3252) Finite-state machines and regular expressions. Context-free grammars and languages. Pushdown automata. Turing machines. Undecideability. The Chomsky hierarchy.

Computational complexity. No credit for students who have earned credit for 3252. SPRING. [3]

CS 5253. Parallel Functional Programming. Conceptual and practical aspects of designing, implementing, and debugging parallel software programs using functional programming language features and frameworks. Systematic reuse of scalable and robust software patterns and architectures for parallel programs. FALL. [3]

CS 5254. Concurrent Object-Oriented Programming. Conceptual and practical aspects of designing, implementing, and debugging concurrent software programs using object-oriented programming language features and frameworks. Systematic reuse of scalable and robust software patterns and architectures for concurrent programs. SPRING. [3]

CS 5258. Computer Graphics. (Also listed as CS 3258) 2D rendering and image-based techniques, 2D and 3D transformations, modeling, 3D rendering, graphics pipeline, ray-tracing, and texture-mapping. No credit for students who have earned credit for 3258. FALL. [3]

CS 5259. Project in Computer Animation Design and Technology. (Also listed as CS 3259) Principles and techniques of computer animation. Storyboarding, camera control, skeletons, inverse kinematics, splines, keyframing, motion capture, dynamic simulation, particle systems, facial animation, and motion perception. Students work in groups on the design, modeling, animation, and rendering of a computer animation project. No credit for students who have earned credit for 3259. FALL. [3]

CS 5260. Artificial Intelligence. (Also listed as CS 4260) Principles and programming techniques of artificial intelligence. Strategies for searching, representation of knowledge and automatic deduction, learning, and adaptive systems. Survey of applications. No credit for students who have earned credit for 4260. FALL. [3]

CS 5262. Foundations of Machine Learning. Theoretical and algorithmic foundations of supervised learning, unsupervised learning, and reinforcement learning. Linear and nonlinear regression, kernel methods, support vector machines, neural networks and deep learning methods, instance-based methods, ensemble classifiers, clustering and dimensionality reduction, value and policy iteration. Explainable AI, ethics, and data privacy. SPRING. [3]

CS 5265. Database Management Systems. (Also listed as CS 3265) Logical and physical organization of databases. Data models and query languages, with emphasis on the relational model and its semantics. Data independence, security, integrity, concurrency. No credit for students who have earned credit for 3265. [3]

CS 5266. Topics in Big Data. Principles and practices of big data processing and analytics. Data storage databases and data modeling techniques, data processing and querying, data analytics and applications of machine learning using these systems. SPRING. [3]

CS 5269. Project in Artificial Intelligence. (Also listed as CS 4269) 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. No credit for students who have earned credit for 4269. SPRING. [3]

CS 5270. Programming Languages. (Also listed as CS 3270) 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. Problem solving using non-standard languages. No credit for students who have earned credit for 3270. FALL, SPRING. [3]

CS 5274. Modeling and Simulation. (Also listed as CS 3274) 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. No credit for students who have earned credit for 3274. [3]

CS 5276. Compiler Construction. (Also listed as CS 3276) 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. No credit for students who have earned credit for 3276. [3]

CS 5277. Cyber Security. Software issues, secure software design, attacks and detection, identity, sessions, human security mistakes, and security auditing. No credit for students who have earned credit for 4277. FALL. [3]

CS 5278. Principles of Software Engineering. (Also listed as CS 4278) 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. No credit for students who have earned credit for 4278. FALL. [3]

CS 5279. Software Engineering Project. (Also listed as CS 4279) 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. No credit for students who have earned credit for 4279. SPRING. [3]

CS 5281. Principles of Operating Systems I. (Also listed as CS 3281) 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 implementing parallel processes on conventional computers. Virtual memory, paging, protection of shared and non-shared information. Structures of data files in secondary storage. Security issues. Case studies. No credit for students who have earned credit for 3281. FALL, SPRING. [3]

CS 5282. Principles of Operating Systems II. (Also listed as CS 3282) 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. Operating system performance measurement, for both efficiency and logical correctness. Two hours lecture and one hour laboratory. No credit for students who have earned credit for 3282. [3]

CS 5283. Computer Networks. (Also listed as CS 4283) Computer communications. Network (Internet) architecture. Algorithms and protocol design at each layer of the network stack. Cross-layer interactions and performance analysis. Network simulation tools. Lab and programming assignments. No credit for students who have earned credit for 4283. [3]

CS 5284. Computer Systems Analysis. (Also listed as CS 4284) 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. No credit for students who have earned credit for 4284. [3]

CS 5285. Network Security. (Also listed as CS 4285) Principles and practice of network security. Security threats and mechanisms. Cryptography, key management, and message authentication. System security practices and recent research topics. No credit for students who have earned credit for 4285. [3]

CS 5287. Principles of Cloud Computing. (Also listed as CS 4287) Fundamental concepts of cloud computing, different service models, techniques for resource virtualization, programming models, management, mobile cloud computing, recent advances, and hands-on experimentation. No credit for students who have earned credit for 4287. [3]

CS 5288. Web-based System Architecture. (Also listed as CS 4288) Core concepts necessary to architect, build, test, and deploy complex web-based systems; analysis of key domain requirements in security, robustness, performance, and scalability. No credit for students who have earned credit for 4288. FALL. [3]

CS 5891. Special Topics. (Also listed as CS 3891) [Variable credit: 1-3 each semester] No credit for students who have earned credit for 3891.

CS 5892. Special Topics. (Also listed as CS 3892) [Variable credit: 1-3 each semester] No credit for students who have earned credit for 3892.

CS 6310. 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 3250. SPRING. [3]

CS 6311. 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 6310 or Math 4710. [3]

CS 6315. 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. [3]

CS 6320. 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 6310. [3]

CS 6350. Artificial Neural Networks. Theory and practice of parallel distributed processing methods using networks of neuron-like computational devices. Neurobiological inspirations, attractor networks, correlational and error-correction learning, regularization, unsupervised learning, reinforcement learning, Bayesian and information theoretic approaches, hardware support, and engineering applications. SPRING. [3]

CS 6351. 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 3259. FALL. [3]

CS 6352. 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. [3]

CS 6358. Computer Vision. 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: EECE 6357. SPRING. [3]

CS 6359. 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 6360. 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 4260 or equivalent. [3]

CS 6362. Advanced Machine Learning. Theory and algorithms for designing systems that learn from data including modern machine learning methods that take advantage of increased complexity to provide improved performance. Data types, data pre-processing, measures of similarity and dissimilarity. Supervised learning: decision trees, logistic regression, support vector machines, Bayesian methods, and neural networks; unsupervised learning: partitional, hierarchical, density-based, and graph clustering algorithms. Feature selection for classification and clustering. Evaluation methods. Reinforcement learning: Markov Decision processes, dynamic programming, Monte Carlo methods, TD-learning. Prerequisite: CS 4262 or 5262 or 6360. FALL. [3]

CS 6364. 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 4260, CS 6360, or equivalent. [3]

CS 6366. 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 4260. [3]

CS 6368. Computational Economics. Models and methods in computational economics, such as linear and non-linear optimization, decision theory, game theory, mechanism design, and computational tools. Applications in areas such as auctions, economics of security and privacy, market design, and algorithmic trading. Prereq: CS 4260 or 5260. SPRING. [3]

CS 6375. 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 6376. 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 6377. 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 6381. Distributed Systems Principles. Techniques and mechanisms in distributed system design, such as logical clocks, distributed consensus, distributed mutual exclusion, consistency models, fault tolerance and paradigms of communication. Contemporary distributed system case studies and open challenges. Prerequisite: CS 3281. [3]

CS 6384. Performance Evaluation of Computer Systems. Techniques for computer systems modeling and analysis. 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 3281 or 6381. SPRING. [3]

CS 6385. 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 4278. FALL. [3]

CS 6386. 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 6381. SPRING. [3]

CS 6387. Topics in Software Engineering. Topics may include empirical software engineering and open-source software engineering. Prerequisite: CS 4278 or consent of instructor. SPRING. [3]

CS 6388. Model-Integrated Computing. Problems of designing, creating, and evolving information systems by providing rich, domain-specific modeling environments including model analysis and model-based program synthesis tools. Class presentation and project are required. FALL. [3]

CS 7999. Master's Thesis Research. [0-6]

CS 8390. Individual Studies. [1-3]

CS 8395. Special Topics. [3]

CS 8396. Special Topics. [3]

CS 8991. Seminar. [1-3 each semester]

CS 8992. Seminar. [1-3 each semester]

CS 8999. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [0-12]

CS 9999. Ph.D. Dissertation Research. [0-12]

EECE 2112. 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: Physics 1602; Math 2300. FALL, SPRING. [3]

EECE 2116. Digital Logic. Numbering systems. Boolean algebra and combinational logic, graphical simplification, sequential logic, registers, and state machines. EECE 2116 is not open to students who have earned credit for EECE 2123. Corequisite: EECE 2116L. FALL, SPRING. [3]

EECE 2116L. Digital Logic Laboratory. Laboratory for EECE 2116. One three-hour laboratory per week. EECE 2116L is not open to students who have earned credit for EECE 2123L. Corequisite: EECE 2116. FALL, SPRING. [1]

EECE 2123. Digital Systems. Digital systems and computer architectures and digital systems, from transistor circuits and logic gates, to simple machine (e.g. von Neumann) models. Boolean algebra, Information representation, state machines, processors, process handling, I/O handling, and assembler concepts. EECE 2123 is not open to students who have earned credit for EECE 2116. Prerequisite: CS 1101 or CS 1104. Corequisite: EECE 2123L. FALL, SPRING [3]

EECE 2123L. Digital Systems Laboratory. Laboratory for EECE 2123. One three-hour laboratory per week. EECE 2123L is not open to students who have earned credit for EECE 2116L. Corequisite: EECE 2123. FALL, SPRING [1]

EECE 2213. Circuits II. Steady-state and transient analysis of electrical networks with emphasis on Laplace transform methods and pole-zero concepts. Prerequisite: EECE 2112, PHYS 1602. Corequisite: EECE 2213L, MATH 2400 or 2420. FALL, SPRING. [3]

EECE 2213L. Circuits II Laboratory. Laboratory for EECE 2213. One three-hour laboratory per week. Corequisite: EECE 2213. FALL, SPRING. [1]

EECE 2218. 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 2116 or EECE 2123, and one of CS 1101 or CS 1103. Corequisite: EECE 2218L. SPRING. [3]

EECE 2218L. Microcontrollers Laboratory. Laboratory for EECE 2218. A small structured project is required. One three-hour laboratory per week. Corequisite: EECE 2218. SPRING. [1]

EECE 3214. 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 2112. FALL, SPRING. [3]

EECE 3233. Electromagnetics. Electromagnetic field theory. Maxwell's equations from a historical approach. Electromagnetic waves with regard to various media and boundary conditions. Prerequisite: PHYS 1602. Corequisite: MATH 2400 or 2420. FALL. [3]

EECE 3235. Electronics I. 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. Prerequisite: EECE 2112. Corequisite: EECE 3235L. FALL. [3]

EECE 3235L. Electronics I Laboratory. Laboratory for EECE 3235. One three-hour laboratory per week. Corequisite: EECE 3235. FALL. [1]

EECE 3860. Undergraduate Research. Supervised projects in electrical engineering, computer engineering, or related fields. Consent of instructor required. No more than 6 hours of EECE 3860 and 3861 may be applied toward graduation. [1-3]

EECE 3861. Undergraduate Research. Supervised projects in electrical engineering, computer engineering, or related fields. Consent of instructor required. No more than 6 hours of EECE 3860 and 3861 may be applied toward graduation. [1-3]

EECE 3891. Special Topics. [1-3 each semester]

EECE 3892. Special Topics. [1-3 each semester]

EECE 4252. Signal Processing and Communications. AM and FM modulation. Advanced topics in signal processing. Prerequisite: EECE 3214. SPRING. [3]

EECE 4257. Control Systems I. Theory and design of feedback control systems, steady-state and transient analysis, stability considerations. Model representation. State-variable models. Prerequisite: EECE 2213 or EECE 3214. FALL. [3]

EECE 4267. Power System Analysis. Analysis of large transmission and distribution networks. Analysis of power lines, load flow, short circuit studies, economic operation, and stability. Prerequisite: EECE 2213. [3]

EECE 4268. Distributed Electrical Energy Systems. Uses of photovoltaics and wind as well as micro-hydro, fuel cells, and geothermal for producing electricity. Comparison with traditional generating methods based on the prime movers (steam, gas, etc.) and types (primarily three-phase) of electrical generators used. The economics of stand-alone and grid connected systems are covered. Prerequisite: EECE 2112. [3]

EECE 4275. 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 2112; EECE 2116 or EECE 2123. SPRING. [3]

EECE 4283. 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 3235. [3]

EECE 4284. Integrated Circuit Technology and Fabrication. Monolithic integrated circuit technology. Basic semiconductor properties and processes that result in modern integrated circuit. Bipolar and MOSFET processes and structures. Fabrication, design, layout, and applications as regards semiconductor microelectronic technologies. Prerequisite: EECE 3235. SPRING. [3]

EECE 4286. 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 2213, EECE 3235. [3]

EECE 4287. Engineering Reliability. Topics in engineering reliability with emphasis on electrical devices and systems. Reliability concepts and models. Risk analysis. Lifetime evaluation. System examples. Prerequisite: EECE 3235 or EECE 4275. [3]

EECE 4288. 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 3233 or equivalent. SPRING. [3]

EECE 4289. Spacecraft Systems. Spacecraft electrical and electronic subsystems with emphasis on practical limitations and hazards in space. Analysis of environments, mechanisms of failure, and implications for design. Prerequisite: EECE 3235 or 4275. SPRING. [3]

EECE 4334. RF and Microwave Design. Modeling of components and transmission structures at RF and microwave frequencies (30 MHz to 30 GHz), with emphasis on the effects of materials and geometry on passive structures for filtering and impedance matching. Modeling and design of active circuits and components such as RF amplifiers with input and output impedance matching structures. Prereq: EECE 3233. SPRING. [3]

EECE 4353. Image Processing. Theory of signals and systems is extended to two dimensions. Filtering, 2-D FFTs, edge detection, and image enhancement. Three lectures and one laboratory period. FALL. [4]

EECE 4354. Computer Vision. Vision as a computational problem. Theories of vision, inverse optics, image representation, and solutions to ill-posed problems. Prerequisite: EECE 4353. [3]

EECE 4356. Digital Signal Processing. Applications of Digital Signal Processing (DSP) chips to sampling, digital filtering, FFTs, etc. Three lectures and one laboratory period. Prerequisite: EECE 3214. SPRING. [4]

EECE 4358. Control Systems II. Modern control design. Discrete-time analysis. Analysis and design of digital control systems. Nonlinear systems and optimum control systems. Fuzzy control systems. Two lectures and one laboratory. Prerequisite: EECE 4257. SPRING. [3]

EECE 4371. Mobile and Wireless Networks. Design, development, and applications of mobile applications and services. Topics include wireless technologies, smart phone programming, cloud computing services. Course not open to students who have earned credit for CS 4283 without permission. Serves as repeat credit for CS 4283. Prerequisite: CS 2201 or equivalent programming experience. [3]

EECE 4376. Embedded Systems. Design and implementation of embedded computer-based systems. Programming for real-time systems and the Internet of Things. Embedded system modeling, design, analysis, and implementation using real-time and event-driven techniques. A structured project is required. Prerequisite: EECE 2218, CS 2201. Corequisite: EECE 4376L. FALL. [3]

EECE 4376L. Embedded Systems Laboratory. Laboratory for EECE 4376. A team-oriented structured project is required. One three-hour laboratory per week. Corequisite: EECE 4376. FALL. [1]

EECE 4377. 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. Prerequisite: EECE 2116 or EECE 2123. [3]

EECE 4380. 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 3235. SPRING. [3]

EECE 4385. 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 2116 or EECE 2123; EECE 3235. FALL. [3]

EECE 4950. 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 3700, but preparatory to the EECE senior design project course, EECE 4951. Credit given for only one of ENGM 3700, CE 4400 or EECE 4950. Prerequisite: senior standing. Corequisite: EECE 4959. FALL. [3]

EECE 4951. 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. Prerequisite: EECE 4950, at least one DE course, senior standing. SPRING. [3]

EECE 4959. 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 4950. FALL. [1]

EECE 5218. Microcontrollers. (Also listed as EECE 2218) Microprocessor and microcontroller architecture with emphasis on control applications. Usage of assembly language and interfacing with programs written in high-level languages. Interfacing and realtime I/O with 8-bit microprocessors, control algorithms, and networking with microcontrollers. Graduate credit only for non-majors. No credit for students who have earned credit for 2218. Corequisite: EECE 5218L. SPRING. [3]

EECE 5218L. Microcontrollers Laboratory. (Also listed as EECE 2218L) Laboratory for EECE 5218. A small structured project is required. One three-hour laboratory per week. Graduate credit only for non-majors. No credit for students who have earned credit for 2218L. Corequisite: EECE 5218. SPRING. [1]

EECE 5233. Electromagnetics. (Also listed as EECE 3233) Electromagnetic field theory. Maxwell's equations developed from a historical approach. Electromagnetic waves with regard to various media and boundary conditions. Graduate credit only for non-majors. No credit for students who have earned credit for 3233. FALL. [3]

EECE 5235. Electronics I. (Also listed as EECE 3235) 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. Graduate credit only for non-majors. Corequisite: EECE 5235L. No credit for students who have earned credit for 3235. FALL. [3]

EECE 5235L. Electronics I Laboratory. (Also listed as EECE 3235L) Laboratory for EECE 3235. One three-hour laboratory per week. Corequisite: EECE 5235. No credit for students who have earned credit for 3235L. FALL. [1]

EECE 5252. Signal Processing and Communications. (Also listed as EECE 4252) AM and FM modulation. Also, advanced topics in signal processing are treated. No credit for students who have earned credit for 4252. SPRING. [3]

EECE 5257. Control Systems I. (Also listed as EECE 4257) Theory and design of feedback control systems, steady-state and transient analysis, stability considerations. Model representation. State-variable models. No credit for students who have earned credit for 4257. FALL. [3]

EECE 5267. Power System Analysis. (Also listed as EECE 4267) Analysis of large transmission and distribution networks. Analysis of power lines, load flow, short circuit studies, economic operation, and stability are introduced. No credit for students who have earned credit for 4267. [3]

EECE 5268. Distributed Electrical Energy Systems. Uses of photovoltaics and wind as well as micro-hydro, fuel cells, and geothermal for producing electricity. Comparison with traditional generating methods based on the prime movers (steam, gas, etc.) and types (primarily three-phase) of electrical generators used. The economics of stand-alone and grid connected systems are covered. Prerequisite: EECE 2112. [3]

EECE 5275. Microelectronic Systems. (Also listed as EECE 4275) 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 realworld interfaces (comparators, A/D/A conversion). No credit for students who have earned credit for 4275. SPRING. [3]

EECE 5283. Principles and Models of Semiconductor Devices. (Also listed as EECE 4283) 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. No credit for students who have earned credit for 4283. [3]

EECE 5284. Integrated Circuit Technology and Fabrication. (Also listed as EECE 4284) Monolithic integrated circuit technology. Basic semiconductor properties and processes that result in modern integrated circuit. Bipolar and MOSFET processes and structures. Fabrication, design, layout, and applications as regards semiconductor microelectronic technologies. No credit for students who have earned credit for 4284. SPRING. [3]

EECE 5286. Audio Engineering. (Also listed as EECE 4286) 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. No credit for students who have earned credit for 4286. [3]

EECE 5287. Engineering Reliability. (Also listed as EECE 4287) Topics in engineering reliability with emphasis on electrical devices and systems. Reliability concepts and models. Risk analysis. Lifetime evaluation. System examples. No credit for students who have earned credit for 4287. [3]

EECE 5288. Optoelectronics. (Also listed as EECE 4288) 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. No credit for students who have earned credit for 4288. SPRING. [3]

EECE 5289. Spacecraft Systems. Spacecraft electrical and electronic subsystems with emphasis on practical limitations and hazards in space. Analysis of environments, mechanisms of failure, and implications for design. No credit for students who have earned credit for 4289. SPRING. [3]

EECE 5334. RF and Microwave Design. Modeling of components and transmission structures at RF and microwave frequencies (30 MHz to 30 GHz), with emphasis on the effects of materials and geometry on passive structures for filtering and impedance matching. Modeling and design of active circuits and components such as RF amplifiers with input and output impedance matching structures. Prereq: EECE 3233. SPRING. [3]

EECE 5353. Image Processing. Digital imaging and computational photography. Image formation. Point processing. Color perception and manipulation. Spatial filtering via convolution. 2D Fourier transforms. Frequency-domain filtering. Intensity quantization. High dynamic range imaging. Resampling for image resizing, rotation, and warping. Image compositing. Panorama generation. Noise reduction. Mathematical morphology. Image compression. Three lectures and one three-hour virtual laboratory. No credit for students who have earned credit for 4353. FALL. [4]

EECE 5354. Computer Vision. Computational processes. Python and OpenCV for real-time processing. Feature detection: edges, corners, and oriented histogram methods. Feature matching. Scale space. Projective geometry. Camera models. Stereopsis. Image rectification. Multi-baseline stereo. Motion estimation. 3D reconstruction. Machine learning for computer vision including multilayer neural networks. No credit for students who have earned credit for 4354. SPRING. [3]

EECE 5356. Digital Signal Processing. (Also listed as EECE 4356) Applications of Digital Signal Processing (DSP) chips to sampling, digital filtering, FFTs, etc. Three lectures and one laboratory period. No credit for students who have earned credit for 4356. SPRING. [4]

EECE 5358. Control Systems II. (Also listed as EECE 4358) Modern control design. Discrete-time analysis. Analysis and design of digital control systems. Nonlinear systems and optimum control systems. Fuzzy control systems. Two lectures and one laboratory. No credit for students who have earned credit for 4358. SPRING. [3]

EECE 5371. Mobile and Wireless Networks. (Also listed as EECE 4371) Design, development, and applications of mobile applications and services. Topics include wireless technologies, smart phone programming, cloud computing services. No credit for students who have earned credit for 4271. [3]

EECE 5376. Embedded Systems. (Also listed as EECE 4376) Design and application of embedded microcontroller-based systems. Programming for real-time systems and the Internet of Things. Embedded system modeling, design, analysis, and implementation using real-time and event-driven techniques. A structured project is required. No credit for students who have earned credit for 4376. Corequisite: EECE 5376L. FALL. [3]

EECE 5376L. Embedded Systems Laboratory. (Also listed as EECE 4376L) Laboratory for EECE 5376. A team-oriented structured project is required. One three-hour laboratory per week. Corequisite: EECE 5376. No credit for students who have earned credit for 4376L. FALL. [1]

EECE 5377. FPGA Design. (Also listed as EECE 4377) 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. No credit for students who have earned credit for 4377. [3]

EECE 5380. Electronics II. (Also listed as EECE 4380) 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. No credit for students who have earned credit for 3380. SPRING. [3]

EECE 5385. VLSI Design. (Also listed as EECE 4385) 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. No credit for students who have earned credit for 4385. FALL. [3]

EECE 5891. Special Topics. (Also listed as EECE 3891) No credit for students who have earned credit for 3891. [1-3 each semester]

EECE 5892. Special Topics. (Also listed as EECE 3892) No credit for students who have earned credit for 3892. [1-3 each semester]

EECE 6301. Solid-State Materials. Properties of charged particles under the influence of an electric field, quantum mechanics, particle statistics, fundamental particle transport, and band theory of solids. FALL. [3]

EECE 6302. Electric and Magnetic Properties of Solids. 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 6301. SPRING. [3]

EECE 6303. Nanophotonic Devices. Review of basic photonics concepts and investigation of applications of nanophotonic devices in free-space, photonic and optoelectronic circuits, medicine, and energy. Emphasis is placed on recent literature and new technologies. SPRING. [3]

EECE 6304. 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 6305. Topics in Applied Magnetics. Selected topics in magnetism, magnetic properties of crystalline and non-crystalline materials; ferrite materials for electronics and microwave applications, resonance phenomena. Prerequisite: EECE 6302. [3]

EECE 6306. 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 6307. Solid-State Effects and Devices II. The structure of solids, phonons, band theory, scattering phenomena, and theory of insulators. [3]

EECE 6311. Systems Theory. Use of linear algebra and matrix analysis for solving systems of linear and ordinary differential equations. State space representations of control systems.

Stability, controllability, and observability. Support-vector machines as applied functional analysis. Gradient-based optimization techniques. Dimensionality reduction. SPRING. [3]

EECE 6321. Cyber-Physical Systems. Modeling, design, and analysis of cyber-physical systems that integrate computation and communication with physical systems. Modeling paradigms and models of computation, design techniques and implementation choices, model-based analysis and verification. Project that covers the modeling, design, and analysis of CPS. [3]

EECE 6341. 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 6342. 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. [3]

EECE 6343. Digital Systems Architecture. Architectural descriptions of various CPU designs, storage systems, IO systems, parallel and von Neumann processors and interconnection networks. [3]

EECE 6354. 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. [3]

EECE 6356. Intelligent Systems and Robotics. Fundamental technologies in autonomous vehicles. Bayesian probability. Probabilistic robotics. Coordinate changes. Representations of rotation. Motion and sensor models. Bayes filters. Simultaneous localization and mapping. Current machine learning approaches. FALL. [3]

EECE 6357. Advanced Image Processing. Techniques of image processing. Topics include image formation, digitization, linear shift-invariant processing, feature detection, and motion. Prerequisite: MATH 2300; programming experience. FALL. [3]

EECE 6358. Quantitative Medical Image Analysis. Image processing and statistical methods for quantitative analysis and interpretation of medical imaging data. Neuroimaging approaches related to brain structure, function, and connectivity. Massively univariate analysis (parametric mapping), multiple comparison issues, random fields, independent components, non-parametric approaches, and Monte Carlo methods. Students should have knowledge of undergraduate probability and computer programming. [3]

EECE 6361. Random Processes. Concepts of random variables, functions of random variables, and random processes. Spectral properties of random processes and of the response of linear systems to random inputs. Linear mean square estimation. Emphasis on engineering applications. FALL. [3]

EECE 6362. Detection and Estimation Theory. Fundamental aspects of signal detection and estimation. Formulation of maximum likelihood, maximum aposteriori, and other criteria. Multidimensional probability theory, signal and noise problems, and Kalman filter structure are studied. SPRING. [3]

EECE 7899. Master of Engineering Project.

EECE 7999. Master's Thesis Research. [0-6]

EECE 8395. Special Topics. Based on research and current developments in electrical engineering of special interest to staff and students. [3]

EECE 8396. Special Topics. Based on research and current developments in electrical engineering of special interest to staff and students. [3]

EECE 8850. 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 8991. Seminar. [1]

EECE 8992. Advanced Seminar for Ph.D. Candidates. [1]

EECE 8999. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit 0-12]

EECE 9999. Ph.D. Dissertation Research. [0-12]

ENGM 2160. Engineering Economy. Economic evaluation and comparison of alternatives: interest, periodic payments, depreciation, criteria, and analytical procedures in investment decision-making, and cost-estimating. FALL, SPRING. [3]

ENGM 2210. Technology Strategy. Critical issues faced by chief technology officers. Assessment of technological capabilities and opportunities, formulation of a technical plan for the product portfolio and commercialization, management of intellectual property, and economic analysis. Prerequisite: Sophomore standing. FALL, SPRING. [3]

ENGM 2440. Applied Behavioral Science. Leadership styles, power team building, conflict resolution, management resolution, interviewing techniques. Prerequisite: sophomore standing. FALL, SPRING, SUMMER. [3]

ENGM 3000. Enterprise System Design. Design of complex enterprise systems and processes including enterprise requirements analysis, process-mapping, modeling, performance measurement, benchmarking, solution development, and change management. Prerequisite: ENGM 2210 or BUS 2700, junior standing. FALL, SPRING. [3] (not offered 2020-21)

ENGM 3010. 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 2210, junior standing. FALL, SPRING. [3]

ENGM 3100. Finance and Accounting for Engineers. Time value of money, capital budgeting and formation, financial accounting and reporting, double entry bookkeeping, taxation, performance ratio measurements, and working capital management. Probabilistic models for expected net present value and rate of return, dividend pricing models for alternative growth scenarios, cost and market based models for average cost of capital, taxation algorithms, and regression analysis for individual firm betas. Prerequisite: Junior standing. FALL, SPRING, SUMMER. [3]

ENGM 3200. Technology Marketing. Strategies for marketing technology-based products and services. Demand analysis, segmentation, distribution, and personal selling. Economic analysis from inception to end use. Prerequisite: ENGM 2210 or BUS 2600, junior standing. FALL. [3]

ENGM 3300. Technology Assessment and Forecasting. Methods of forecasting technological advancements and assessing their potential intended and unintended consequences. Delphi method, trend exploration, environmental monitoring, and scenario development. Prerequisite: Junior standing. SPRING. [3]

ENGM 3350. Organizational Behavior. Study of the factors that impact how individuals and groups interact and behave within organizations, and how organizations respond to their environment. Motivation theory, communication within organizations, group dynamics, conflict management, decision making, power, strategic planning, organizational culture, and change. Focus on utilizing analytical tools to understand organizations: symbolic, political, human resources, and structural. Prerequisite: ENGM 2440. [3]

ENGM 3600. 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: junior standing. FALL. [3]

ENGM 3650. 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: MATH 1301 or BUS 2700, junior standing. FALL. [3]

ENGM 3700. Program and Project Management. Scheduling, cost estimation/predictions, network analysis, optimization, resource/load leveling, risk/mitigation, quality/testing, international projects. Term project required. Provides validated preparation for the Project Management Institute CAPM certification for undergraduates or the PMP for graduate students. Credit given for only one of ENGM 3700, CE 4400, or EECE 4950. Prerequisite: MATH 1301 or BUS 2700, junior standing. FALL, SPRING, SUMMER. [3]

ENGM 3850. Independent Study. Readings or projects on topics in engineering management under the supervision of the ENGM faculty. Consent of instructor required. [1-3 each semester, not to exceed a total of 3].

ENGM 3851. Independent Study. Readings or projects on topics in engineering management under the supervision of the ENGM faculty. Consent of instructor required. [1-3 each semester, not to exceed a total of 3]

ENGM 3890. Special Topics. [Variable credit, 1-3 each semester]

ENGM 3891. Special Topics. [Variable credit: 1-3 each semester]

ENGM 4500. Product Development. Project-based course focused on the methods for managing the design, development, and commercialization of new products. Generating product concepts, developing a prototype strategy, modeling financial returns, securing intellectual property, designing retail packaging, and performing market testing to establish an optimal price. Teams include Engineering and MBA students. Prerequisite: ENGM 2210; ENGM 3700 or CE 4400 or EECE 4950; junior standing. SPRING. [4]

ENGM 4800. Wealth Management for Engineers. Foundations of financial planning; managing basic assets, credit, and insurance needs; employee incentive plans such as stock options, deferred compensation and severance; managing investments in stocks, bonds, mutual funds, and real estate; retirement and estate planning such as 401k, 403b, IRA, Roth, estate preservation. Students in the School of Engineering may only receive open elective credit for ENGM 4800. Prerequisite: senior standing. SPRING [1]

ENGM 4951. Engineering Management Capstone Project. Application of engineering management concepts through team projects sponsored by faculty or seed-stage technology companies. Thinking, analysis, and planning processes needed to commercialize a concept and develop a business plan for presentation to investors. Prerequisite: ENGM 2210; ENGM 3000 or 3010. Corequisite: ENGM 3700. SPRING. [3]

ENGM 5000. Enterprise System Design. (Also listed as ENGM 3000) Design of complex enterprise systems and processes including enterprise requirements analysis, process-mapping, modeling, performance measurement, benchmarking, solution development, and change management. No credit for students who have earned credit for 3000. FALL, SPRING. [3] (not offered 2020-21)

ENGM 5010. Systems Engineering. (Also listed as ENGM 3010) Fundamental considerations associated with the engineering of large-scale systems. Models and methods for systems engineering and problem solving using a systems engineering approach. No credit for students who have earned credit for 3010. FALL, SPRING. [3]

ENGM 5100. Finance and Accounting for Engineers. (Also listed as ENGM 3100) Time value of money, capital budgeting and formation, financial accounting and reporting, double entry bookkeeping, taxation, performance ratio measurements, and working capital management. Probabilistic models for expected net present value and rate of return, dividend pricing models for alternative growth scenarios, cost and market based models for average cost of capital, taxation algorithms, and regression analysis for individual firm betas. No credit for students who have earned credit for 3100. FALL, SPRING, SUMMER. [3]

ENGM 5200. Technology Marketing. (Also listed as ENGM 3200) Strategies for marketing technology-based products and services. Demand analysis, segmentation, distribution, and personal selling. Economic analysis from inception to end use. No credit for students who have earned credit for 3200. FALL. [3]

ENGM 5300. Technology Assessment and Forecasting. (Also listed as ENGM 3300) Methods of forecasting technological advancements and assessing their potential intended and unintended consequences. Delphi method, trend exploration, environmental monitoring, and scenario development. No credit for students who have earned credit for 3300. SPRING. [3]

ENGM 5600. Technology-Based Entrepreneurship. (Also listed as ENGM 3600) 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. No credit for students who have earned credit for 3600. FALL. [3]

ENGM 5650. Operations and Supply Chain Management. (Also listed as ENGM 3650) 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. No credit for students who have earned credit for 3650. FALL. [3]

ENGM 5700. Program and Project Management. (Also listed as ENGM 3700) Scheduling, cost estimation/predictions, network analysis, optimization, resource/load leveling, risk/mitigation, quality/testing, international projects. Term project required. Provides validated preparation for the Project Management Institute CAPM certification for undergraduates or the PMP for graduate students. Credit given for only one of ENGM 3700 or 5700, CE 4400 or 5400, or EECE 4950. FALL, SPRING, SUMMER. [3]

ENGM 5890. Special Topics. Variable credit each semester. [1-3]

ENGM 6100. Strategic Technology Management. Assessment of new opportunities in an enterprise-developing technology product. Selection of opportunities to pursue. The stage gate model as a tool for technology and opportunity assessment. Formulation of a plan for new product introduction. Product lifecycle management, intellectual property management, and economic analysis. [3]

ENGM 6200. Technology Forecasting. Forecasting technological advancements and assessing their potential intended and unintended consequences. Delphi method, trend extrapolation, environmental monitoring, and scenario development. [3]

ENGM 6300. Marketing Principles of Technology. Strategy formulation and implementation with an emphasis on technology products and fundamental concepts. Corporate strategic framework, branding, consumer preferences, buying behavior, and brand equity. Types of markets and segments, digital marketing trends, channels, and pricing. [3]

ENGM 6400. Operations and Supply Chain Strategy. Manufacturing and service processes for transforming resources into technology-based products. Strategies and processes for moving information and materials through technology-based product supply chains, and supporting overall firm objectives, product development programs and capacity utilization requirements. Manufacturing for flow design and facility layout. Processes, blueprinting, and waiting line analysis for structuring the service encounter. Six sigma quality and statistical process control. Lean supply chains, logistics, distribution and global sourcing. Enterprise resource planning, inventory management and materials requirement planning. [3]

ENGM 6500. Engineering Leadership and Program Management. Application of core principles of leadership and program management for engineering professionals. Strategic planning, people management, staffing, compensation, business process improvement theory, business interruption, leadership styles, emotional intelligence, negotiation, ethical business practices. [3]

ENGM 6500. Engineering Leadership and Program Management. Application of core principles of leadership and program management for engineering professionals. Strategic planning, people management, staffing, compensation, business process improvement theory, business interruption, leadership styles, emotional intelligence, negotiation, ethical business practices. [3]

ENGM 6600. Program and Project Management Strategies. Management of small to medium sized projects ($10K to $10M), and introduction to the management of very large and complex projects. The engineering design process, design tools, software assisted decision making, and professional management skills. [3]

ENGM 6700. Intellectual Property for Engineering and Scientists. Assessment of intellectual property law for a technical (non-legal) audience. Forms of IP protection (trademark, copyright, patents), with a focus on patents. Use of intellectual property on business strategy and effects on business and technology development decisions. Open source and its impact. Discussion of practical legal considerations and broader policy questions. [3].

ENGM 6800. Finance and Accounting. Capital budgeting, time value of money, cost of capital, and financial statement presentations. Capital formation for technology based firms. Sample debt and equity financings, leases and hybrid forms of capital. Financial accounting and reporting, metrics, sources of information, and statement analysis. Taxation of business income, financial modeling, asset based line of credit, and working capital management. [3]

ENGM 7897. Master of Engineering Project. [2]

ENGM 7898. Master of Engineering Project. Prerequisite: ENGM 7897. [2]

ENGM 7899. Master of Engineering Project. Prerequisite: ENGM 7898. [2]

ES 1001. Engineering Commons iSeminar. Topics vary. Open elective credit only. [1]

ES 1115. Engineering Freshman Seminar. First-year Engineering Seminar. [1]

ES 1401. Introduction to Engineering, Module1. 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 1402. Introduction to Engineering, Module 2. Continuation of ES 1401. ES 1401-1403 must be completed in one semester for full course credit. FALL. [1]

ES 1403. Introduction to Engineering, Module 3. Continuation of ES 1402. ES 1401-1403 must be completed in one semester for full course credit. FALL. [1]

ES 2100W. 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 includes writing and editing reports of various lengths, preparing and using visual aids, and presenting oral reports. Prerequisite: Sophomore standing. FALL, SPRING. [3]

ES 2700. Engineering Career Development. A practical course designed to help students succeed in the job/internship search and career development. Interviewing, networking, online tools, elevator pitch, career fair strategies, career center resources, company research techniques, resumes, cover letters, negotiating, follow-up messages. FALL [1]

ES 2900. Engineering and Public Policy. Role of federal policy in supporting and promoting engineering and science for the benefit of the U.S. Ways engineering, science and public policy impact each other. Federal government involvement, policy making, federal budget, role of universities and national labs, national defense, homeland security, biomedical enterprise. SPRING [3]

ES 3230. Ships Engineering Systems. Ship characteristics and types, including design and control, propulsion, hydrodynamic forces, stability, compartmentation, and electrical and auxiliary systems. Theory and design of steam, gas turbine, and nuclear propulsion. FALL. [3]

ES 3231. Navigation. Naval piloting procedures. Charts, visual and electronic aids, and theory and operation of magnetic and gyro compasses; inland and international rules of the nautical road. The celestial coordinate system, including spherical trigonometry and application for navigation at sea. Environmental influences on naval operations. SPRING. [3]

ES 3232. Ships Weapons Systems. Theory and employment of weapons systems, including the processes of detection, evaluation, threat analysis, weapon selection, delivery, guidance, and explosives. Fire control systems and major weapons types, including capabilities and limitations. Physical aspects of radar and underwater sound. Command, control, and communications and means of weapons system integration. SPRING. [3]

ES 3233. Naval Operations. Methods of tracking and intercepting at sea. Maritime maneuvering problems, formation tactics, and shipboard operations. Naval communications, ship behavior and maneuvering, and applied aspects of ship handling. Prerequisite: ES 231. FALL. [3]

ES 3300. Energy and Sustainability - An Engineering Approach. Uses basic understanding of mechanics, thermodynamics, and electrodynamics to describe primary and secondary energy generation and use. Emphasis on current applications, energy efficiency at both the source and demand sides, and future (near and long-term) energy scenarios. Various economic models are explored. Prerequisite: junior or senior standing. [3]

ES 3860. Undergraduate Research. Independent study under the direction of a faculty member with expertise in the area of study. [1-3 each semester]

ES 3884. Internship. Internship credit for work approved by the Associate Dean of the School of Engineering. A written scholarly project must be produced in the internship. Course must be taken P/F. May be repeated for credit; maximum of total 4 hours. No more than 2 hours may count toward degree requirements. FALL, SPRING, SUMMER. [1]

ES 3890. 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]

ES 4951. Senior Capstone Experience. Based on project specifications typically supplied by industrial sponsors or part of a student's immersive experience. Students are responsible for the formulation, execution, qualification, and documentation of a culminating capstone experience. Application of knowledge acquired from earlier coursework, both within and outside the engineering core area, along with realistic technical, managerial, and budgetary constraints using standard systems engineering methodologies and practices. Prerequisite: Senior standing. Corequisite: ENGM 3700. SPRING. [3]

ES 4959. 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]

ENVE 3610. Sustainable Development. 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. SPRING. [3]

ENVE 4305. Enterprise Risk Management. Development of an organization-wide risk management program 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. SPRING. [3]

ENVE 4600. 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 1602. FALL. [3]

ENVE 4605. Environmental Thermodynamics, Kinetics, and Mass Transfer. Examination of fundamental environmental processes and phenomena. Uses of equilibrium phenomena, process rate and mass transport phenomena to solve a broad range of environmental problems. Prerequisite: CHEM 1602, MATH 2420, CE 3600. SPRING. [3]

ENVE 4610. Biological Processes in Environmental Systems. 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. SPRING. [3]

ENVE 4615. 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. FALL. [3]

ENVE 4620. Environmental Characterization and Analysis. 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 through demonstrations featuring state-of-the-art analytical instrumentation. Prerequisite: CE 3600, ENVE 4600. SPRING. [3]

ENVE 4625. Environmental Separations Processes. Fundamentals and applications of separations processes relevant to water and wastewater treatment and other environmental systems. Topics include coagulation/flocculation, sedimentation, granular filtration; advanced separation processes such as various membrane processes, absorption, ion exchange, thermally driven separations, and electrically driven separations including electrodialysis and capacitive deionization. SPRING. [3]

ENVE 4700. 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 4705. 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. Prerequisites: CE 3700 or ME 3224 or ChBE 3300 or EES 4550. FALL. [3]

ENVE 4710. 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 3700, CE 3705. FALL. [3]

ENVE 4715. 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. Prerequisite: MATH 2420, CE 3700. SPRING. [3]

ENVE 4720. 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 4605. SPRING. [3]

ENVE 4800. 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 5305. Enterprise Risk Management. (Also listed as ENVE 4305) Development of an organization-wide risk management program 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. No credit for students who have earned credit for ENVE 4305. SPRING. [3]

ENVE 5600. Environmental Chemistry. (Also listed as ENVE 4600) 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. No credit for students who have earned credit for 4600. FALL. [3]

ENVE 5605. Environmental Thermodynamics, Kinetics, and Mass Transfer. (Also listed as ENVE 4605) Examination of fundamental environmental processes and phenomena that provide the analytical tools necessary to solve a broad range of environmental problems. These tools include equilibrium phenomena, process rate and mass transport phenomena. No credit for students who have earned credit for 4605. SPRING. [3]

ENVE 5610. Biological Processes in Environmental Systems. (Also listed as ENVE 4610) 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. No credit for students who have earned credit for ENVE 4610. SPRING. [3]

ENVE 5615. Environmental Assessments. (Also listed as ENVE 4615) 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. No credit for students who have earned credit for 4615. FALL. [3]

ENVE 5620. Environmental Characterization and Analysis. (Also listed as ENVE 4620) 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 through demonstrations featuring state-of-the-art analytical instrumentation. No credit for students who have earned credit for 4620. SPRING. [3]

ENVE 5625. Environmental Separations Processes. (Also listed as ENVE 4625) Fundamentals and applications of separations processes relevant to water and wastewater treatment and other environmental systems. Topics include coagulation/flocculation, sedimentation, granular filtration; advanced separation processes such as various membrane processes, absorption, ion exchange, thermally driven separations, and electrically driven separations including electrodialysis and capacitive deionization. No credit for students who have earned credit for ENVE 4625. SPRING. [3]

ENVE 5700. Energy and Water Resources. (Also listed as ENVE 4700) 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. No credit for students who have earned credit for 4700. SPRING. [3]

ENVE 5705. Physical Hydrology. (Also listed as ENVE 4705) Development of fundamental bases of hydrological processes. Landatmosphere processes, surfacewater 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. No credit for students who have earned credit for 4705. FALL. [3]

ENVE 5710. Hydrology. (Also listed as ENVE 4710) The hydrologic cycle, study of precipitation, evapotranspiration, hydrometeorology, stream flow, flood flow, flood routing, storm sewer design, detention basin design, and water quality. No credit for students who have earned credit for 4710. FALL. [3]

ENVE 5715. Groundwater Hydrology. (Also listed as ENVE 4715) 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. No credit for students who have earned credit for 4715. SPRING. [3]

ENVE 5720. Surface Water Quality Modeling. (Also listed as ENVE 4720) 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. No credit for students who have earned credit for 4720. SPRING. [3]

ENVE 5800. Nuclear Environmental Engineering. (Also listed as ENVE 4800) 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. No credit for students who have earned credit for 4800. SPRING. [3]

ENVE 6800. 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. SPRING. [3]

ENVE 6805. 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. FALL. [3]

ENVE 7531. Nuclear Chemistry and Processes. Chemistry and chemical processing of the actinides and important fission products and byproducts. Development of nuclear chemical engineering processes for these materials. SPRING. [3]

ENVE 7533. 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. FALL. [3]

ENVE 7534. 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 7899. Master of Engineering Project.

ENVE 7999. Master's Thesis Research. [0-6]

ENVE 8000. 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 8001. 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 8002. 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 8300. Research Methods Seminar. Coverage of graduate-level skills required to conduct critical review of a topic and produce research proposals, research presentations, and peer-reviewed journal publications. Includes discussion of responsible conduct in research and ethics. FALL. [0]

ENVE 8999. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

ENVE 9999. Ph.D. Dissertation Research. [0-12]

MSE 1500. 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: MSE 1500L. SPRING. [3]

MSE 1500L. Materials Science Laboratory. Laboratory for MSE 1500. One three-hour laboratory per week. Corequisite: MSE 1500. SPRING. [1]

MSE 2205. Strength and Structure of Engineering Materials. Laboratory supplement to CE 2205. 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 2205. FALL. [1]

MSE 2500. Materials Science II. Functional materials based on their electromagnetic, thermal and optical properties. Electrical and magnetic behavior of materials, semiconductivity, band gap engineering, nanostructures, and new materials, such as metamaterials. Case studies of devices found in modern vehicles, homes, communications systems, and computing devices. Prerequisite: MSE 1500. FALL. [3]

MSE 3860. Undergraduate Research. Open to select engineering students to do research under the guidance of a faculty member. A formal written report is required. [1-3]

MSE 3889. 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. [Variable credit: 1-3 each semester]

MSE 3890. 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]

MSE 6310. Atomic Arrangements in Solids. Atomic arrangements in metals, ceramics, semiconductors, glasses, and polymers. Lattice geometry and crystal symmetry to describe crystal structures. Nanocrystalline materials. Scattering theory and diffraction phenomena for structural characterization. FALL. [3]

MSE 6343. 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. FALL. [3]

MSE 6391. Special Topics. Based on faculty research projects and highly specialized areas of concentration. FALL, SPRING. [Variable credit: 1-3 each semester]

MSE 6392. Special Topics. Based on faculty research projects and highly specialized areas of concentration. FALL, SPRING. [Variable credit: 1-3 each semester]

MSE 7999. Master's Thesis Research. [0-6]

MSE 8991. 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]

MSE 8992. 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]

MSE 8999. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit: 0-12]

MSE 9999. Ph.D. Dissertation Research. [0-12]

ME 1150. 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. [1]

ME 1151. Laboratory in Machining. Machining and fabrication of metals and plastics. Fabrication, design and manufacturability of parts or components. [1]

ME 1152. Laboratory in Welding. Theory of welding processes and welding of metals. Design, fabrication, and manufacturability of parts or components using welding processes. [1]

ME 1153. Computer Aided Design. Use of computers for solid modeling of machine parts and assemblies. [1]

ME 2160. Introduction to Mechanical Engineering Design. Design fundamentals, computer-aided design, machine fabrication techniques, technical drawing, team-based learning, and a comprehensive design project. Two lectures and one lab. Prerequisite: ES 1401-1403 and Mechanical Engineering major. FALL. [3]

ME 2171. Instrumentation Laboratory. Techniques associated with engineering measurements, curve fitting, presentation, and analysis of data. Corequisite: MATH 2300. SPRING. [2]

ME 2190. Dynamics. The principles of dynamics (kinematics and kinetics) of particles and rigid bodies. Mechanical vibrations. Continuous media. Prerequisite: CE 2200, PHYS 1601. Corequisite: MATH 2300. FALL, SPRING, SUMMER. [3]

ME 2220. Thermodynamics. Application of the first and second laws to energy transformation processes and properties of technologically important materials. Prerequisite: PHYS 1601, MATH 2300. FALL, SPRING, SUMMER. [3]

ME 3202. Machine Analysis and Design. Application of the principles of mechanics of materials to the analysis and synthesis of machine elements. Corequisite: CE 2205. FALL. [3]

ME 3204. Mechatronics. Design of analog and digital electromechanical sensors and actuators, signal and power electronics, and application of digital microcontrollers to mechatronic systems. Prerequisite: EECE 2112; CS 1101 or 1103 or 1104. SPRING. [3]

ME 3224. 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 2190, MATH 2420. Credit not awarded for both ME 3224 and CE 3700. FALL. [3]

ME 3234. 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 2190, MATH 2420. FALL. [4]

ME 3248. 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 2220, ME 3224. SPRING. [3]

ME 3850. Independent Study. Under the direction of a faculty member, students study in a focused area of mechanical engineering culminating in an engineering report of the activities and findings. [1-3]

ME 3860. Undergraduate Research. Under the direction of a faculty member, students conduct a research project. A formal, written report is required. [1-3]

ME 3890. 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. FALL, SPRING, SUMMER. [Variable credit: 1-3 each semester] (Offered on demand)

ME 4213. Energetics Laboratory. Experimental methods in heat transfer, fluid mechanics, and thermodynamics as applied to energy conversion systems and their analyses. Prerequisite: Senior standing. FALL. [2]

ME 4221. Intermediate Thermodynamics. Application of principles of thermodynamics to vapor and gas cycles, mixtures, combustion, and compressible flow. Prerequisite: ME 2220. Corequisite: MATH 2420. [3]

ME 4226. Gas Dynamics. Compressible flow from subsonic to supersonic. Shock waves, expansion waves, shock tubes, and supersonic airfoils. Prerequisite: ME 3224. [3]

ME 4236. 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. Prerequisite: ME 3234. FALL. [3]

ME 4251. Modern Manufacturing Processes. Manufacturing science and processes. A quantitative approach dealing with metals, ceramics, polymers, composites, and nanofabrication and microfabrication technologies. Prerequisite: ME 3202. Corequisite: ME 4950. [3]

ME 4258. Engineering Acoustics. The wave equation and its solutions; acoustic sources; reflection and transmission of sound; propagation in pipes, cavities, and waveguides; noise standards and effects of noise on people; principles of noise and vibration control; signal processing in acoustics; environmental noise measurement and control; and various contemporary examples. Prerequisite: MATH 2400 or 2420. [3]

ME 4259. 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 2190, MATH 2420. [3]

ME 4260. Energy Conversion. 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 2220, ME 3224. [3]

ME 4261. Basic Airplane Aerodynamics. Study of the atmosphere; analysis of incompressible and compressible flows, shock waves, boundary layer and skin friction drag, lift and drag forces over airfoils and wings, and flight performance; aircraft stability and control, wing icing, and parachute-based recovery; history of flight and aerodynamics. Corequisite: ME 3224. [3]

ME 4262. Environmental Control. Heating and cooling systems, energy conservation techniques, use of solar energy and heat pumps. Prerequisite: ME 2220. Corequisite: ME 3248. [3]

ME 4263. 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 3224. SPRING. [3]

ME 4264. Internal Combustion Engines. Thermodynamics of spark ignition and compression ignition engines; gas turbines and jet propulsion. Prerequisite: ME 2220. [3]

ME 4265. 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 2220. [3]

ME 4267. Aerospace Propulsion. Application of classical mechanics and thermodynamics to rocket and aircraft propulsion. Design and performance analysis of air-breathing and chemical rocket engines. Advanced propulsion systems for interplanetary travel. Contemporary issues in aerospace propulsion: space exploration, renewable fuels. Prerequisite: ME 2220, ME 3224. [3]

ME 4271. 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 2410. [3]

ME 4275. Finite Element Analysis. Development and solution of finite element equations for solid mechanics and heat transfer problems. Commercial finite element and pre- and post-processing software. Two lectures and one three-hour laboratory each week. Prerequisite: CE 2205, MATH 2420. [3]

ME 4280. 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 2190, MATH 2420. [3]

ME 4284. 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 3234. [3]

ME 4950. 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 3202. FALL. [2]

ME 4951. 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 4950. SPRING. [3]

ME 4959. 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 4950. FALL. [1]

ME 5236. Linear Control Theory. (Also listed as ME 4236) 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. No credit for students who have earned credit for 4236. [3]

ME 5251. Modern Manufacturing Processes. (Also listed as ME 4251) Manufacturing science and processes. A quantitative approach dealing with metals, ceramics, polymers, composites, and nanofabrication and microfabrication technologies. No credit for students who have earned credit for 4251. [3]

ME 5258. Engineering Acoustics. (Also listed as 4258) The wave equation and its solutions; acoustic sources; reflection and transmission of sound; propagation in pipes, cavities, and waveguides; noise standards and effects of noise on people; principles of noise and vibration control; signal processing in acoustics; environmental noise measurement and control; and various contemporary examples. No credit for students who have earned credit for 4258. [3]

ME 5259. Engineering Vibrations. (Also listed as ME 4259) 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. No credit for students who have earned credit for 4259. [3]

ME 5260. Energy Conversion. (Also listed as ME 4260) 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. No credit for students who have earned credit for 4260. [3]

ME 5261. Basic Airplane Aerodynamics. (Also listed as ME 4261) Study of the atmosphere; analysis of incompressible and compressible flows, shock waves, boundary layer and skin friction drag, lift and drag forces over airfoils and wings, and flight performance; aircraft stability and control, wing icing, and parachute-based recovery; history of flight and aerodynamics. Corequisite: ME 3224. No credit for students who have earned credit for 4261. [3]

ME 5262. Environmental Control. (Also listed as ME 4262) Heating and cooling systems, energy conservation techniques, use of solar energy and heat pumps. No credit for students who have earned credit for 4262. [3]

ME 5263. Computational Fluid Dynamics and Multiphysics Modeling. (Also listed as ME 4263) 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. No credit for students who have earned credit for 4263. SPRING. [3]

ME 5264. Internal Combustion Engines. (Also listed as ME 4264) Thermodynamics of spark ignition and compression ignition engines; gas turbines and jet propulsion. No credit for students who have earned credit for 4264. [3]

ME 5265. Direct Energy Conversion. (Also listed as ME 4265) 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. No credit for students who have earned credit for 4265. [3]

ME 5267. Aerospace Propulsion. (Also listed as ME 4267) Application of classical mechanics and thermodynamics to rocket and aircraft propulsion. Design and performance analysis of air-breathing and chemical rocket engines. Advanced propulsion systems for interplanetary travel. Contemporary issues in aerospace propulsion: space exploration, renewable fuels. No credit for students who have earned credit for 4267. [3]

ME 5271. Robotics. (Also listed as ME 4271) 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. No credit for students who have earned credit for 4271. [3]

ME 5275. Finite Element Analysis. (Also listed as ME 4275) Development and solution of finite element equations for solid mechanics and heat transfer problems. Commercial finite element and pre- and post-processing software. Two lectures and one three-hour laboratory each week. No credit for students who have earned credit for 4275. [3]

ME 5280. Advanced Dynamics of Mechanical Systems. (Also listed as ME 4280) 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. No credit for students who have earned credit for 4280. [3]

ME 5284. Modeling and Simulation of Dynamic Systems. (Also listed as ME 4284) Incorporates bond graph techniques for energybased lumped-parameter systems. Includes modeling of electrical, mechanical, hydraulic, magnetic and thermal energy domains. Emphasis on multi-domain interaction. No credit for students who have earned credit for 4284. [3]

ME 7899. Master of Engineering Project.

ME 7999. Master's Thesis Research. [0-6]

ME 8320. 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. Gibbs method. Prerequisite: ME 2220. [3]

ME 8323. Micro/NanoElectroMechanical Systems. Fabrication techniques and mechanical behavior of modern MEMS/NEMS structures. Application of NEMS/MEMS devices to sensing and actuation. [3]

ME 8326. 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 3224. [3]

ME 8327. 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. [3]

ME 8331. 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 4271. [3]

ME 8333. 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. [3]

ME 8340. Wireless Mechatronics. Design of mechatronic devices with emphasis on miniaturization and wireless transmission of data. Programming of wireless microcontrollers with data acquisition and transmission from sensors and to actuators. Group design project to simulate, fabricate, and test a miniaturized wireless robot. [3]

ME 8348. 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 3248. [3]

ME 8351. Adaptive Control. Real-time parameter estimation methods. Self-tuning regulators. Model reference adaptive control. Adaptive control for nonlinear systems. A research project is required. Prerequisite: ME 5236. [3]

ME 8352. Non-linear Control Theory. Phase plane analysis, nonlinear transformations, Lyapunov stability, and controllability/observability calculations. A multidimensional geometric approach is emphasized. Prerequisite: MATH 2410. [3]

ME 8353. 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 3234. [3]

ME 8359. 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 4259; MATH 3120, MATH 4110. [3]

ME 8363. 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 3248. [3]

ME 8364. Nanophotonic Materials. Physics, design, modeling, and applications of nanophotonic materials in modern optical systems. Topics include waveguides and chip-based photonics, photonic crystals, plasmonics, and metamaterials. [3]

ME 8365. Micro/Nano 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. [3]

ME 8366. Combustion. Processes, thermodynamics, chemical kinetics, premixed flame theory, diffusion flame theory, ignition and detonation. Prerequisite: ME 3224, ME 4221. [3]

ME 8391. Special Topics. A course based on faculty research projects and highly specialized areas of concentration. [Variable credit: 1-3 each semester]

ME 8393. 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 8991. Seminar. [0]

ME 8999. Non-Candidate Research. Research prior to entry into candidacy (completion of qualifying examination) and for special non-degree students. [Variable credit 0-12]

ME 9999. Ph.D. Dissertation Research. [0-12]

NANO 3000. Materials Characterization Techniques in Nanoscale Engineering. Principles and applications of advanced materials characterization techniques to characterize specimens and engineered structures at the nano/microscale. X-ray diffraction analysis, optical microscopy, electron microscopy, surface probe techniques, focused ion-beam instruments, Rutherford backscatter analysis and chemical microanalytical techniques, treated both qualitatively and quantitatively. Lectures alternate with laboratory on a weekly basis. Prerequisites: MATH 1301; CHEM 1602 or MSE 1500. FALL. [3]

SC 3250. 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 2201 or 2204; MATH 1100 or higher. FALL. [3]

SC 3260. High Performance Computing. Parallel computing, grid computing, GPU computing, data communication, high performance security issues, performance tuning on shared-memory-architectures. Prerequisite: CS 2201 or 2204. SPRING. [3]

SC 3850. Independent Study. 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 3250. [1-3]

SC 3851. Independent Study. 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 3250. [1-3 each semester]

SC 3890. Special Topics. [1-3]

SC 5250. Scientific Computing Toolbox. (Also listed as SC 3250) 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. No credit for students who have earned credit for 3250. FALL. [3]

SC 5260. High Performance Computing. (Also listed as SC 3260) Parallel computing, grid computing, GPU computing, data communication, high performance security issues, performance tuning on shared-memory-architectures. SPRING. [3]

SC 5890. Special Topics. (Also listed as SC 3890) No credit for students who have earned credit for 3890. [1-3]