Santa Clara University

2016-17

School of Engineering Graduate Program

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Graduate Programs
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Letter from the Dean

On behalf of the School of Engineering faculty and staff, it is my great pleasure to welcome you as you embark on a new stage in your academic and personal journey. Here at Santa Clara University, we are "Engineering with a Mission," committed to providing an education that combines rigorous instruction with leading-edge practice, while providing a heightened awareness of the essential role engineering plays in contributing to the common good. Your education will advance not only your technical knowledge and skills, but will also foster a sense of life-long learning that is critical in today's rapidly changing workplace and innovation-driven global economy. The engineering profession empowers you to imagine, create, and deploy the tools, systems, and built environment that will enhance the quality of life for present and future generations.

Today's engineering requires leaders of uncompromising dedication, integrity and conscience to solve the unique challenges of an interconnected, global environment. Silicon Valley pioneers were driven by the desire to explore, to innovate, and to improve society through advances in engineering. This is a never-ending quest, not just for the Valley, but for all the world at large. If this is also your dream, you will find here the kind of community that will stimulate your imagination, expand your knowledge, and nurture the voice of conscience and compassion that extends the best practices of engineering to help create a more just, humane, prosperous, and sustainable world for all.

For over 100 years, the School of Engineering at Santa Clara University has helped students turn their dreams to reality for the betterment of society. As we continue on our second century of engineering excellence, we welcome the opportunity to be a part of your journey as you fulfill your mission!

Sincerely,

Godfrey Mungal
Dean of Engineering

Engineering at Santa Clara

The undergraduate programs leading to the Bachelor of Science degree in Civil, Electrical, and Mechanical Engineering were first offered at Santa Clara University in 1912; the programs were accredited by the Accreditation Board for Engineering and Technology in 1937. Since that time, the following degree programs have been added: Bachelor of Science in Computer Science and Engineering and in Engineering; Master of Science in Applied Mathematics, Bioengineering, Computer Science and Engineering, Electrical Engineering, Engineering Management and Leadership, Mechanical Engineering, Software Engineering and Sustainable Energy; Engineer's degree in Computer Science and Engineering, Electrical Engineering and Mechanical Engineering; and Doctor of Philosophy in Computer Science and Engineering, Electrical Engineering, and Mechanical Engineering. In addition, the School of Engineering offers a variety of certificate programs, as well as an Open University program.

SCHOOL OF ENGINEERING MISSION STATEMENT

The mission of Santa Clara University's School of Engineering is to prepare diverse students for professional excellence, responsible citizenship, and service to society. The engineering school does this through:

- Distinctive academic programs that are designed to produce engineers who approach their profession with competence, conscience, and compassion
- Broadly educated faculty, who model and encourage the notion of lifelong learning
- Scholarly activities that create new knowledge and advance the state of the art of technology
- Interactions with professional societies and companies in Silicon Valley and beyond
- Service activities that benefit our diverse constituencies and humanity in general

SCHOOL OF ENGINEERING VISION

The School of Engineering will be known and treasured, in Silicon Valley and beyond, for the impact of its graduates and faculty on improving the human condition through engineering education, practice, and scholarship.

Academic Calendar 2016-2017

FALL QUARTER 2016

July 11-15	Monday-Friday	Fall 2016 registration period
July 18	Monday	Open Enrollment Period Begins
August 21	**Sunday**	**Tuition and fee payment due**
September 5	Monday	Labor Day; administrative holiday.
September 12	Monday	Drop/Swap begins; $50 per course
September 12	Monday	Late registration; $100 fee if no previous enrollment
September 19	**Monday**	**Classes begin**
September 21	Wednesday	New Student Orientation
September 23	**Friday**	**Last day to petition for graduate degrees to be conferred in December 2016**
September 25	Sunday	Last day to change registration or withdraw from classes with a 100% tuition refund (Clear registration holds by Friday, 9/23 5 p.m.)
September 28	Wednesday	Mass of the Holy Spirit, 12 p.m. at the Mission Church. Classes will not meet from11:45-1:15 p.m. Classes scheduled to begin at 1 p.m. will begin at 1:15 p.m. (some classes may meet, consult with instructor)
October 2	Sunday	Last day to withdraw from classes with a 50% tuition refund
October 7	Friday	Last day to submit incomplete work to faculty for spring and summer 2016
October 9	Sunday	Last day to withdraw from classes with a 25% tuition refund
October 14	**Friday**	**Last day to drop class without a W (no tuition refund)**
October 14	Friday	Last day for faculty to remove Spring 2016 and Summer Session 2016 incompletes
October 17-21	Monday-Friday	Winter 2017 registration period
November 4	Friday	Last day to drop classes with a W
November 21-25	Monday-Friday	Thanksgiving recess; academic holiday (consult instructor)
November 24-25	Thursday-Friday	Thanksgiving recess; administrative holiday
December 2	**Friday**	**Classes end**
December 5-9	Monday-Friday	Fall quarter final examinations
December 14	Wednesday	Fall quarter grades due
December 21	**Wednesday**	**Tuition and fee payment due**
December 23-26	Friday-Monday	Christmas recess; administrative holiday
Dec 30 - Jan 2	Friday-Monday	New Year's recess; administrative holiday

WINTER QUARTER 2017

October 17-21	Monday-Friday	Winter 2017 registration period
October 24	Monday	Open enrollment period begins
December 21	**Wednesday**	**Tuition and fee payment due**
January 2	Monday	Drop/Swap begins; $50 per course
January 2	Monday	Late registration begins; $100 fee if no previous enrollment
January 9	**Monday**	**Classes begin**
January 11	Wednesday	New Student Orientation
January 13	Friday	Last day to petition for graduate degrees to be conferred in March 2017
January 15	Sunday	Last day to change registration or withdraw from classes with a 100% tuition refund (Clear registration holds by Friday 1/13 5 p.m.)
January 16	Monday	Martin Luther King Day; administrative holiday. Consult instructor.
January 22	Sunday	Last day to withdraw from classes with a 50% tuition refund
January 27	Friday	Last day to submit incomplete Fall 2016 work to faculty
January 29	Sunday	Last day to withdraw from classes with a 25% tuition refund
Jan 30 - Feb 3	**Monday-Friday**	**Spring 2017 registration period**
February 3	Friday	Last day drop classes without a W (no tuition refund)
February 3	Friday	Last day for faculty to remove Fall 2016 incompletes
February 20	Monday	Presidents' Day; administrative holiday. Consult instructor.
February 24	Friday	Last day to drop classes with a W
March 3	Friday	Last day to petition for graduate degrees to be conferred in June 2017
March 17	**Friday**	**Classes end**
March 20-24	Monday-Friday	Winter quarter final examinations
March 21	**Tuesday**	**Tuition and fee payment deadline**
March 29	Wednesday	Winter quarter grades due

SPRING QUARTER 2017

Jan 30-Feb 3	Monday-Friday	Spring 2017 registration period
February 6	Monday	Open enrollment period begins
March 21	**Tuesday**	**Tuition and fee payment due**
March 27	Monday	Drop/Swap begins; $50 per course
March 27	Monday	Late registration begins; $100 fee if no previous enrollment
April 3	**Monday**	**Classes begin**
April 5	Wednesday	New Student Orientation
April 9	Sunday	Last day to change registration or withdraw from classes with a 100 %tuition refund (Clear registration holds by Friday 4/7 5:00 p.m.)
April 14	**Friday**	**Good Friday, administrative holiday**
April 16	Sunday	Last day to withdraw from classes with a 50 % tuition refund
April 17-21	Monday-Friday	Summer 2017 registration period for current students for all three sessions
April 21	Friday	Last day to submit incomplete work to faculty for Winter 2017
April 23	Sunday	Last day to withdraw from classes with 25% tuition refund
April 28	Friday	Last day for faculty to remove winter 2017 incompletes
April 28	Friday	Last day to drop classes without a W (no tuition refund)
May 19	Friday	Last day to drop classes with a W
May 21	**Sunday**	**Tuition and fee payment deadline**
May 29	Monday	Memorial Day; academic and administrative holiday. (consult instructor)
June 9	**Friday**	**Classes end**
June 12-16	Monday-Friday	Spring quarter final examinations
June 16	Friday	Graduate Commencement
June 21	Wednesday	Spring quarter grades due

SUMMER SESSIONS 2017

April 17-21	Monday-Friday	Registration period for current students for all three sessions
April 24	Monday	Open enrollment period begins
May 21	Sunday	Tuition and fee payment deadline
June 19	Monday	Late registration; $100 fee if no previous enrollment
June 19	Monday	Drop/Swap begins; $50 per course
June 26	**Monday**	**Classes begin for Summer Sessions I and II**
June 30	Friday	Last day to register for all three sessions
July 4	Tuesday	Independence Day observed; administrative holiday. Classes will meet
July 7	Friday	Last day to petition for graduate degree to be conferred in September 2017
July 28	Friday	Last day to withdraw from classes for Session II only (no tuition refund)
July 28	**Friday**	**Classes end for Session II only**
July 31 - Aug 1	Monday-Tuesday	Summer Session II final examinations
August 7	**Monday**	**Classes begin for Summer Session III**
September 1	Friday	Last day to withdraw from classes for Session I only (no tuition refund)
September 1	**Friday**	**Classes end for Session I only**
September 4-8	Monday-Friday	Summer Session I final examinations
September 4	Monday	Labor day observed; administrative holiday: classes will meet
September 8	Friday	Last day to withdraw from classes for Session III only no tuition refund
September 8	**Friday**	**Classes end for Session III only**
September 11-12	Monday-Tuesday	Summer Session III final examinations

All dates are inclusive.
Registration dates are subject to change.
Registration holds must be cleared with the appropriate office by 5 p.m. on Friday when an e-campus deadline to add or drop a class falls on a Sunday.
Fall, Winter, Spring and Summer Quarter refund polices: www.scu.edu/bursar

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Santa Clara University

Santa Clara University is a comprehensive Jesuit, Catholic university located in the heart of Silicon Valley with approximately 9,000 students. Founded in 1851 by the Society of Jesus, California's oldest operating higher education institution offers a rigorous undergraduate curriculum in arts and sciences, business, and engineering, plus nationally recognized graduate and professional programs in business, education, engineering, counseling psychology, law, and pastoral ministries. The University boasts a diverse community of scholars characterized by small classes and a values-oriented curriculum. The traditions of Jesuit education—educating the whole person for a life of service—run deep in all of its curricular and co-curricular programs.

UNIVERSITY VISION, MISSION, AND FUNDAMENTAL VALUES

Santa Clara University has adopted three directional statements to describe the kind of university that it aspires to become (Strategic Vision), its core purpose and the constituencies it serves (University Mission), and the beliefs that guide its actions (Fundamental Values).

Strategic Vision

Santa Clara University will educate citizens and leaders of competence, conscience, and compassion and cultivate knowledge and faith to build a more humane, just, and sustainable world.

University Mission

The University pursues its vision by creating an academic community that educates the whole person within the Jesuit, Catholic tradition—making student learning our central focus, continuously improving our curriculum and co-curriculum, strengthening our scholarship and creative work, and serving the communities of which we are a part in Silicon Valley and around the world.

As an academic community, we expand the boundaries of knowledge and insight through teaching, research, artistic expression, and other forms of scholarship. Primarily through discovering, communicating, and applying knowledge, we exercise our institutional responsibility as a voice of reason and conscience in society.

We offer challenging academic programs and demonstrate a commitment to the development of:

- Undergraduate students who seek an education with a strong humanistic orientation in a primarily residential setting.
- Graduate students, many of them working professionals in Silicon Valley, who seek advanced degree programs that prepare them to make significant contributions to their fields.

In addition to these core programs, we also provide a variety of continuing education and professional development opportunities for nonmatriculated students.

Fundamental Values

We hold ourselves responsible for living out these core values, which are critical for carrying out our mission in pursuit of our vision:

Academic Excellence. We seek an uncompromising standard of excellence in teaching, learning, creativity, and scholarship within and across disciplines.

Search for Truth, Goodness, and Beauty. We prize scholarship and creative work that advance human understanding, improve teaching and learning, and add to the betterment of society by illuminating the most significant problems of the day and exploring the enduring mysteries of life. In this search, our commitment to academic freedom is unwavering

Engaged Learning. We strive to integrate academic reflection and direct experience in the classroom and the community, especially to understand and improve the lives of those with the least education, power, and wealth.

Commitment to Students. As teachers and scholars, mentors and facilitators, we endeavor to educate the whole person. We nurture and challenge students—intellectually, spiritually, aesthetically, morally, socially, and physically—preparing them for leadership and service to the common good in their professional, civic, and personal lives.

Service to Others. We promote throughout the University a culture of service—service not only to those who study and work at Santa Clara but also to society in general and its most disadvantaged members as we work with and for others to build a more humane, just, faith-filled, and sustainable world.

Community and Diversity. We cherish our diverse and inclusive community of students, faculty, staff, administrators, and alumni, a community that is enriched by people of different backgrounds, respectful of the dignity of all its members, enlivened by open communication, and caring and just toward others.

Jesuit Distinctiveness. We treasure our Jesuit heritage and tradition, which incorporates all of these core values. This tradition gives expression to our Jesuit educational mission and Catholic identity while also welcoming and respecting other religious and philosophical traditions, promoting the dialogue between faith and culture, and valuing opportunities to deepen religious beliefs.

ACADEMIC PROGRAMS

Santa Clara University offers undergraduate degrees leading to the bachelor of arts (B.A.), bachelor of science (B.S.), and bachelor of science in commerce. The College of Arts and Sciences offers the B.A. degree and the B.S. degree in 37 subject areas and includes the graduate program in pastoral ministries, through which it offers the master of arts (M.A.) degree in catechetics, pastoral liturgy, spirituality, and liturgical music. The Leavey School of Business offers the B.S. degree in commerce with majors in seven subject areas. The School of Engineering offers a B.S. degree with majors in seven subject areas. A variety of interdisciplinary minors and discipline-based minors are also offered in the undergraduate program.

The School of Law offers programs leading to the degrees of juris doctor (J.D.) and master of laws (LL.M.). J.D. students may earn certificates of specialization in high technology law, international law, and public interest and social justice law. A broad curriculum also includes business and commercial law, taxation, criminal law and trial advocacy, environmental law, estate planning, labor law, health law, legal writing and research, as well as opportunities for externships, clinical work, and professional skill development. The Leavey School of Business offers graduate programs leading to the master of business administration (MBA) degree with coursework in accounting, economics, finance, management, marketing, and operations management and information systems. The executive MBA program is an intensive 17-month program designed for seasoned professionals. The business school also offers a graduate program leading to the master of science (M.S.) in information systems, entrepreneurship, supply chain management, or finance. In conjunction with the law school, the business school also offers joint degree programs leading to a J.D./MBA and J.D./MSIS.

The School of Engineering offers graduate programs leading to the master of science (M.S.) degree in applied mathematics, bioengineering, civil engineering, computer science and engineering, electrical engineering, engineering management, mechanical engineering, software engineering, and sustainable energy; and the engineer's degree in computer science and engineering, electrical engineering, and mechanical engineering. The engineering school also offers the doctor of philosophy (Ph.D.) degree in computer science and engineering, electrical engineering, and mechanical engineering.

The two departments in the School of Education and Counseling Psychology offer credential and graduate programs. The Department of Education focuses on preparing teachers and administrators for public and Catholic schools. It offers programs in teacher preparation leading to credentials (i.e., California preliminary multiple-subject and single-subject teaching credentials, and California Clear credential) and the master of arts in teaching (MAT) degree. Its programs in educational administration prepare public K–12 administrators (i.e., the Preliminary California Administrative Services credential and the California Clear Administrative Services credential), and Catholic school leaders through the certificate program in Catholic School Leadership. The department also offers an M.A. program in interdisciplinary education—with emphases in curriculum and instruction; science, technology, environmental education, and mathematics (STEEM)—and educational administration. The departments of Education and Counseling Psychology jointly offer the certificate program in Alternative and Correctional Education. The Department of Counseling Psychology offers two degree programs: M.A. in counseling psychology and M.A. in counseling. The M.A. in counseling psychology can lead to state licensure for marriage and family therapists and/or licensed professional clinical counselors. The department includes emphasis programs in health, correctional, and Latino counseling.

The Jesuit School of Theology of Santa Clara University is one of only two Jesuit theological centers in the United States operated by the Society of Jesus, as the order of Catholic priests is known. Moreover, it is one of only two Jesuit theological centers in the country that offer three ecclesiastical degrees certified by the Vatican Congregation for Catholic Education. JST also offers four other advanced theological degrees, as well as sabbatical and certificate programs for clergy, religious, and lay people.

CENTERS OF DISTINCTION

Santa Clara University has three Centers of Distinction that serve as major points of interaction between the University and society. Each center's theme is central to Santa Clara's distinctive mission as a Jesuit university offering an educational environment that integrates rigorous inquiry and scholarship, creative imagination, reflective engagement with society, and a commitment to fashioning a more humane and just world. Each center, home to faculty and students from multiple disciplines, engages experts and community leaders through speaking events, conferences, workshops, and experiential learning opportunities.

Miller Center for Social Entrepreneurship

The mission of the Miller Center for Social Entrepreneurship — formerly the Center for Science, Technology, and Society before being renamed in 2015 — is to accelerate global, innovation-based entrepreneurship in service to humanity. Through an array of programs including its signature Global Social Benefit Incubator (GSBI), the Miller Center unites an international network of business, investment capital, and technical resources to build the capacity of social enterprises around the world. Its programs inspire faculty and students with real-world case studies, distinctive curricula, and unique research opportunities, advancing the University's vision of creating a more just, humane, and sustainable world (learn more at www.scu.edu/millercenter).

Ignatian Center for Jesuit Education

The Ignatian Center for Jesuit Education promotes and enhances the distinctively Jesuit, Catholic tradition of education at Santa Clara University, with a view toward serving students, faculty, staff, and through them the larger community, both local and global.

- Bannan Institutes provide yearlong thematic programs including academic events and scholarly activities that further the Jesuit, Catholic character of the University.
- Community-based learning places over 1,200 students each year with community partners, frequently in connection with an academic course.
- Immersion programs offer students, during academic breaks, the opportunity to experience local, domestic, and international communities with little access to wealth, power, and privilege.
- Spiritual Exercises of St. Ignatius provide opportunities for members of the community to encounter the spiritual sources of the Jesuit tradition.

Through these four programs, the Ignatian Center aspires to be recognized throughout Silicon Valley and beyond as providing leadership for the integration of faith, justice, and the intellectual life. Learn more at www.scu.edu/ignatiancenter.

Markkula Center for Applied Ethics

The Markkula Center for Applied Ethics is one of the preeminent centers for research and dialogue on ethical issues in critical areas. The center works with faculty, staff, students, community leaders, and the public to address ethical issues more effectively in teaching, research, and action. The center's focus areas are business, health care and biotechnology, character education, government, global leadership, technology, and emerging issues in ethics. Articles, cases, briefings, and dialogue in all fields of applied ethics are available through the center. Learn more at www.scu.edu/ethics.

FACULTY

Santa Clara University's emphasis on a community of scholars and integrated education attracts faculty members who are as committed to students' intellectual and moral development as they are to pursuing their own scholarship. The University's 500-plus full-time faculty members include Fulbright professors, nationally recognized authors and poets, groundbreaking scientists, and distinguished economic theorists.

STUDENT BODY

Santa Clara University has a student population of more than 9,000, with about 5,500 undergraduate students and 3,500 graduate students. The undergraduate population has a male-to-female ratio of 51 percent to 49 percent, and about 50 percent of undergraduate students identify themselves as persons of color. About 61 percent of undergraduates are from California, with the others coming from throughout the United States and 28 foreign countries. Seventy-seven percent of undergraduate students receive some kind of financial aid—scholarships, grants, or loans.

Half of the undergraduate population lives in University housing, with 95 percent of first-year students living on campus. Students experience an average class size of 23, The student-to-faculty ratio is 12-1.

The University's commitment to learning is demonstrated by the fact that 95 percent of first-year students advance to the sophomore year, and the percentage of Santa Clara students who graduate is among the highest in the country. The four-year graduation rate for entering freshmen is about 80 percent, and the six-year graduation rate is 85 percent.

ALUMNI

Santa Clara University has approximately 94,000 alumni living in all 50 states and more than 110 foreign countries. About 45 percent of alumni live in the San Francisco Bay Area, where many of them are leaders in business, law, engineering, academia, and public service.

ATHLETICS AND RECREATION

Santa Clara University supports a broad intercollegiate athletic program and is a Division I member of the National Collegiate Athletic Association and a founding member of the West Coast Conference (WCC). With 20 intercollegiate sports, the Broncos field teams in men's and women's basketball, crew, cross-country, golf, soccer, tennis, track, and water polo, along with men's baseball, women's softball, and women's volleyball and sand volleyball. The men's and women's soccer teams are perennially among the nation's elite

programs, both having won national championships. Men's tennis has also emerged in recent years as one of the nation's top programs. Santa Clara is one of the WCC's top broad-based programs, having won the WCC Commissioner's Cup in 2005 and 2007—an all-sports award presented to the league's top performing school in conference competition.

Informal recreation opportunities include drop-in use of the weight and cardiovascular equipment and gymnasium in the 9,500-square-foot weight training and cardiovascular exercise room in the Pat Malley Fitness and Recreation Center, lap swimming in the Sullivan Aquatic Center, and playing tennis at the Degheri Tennis Center, which features nine lighted championship courts. Noncredit lifetime recreation fitness classes are also provided for a nominal quarterly fee to all members. Available classes include yoga, Pilates, kickboxing, cycling, step aerobics, and more.

The University's intercollegiate athletic teams compete in the Leavey Center, which has a roof surrounded by spectacular 23-foot glass walls, and a high-definition video board; the Stephen Schott Baseball Stadium, equipped with state-of the-art facilities and seating for 1,500 people; the soccer complex of Stevens Stadium; and the Degheri Tennis Center. Rounding out the other athletic facilities are 12 acres of intramural athletic fields.

CAMPUS

The University is located on a 106-acre campus in the city of Santa Clara near the southern end of the San Francisco Bay in one of the world's great cultural centers and in the heart of Silicon Valley. At the campus center is the Mission Church, restored in 1928 and surrounded by the roses and palm and olive trees of the historic Mission Gardens. The adjacent Adobe Lodge is the oldest building on campus, having been restored in 1981 to its 1822 decor. There are more than 50 buildings on campus, housing 15 student residences, a main library and a law library, a student center, the de Saisset Museum, the Center of Performing Arts, extensive athletic facilities, and a recreation and fitness center. Computer and telecommunications technology is an integral part of life and learning at Santa Clara University. All residence hall rooms and most classrooms are connected to high-speed Internet access and campus email, and most of the campus is covered by a wireless network.

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Academic Programs and Requirements

GENERAL INFORMATION

More than 800 students attend Santa Clara University's graduate engineering programs each quarter. The School of Engineering offers a large variety of programs to meet the needs of these engineering professionals.

B.S./M.S. FIVE-YEAR DUAL DEGREE PROGRAM

The School of Engineering offers qualified Santa Clara University undergraduates the opportunity to earn both a bachelor of science and a master of science degree in five years. This is an excellent way to save time and open up more career possibilities early on. The degree is offered in bioengineering, civil engineering, computer science and engineering, electrical engineering, engineering management and leadership**, mechanical engineering and software engineering. This program is also open to students in the College of Arts and Sciences who are majoring in mathematics, biology, computer science or engineering physics.

The application fee and GRE General Test requirement are waived. Automatic admission into the five year program is based on a minimum GPA of 3.0 in the major. Upon notification of acceptance into the B.S./M.S. program, students may begin taking graduate-level courses in their senior year and a maximum of 20 units can be transferred into the graduate program. Students must meet with a graduate advisor and submit a program of studies with the undergraduate transfer credit listed.

Please Note: Undergraduate students will be charged the current undergraduate tuition rate while enrolled in those graduate courses. Once students have been matriculated into the master's degree program, current graduate tuition rates will be charged.

**For more information on the engineering management and leadership option, please see Chapter 14.

CERTIFICATE PROGRAMS

Certificate programs are designed to provide intensive background in a focused area at the graduate level. With 16-20 required units for completion, each certificate is designed to be completed in a much shorter period of time than an advanced degree. Santa Clara's certificate programs are appropriate for students working in industry who wish to update their skills or for those interested in changing their career path. All units applied toward the certificate program must be earned within a two year period.

All Santa Clara University courses applied toward the completion of a certificate program earn graduate credit that may also be applied toward a graduate degree, subject to the requirements of the degree program. Students who wish to continue for such a degree must submit a separate application and satisfy all normal admission requirements. The general Graduate Record Examination (GRE) test requirement for graduate admission to the master's degree will be waived for students who have been formally admitted to and who have completed a certificate program with a GPA of 3.5 or better.

Certificate programs are offered in frugal innovation, renewable energy, software engineering, information assurance, networking, ASIC design and test, analog circuit design, digital signal processing applications, digital signal processing theory, microwave and antennas, fundamentals of electrical engineering, , mechanical design analysis, mechatronics systems engineering, dynamics, controls, and thermofluids. For more specific information on each certificate, please see Chapter 7.

Please Note: Santa Clara University does not issue F-1 visas to applicants who wish to enter directly into this program.

Continuation for a Master's Degree

As stated above, all Santa Clara University courses applied toward the completion of a certificate program earn graduate credit that may also be applied toward a graduate degree. Students who wish to pursue such a degree must submit a separate application and satisfy all normal admission requirements. The general GRE test requirement for graduate admission to the master's degree will be waived for students who complete a certificate program with a GPA of 3.5 or better.

MASTER OF SCIENCE PROGRAM

The master's program is designed to extend the technical breadth and depth of an engineer's knowledge. Students in this program complete a program of studies approved by the faculty advisor in the major department. The program must include no less than 45 quarter units and a 3.0 GPA (B average) must be earned in all coursework taken at Santa Clara. Residence requirements of the University are met by completing 36 quarter units of the graduate program at Santa Clara. A maximum of 9 quarter units (6 semester units) of graduate-level coursework may be transferred from other accredited institutions that have not been applied to a previous degree at the discretion of the student's advisor. All units applied toward the degree, including those transferred from other institutions, must be earned within a six-year period.

Students have the option to write a thesis as part of their master's degree. Students who choose this option are responsible for obtaining an advisor for their thesis work. The maximum number of units awarded for the master's thesis is nine. Please note that the thesis option is not available in Engineering Management.

The School of Engineering offers master's programs in applied mathematics, bioengineering, civil engineering, computer science and engineering, software engineering, electrical engineering, engineering management and leadership, mechanical engineering and sustainable energy. The coursework requirements for the degree are determined by each of the major departments. In order to graduate, students must complete the required coursework for the program to which they are admitted and must have a cumulative GPA of 3.0 in all coursework listed on their approved program of study. In addition to this requirement, Engineering Management and Leadership degree candidates must earn a 3.0 GPA in those courses applied to their technical stem and a 3.0 GPA in their engineering management course stem. *Please note: Only classes with assigned grades of C- or higher will count toward the completion of the certificates, M.S. or Ph.D. degrees.*

Note that the number of engineering management courses accepted for other degrees in the graduate engineering program is restricted to six units in computer engineering, electrical engineering, and most options of mechanical engineering.

GRADUATE MINOR IN SCIENCE, TECHNOLOGY, AND SOCIETY (STS)

The graduate minor in science, technology, and society (STS) is designed to help students gain a deeper understanding of the influence that engineering has on society (and vice versa). Knowledge of this kind has become essential in an increasingly complex and interconnected world, in which purely technical expertise often needs to be supplemented by additional skills. In order to successfully operate in such an environment, engineers must (at the very least) have the ability to communicate clearly, function on interdisciplinary and diverse teams, and make ethically and socially responsible decisions. The minor consists of a Core and a set of electives, and entails a minimum of 12 units of coursework. It is open to all students who are pursuing a master's degree in engineering, regardless of the specific program in which they are enrolled.

For more comprehensive information, please see Chapter 6.

ENGINEER'S DEGREE PROGRAM

The program leading to the engineer's degree is particularly designed for the education of the practicing engineer. It is offered in the computer science and engineering, electrical engineering, and mechanical engineering departments. The degree is granted on completion of an approved academic program and a record of acceptable technical achievement in the student's field of engineering. The academic program consists of a minimum of 45 quarter units beyond the master's degree. Courses are selected to advance competence in specific areas relating to the engineering professional's work. Evidence of technical achievement must include a paper principally written by the student and accepted for publication by a recognized engineering journal prior to the granting of the degree. A letter from the journal accepting the paper must be submitted to the department chairperson. In certain cases, the department may accept publication in the proceedings of an appropriate conference.

Admission to the program will generally be granted to those students who demonstrate superior ability in meeting the requirements for their master's degree. Normally, the master's degree is earned in the same field as that in which the engineer's degree is sought. Students who have earned a master's degree from Santa Clara University must file a new application (by the deadline) to continue work toward the engineer's degree. A program of studies for the engineer's degree should be developed with the assistance of an advisor and submitted during the first term of enrollment.

DOCTOR OF PHILOSOPHY PROGRAM

The doctor of philosophy (Ph.D.) degree is sought by those engineers who wish to become experts in a specific area within their field. The work for the degree consists of engineering research, the preparation of a thesis based on that research, and a program of advanced studies in engineering, mathematics, and related physical sciences. The student's

work is directed by the degree-conferring department, subject to the general supervision of the School of Engineering. The school grants the Ph.D. in computer science and engineering, electrical engineering, and mechanical engineering.

Preliminary Examination

The preliminary examination shall be written and oral, and shall include subject matter deemed by the major department to represent sufficient preparation in depth and breadth for advanced study in the major. Only those who pass the written examination may take the oral.

Students currently studying at Santa Clara University for a master's degree who are accepted for the Ph.D. program and who are at an advanced stage of the M.S. program may, with the approval of their academic advisor, take the preliminary examination before completing the M.S. degree requirements.

Students who have completed the M.S. degree requirements and have been accepted for the Ph.D. program should take the preliminary examination as soon as possible but not more than one and one-half years after beginning the program.

Only those students who pass the preliminary examination shall be allowed to continue in the doctoral program. The preliminary examination may be repeated only once and only at the discretion of the thesis advisor.

Thesis Advisor

It is the student's responsibility to obtain consent from a full-time faculty member in the student's major department to serve as his/her prospective thesis advisor.

It is strongly recommended that Ph.D. students find a thesis advisor before taking the preliminary examination. After passing the preliminary examination, Ph.D. students should have a thesis advisor before the beginning of the next quarter following the preliminary examination. Students currently pursuing a master's degree at the time of their preliminary examination should have a thesis advisor as soon as possible after being accepted as a Ph.D. student.

The student and the thesis advisor jointly develop a complete program of studies for research in a particular area. The complete program of studies (and any subsequent changes) must be filed with Engineering Graduate Programs and approved by the student's doctoral committee. Until this approval is obtained, there is no guarantee that courses taken will be counted toward the Ph.D. course requirements.

Doctoral Committee

After passing the Ph.D. preliminary exam, a student requests his or her thesis advisor to form a doctoral committee. The committee consists of at least five members, each of which must have earned a doctoral degree in a field of engineering or a related discipline. This includes the student's thesis advisor, at least two other current faculty members of the student's major department at Santa Clara University, and at least one current faculty member from another appropriate academic department at Santa Clara University. The committee reviews the student's program of study, conducts an oral comprehensive exam, conducts the dissertation defense, and reviews the thesis. Successful completion of the doctoral program requires that the student's program of study, performance on the oral comprehensive examination, dissertation defense, and thesis itself meet with the approval of all committee members.

Residence

The Ph.D. degree is granted on the basis of academic achievement. The student is expected to complete a minimum of 72 units of graduate credit beyond the master's degree with an overall GPA of 3.0 or better. *Please note: Only classes with assigned grades of C- or higher will count toward the completion of the certificates, M.S. or Ph.D. degrees.* Of these, 36 quarter units may be earned through coursework, independent study and directed research, and 36 through the thesis. Deviation from this distribution must be approved by the student's doctoral committee and must not be more than six units. All Ph.D. thesis units are graded on a Pass/No Pass basis. A maximum of 18 quarter units (12 semester units), not previously used for the completion of another degree, may be transferred from any accredited institutions at the discretion of the student's advisor.

Comprehensive Examinations and Admission to Candidacy

After completion of the formal coursework approved by the doctoral committee, the student shall present his/her research proposal for comprehensive oral examinations on the subject of his/her research work. The student should make arrangements for the comprehensive examinations through the doctoral committee. A student who passes the comprehensive examinations is considered a degree candidate.

The comprehensive examinations normally must be completed within four years from the time the student is admitted to the doctoral program. These examinations may be repeated once, in whole or in part, at the discretion of the doctoral committee.

Thesis Research and Defense

The period following the comprehensive examinations is devoted to research for the thesis, although such research may begin before the examinations are complete. After successfully completing the comprehensive examinations, the student must pass an oral examination on his/her research, conducted by the doctoral committee and whomever they appoint as examiners. The thesis must be made available to all examiners one month prior to the examination. The oral examination shall consist of a presentation of the results of the thesis and the defense. This examination is open to all faculty members of Santa Clara University, but only members of the doctoral committee have a vote.

Thesis and Publication

At least one month before the degree is conferred, the candidate must submit one copy of the final version of the thesis to the department and one copy to the Orradre Library. The thesis will not be considered as accepted until approved by the doctoral committee and one or more refereed articles based on it are accepted for publication in a professional or scientific journal approved by the doctoral committee. The quality of the refereed journal must be satisfied by one of two criteria: (1) the refereed journal should have an impact factor of at least 1.0; or (2) prior to submitting the candidate's work to a refereed journal, written approvals on satisfying the journal's quality should be obtained from the candidate's advisor, the doctoral committee, the department chair, and the dean's office. This written approval must be kept in the candidate's file.

All doctoral theses must also be reproduced on microfilm by University Microfilms International, which keeps on deposit the master microfilm copy and responds to requests for copies by individuals and libraries.

Time Limit for Completing Degrees

All requirements for the doctoral degree must be completed within eight years following initial enrollment in the Ph.D. program. Extensions will be allowed only in unusual circumstances and must be recommended in writing by the student's doctoral committee, and approved by the dean of engineering in consultation with the Graduate Program Leadership Council.

Non-Enrollment Period

Ph.D. students are expected to enroll in at least one unit for the fall, winter and spring quarters. Those who do not wish to do so must submit a leave of absence form or a withdrawal form to the Graduate Services office. A leave of absence form is required if a student plans to miss one or two quarters, while any longer absence requires a withdrawal form. Students who wish to resume their Ph.D. studies after withdrawing from the program must apply for readmission, and obtain the signatures of their academic advisor and the department chair.

Students are required to complete their degree within eight years from their original admit term date. The eight year time frame includes quarters during which a student was not enrolled. Those who fail to complete their Ph.D. in eight years can request an extension only under special circumstances. In such cases, the student's advisor will need to discuss the case with the Graduate Program Leadership Council, which will determine whether an extension is warranted (and for how long).

Note: Students who miss one or more quarters and fail to submit the appropriate form(s) will be discontinued automatically, and will have to reapply to the Ph.D. program. They will need to follow the same procedure as students who withdrew from the program.

Additional Graduation Requirements

The requirements for the doctoral degree in the School of Engineering have been made to establish the structure in which the degree may be earned. The student's Ph.D. committee looks at the proposed research and the prior background of the student to determine whether or not there are specific courses that must be added as requirements. The University reserves the right to evaluate the undertakings and the accomplishments of the degree candidate in total and award or withhold the degree as a result of its deliberations.

THE INDUSTRIAL TRACK

In addition to our regular Ph.D. program, Engineering Graduate Programs also offer an "industrial track" for working professionals as an option to facilitate the collaboration between academia and industry. Details are as follows:

1. The topic of the research should be coordinated with the needs of the candidate's employer, and must be agreed upon by all parties. This topic must have a component that is publishable, and is presentable in open forums. If necessary, a collaborative research agreement will be enacted to indicate the rights of the School and the industrial partner.

2. As a part of the application process, candidates must submit a letter of support from their employer. This letter should contain a pledge of financial support, and must identify a co-advisor within the company. The co-advisor shares responsibilities for guiding the candidate's research with a full-time faculty advisor. This person is also expected to be a member of the doctoral committee.

3. The full-time study component of the residence requirement is waived, but other residence requirements remain the same. Students who opt for this "industrial track" are responsible for meeting all other requirements for the Ph.D. The awarded degree will be the same for all students, regardless of the track that they choose to pursue.

OPEN UNIVERSITY PROGRAM

Engineers who wish to update their skills or learn new technologies without pursuing a specific degree may enroll in the School of Engineering's Open University program.

If a student from the Open University program is accepted into a degree program, **a maximum of 16 units may apply toward the degree** (if the courses are in the same discipline to which the student is accepted). The general GRE test requirement for admission to the master's degree program will be waived if the student has completed a set of required courses in the department to which they are applying, and has earned a GPA of 3.5 or higher. A list of these courses can be found on the Graduate Engineering website: www.scu.edu/engineering/academic-programs/waiving-the-gre/

Open University students who are considering enrolling in the master's program should be aware that each specialization has its own set of requirements, and that the number of "free electives" is very limited. Such students are therefore strongly encouraged to choose their classes in consultation with a faculty advisor from the very beginning.

Students should remember, however, that all coursework taken at SCU, whether as a degree-seeking or an Open University student becomes a part of the student's academic history.

Please Note: Santa Clara University does not issue F-1 visas to applicants who wish to enter directly into this program.

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Admissions

Applications for admission and related deadlines are available on the School of Engineering website: www.scu.edu/engineering/graduate/admissions-deadlines/.

APPLICATION REQUIREMENTS

Certificate Programs

Depending on the certificate, students will complete 16-18 units of coursework. Applicants for admission to the certificate programs must submit the following materials:

- A completed online Application for Admission to Engineering Graduate Programs, including a nonrefundable $60 application fee
- One official transcript from each academic institution attended, indicating the degree received and date of conferral

Please note that all applicants with degrees from universities outside of the United States must also submit a transcript evaluation report from Educational Credential Evaluators (ECE) or World Education Services (WES). The report must include a course-by-course evaluation which will verify a GPA (based on a 4.0 scale), and the U.S. equivalence of each educational credential. For additional information, please refer to the ECE or WES website: www.ece.org or www.wes.org (There is no exception to this requirement.)

Also please note that GRE and TOEFL scores are not required for admission. Certificate programs are not appropriate for international students, who must pursue full-time study.

All certificate units in the discipline may be applied toward a master's degree. Students who wish to pursue such a degree must submit a separate online application and satisfy all normal admission requirements. The application fee will be waived for currently enrolled certificate students. The general GRE and TOEFL test requirement for graduate admission to the master's degree will be waived for students who complete a certificate with a GPA of 3.5 or higher.

Please Note: Santa Clara University does not issue F-1 visas to applicants who wish to enter directly into this program.

Master of Science Degrees

Domestic applicants for admission to the master's programs must submit the following materials:

- A completed online Application for Admission to Engineering Graduate Programs, including a nonrefundable $60 application fee
- One official transcript from each academic institution attended, indicating the degree received and date of conferral

- Official Graduate Record Examination (GRE) scores, which must be sent directly to Engineering Graduate Programs by the Educational Testing Service (ETS). Our institution code is 4851. For information on the GRE, please visit the website: www.ets.org/

Please Note: Students applying to the M.S. program in Applied Mathematics, Computer Science and Engineering, Software Engineering and Mechanical Engineering may petition to waive the GRE requirement by completing the Petition to Waive GRE Requirement form. However, applicants must be aware that there is no guarantee that the waiver will be granted.

This option is also available to applicants for the Engineering Management Program who have two or more years of working experience in the U.S. These students will also complete the Petition to Waive GRE Requirement form, as indicated above.

International applicants for admission to the master's programs must submit the following materials:

- A completed online Application for Admission to Engineering Graduate Programs, including a nonrefundable $60 application fee
- One official transcript from each academic institution attended, indicating the degree received and date of conferral. All applicants with degrees from universities outside of the United States must submit a transcript evaluation report from Educational Credential Evaluators (ECE) or World Education Services (WES). The report must include a course by course evaluation which will verify a GPA based on a 4.0 scale, and the U.S. equivalence of each educational credential. Please refer to the ECE or WES website: www.ece.org or www.wes.org. (There is no exception to this requirement.)
- Official Graduate Record Examination (GRE) scores, which must be sent directly to Engineering Graduate Programs by the Educational Testing Service (ETS). Our institution code is 4851. For information on the GRE, please visit the website: www.ets.org/.

Please Note: Students applying to the M.S. program in Applied Mathematics or in Mechanical Engineering may petition to waive the GRE requirement by completing the Petition to Waive GRE Requirement form. However, applicants must be aware that there is no guarantee that the waiver will be granted. The department of Computer Engineering DOES NOT accept GRE waiver.

This option is also available to applicants for the Engineering Management Program who have two or more years of working experience in the U.S. These students will also complete the Petition to Waive GRE Requirement form, as indicated above.

- Scores from the Test of English as a Foreign Language (TOEFL) or the International English Language Testing Systems (IELTS) exam (applies to non-U.S. citizens or those students who have received a degree from a university outside of the United States). Our institution code is 4851. Test scores over three years old will not be accepted.

Please Note: International students requiring an F-1 student visa must submit financial statements showing adequate funds for tuition, fees, and living expenses for the entire program. Accepted students will be mailed an I-20 Request Form with their acceptance letter. This form and the financial documents must be returned to the Engineering Graduate Programs Admissions Office no earlier than 90 days before classes begin.

Ph.D. and Engineer's Degrees

Ph.D. and Engineer's degrees are offered in the departments of Computer Engineering, Electrical Engineering, and Mechanical Engineering.

Domestic applicants must submit the following materials:

- A completed online Application for Admission to Engineering Graduate Programs, including a nonrefundable $60 application fee
- A 500-word statement of purpose emphasizing the applicant's research interests and outlining the applicant's professional and academic goals, which must be included with the online application
- One official transcript from each academic institution attended, indicating the degree received and date of conferral
- Official Graduate Record Examination (GRE) scores must be sent directly to Engineering Graduate Programs by the Educational Testing Service (ET). Our institution code is 4851. For further information on the GRE, please visit the website: www.ets.org/.
- Three letters of recommendation are required. These letters should attest to the applicant's academic preparation and capability for advanced studies. (There are no standard recommendation forms.) Please send signed and sealed original letters with other supporting documents in one envelope to: Engineering Graduate Admissions, Santa Clara University, 500 El Camino Real, Santa Clara, CA 95053.

International applicants must submit the following materials:

- A completed online Application for Admission to Engineering Graduate Programs, including a nonrefundable $60 application fee
- A 500-word statement of purpose emphasizing the applicant's research interests and outlining the applicant's professional and academic goals, which must be included with the online application
- One official transcript from each academic institution attended, indicating the degree received and date of conferral. All applicants with degrees from universities outside of the United States must submit a transcript evaluation report from Educational Credential Evaluators (ECE) or World Education Services (WES). The report must include a course-by-course evaluation which will verify a GPA based on a 4.0 scale, and the U.S. equivalence of each educational credential. Please refer to the ECE or WES website: www.ece.org or www.wes.org. (There is no exception to this requirement.)
- Scores from the Test of English as a Foreign Language (TOEFL) or the International English Language Testing Systems (IELTS) exam (applies to non-U.S. citizens or those students who have received a degree from a university outside of the United States). Our institution code is 4851. Test scores over three years old will not be accepted.
- Official Graduate Record Examination (GRE) scores must be sent directly to Engineering Graduate Programs by the Educational Testing Service (ETS). Our institution code is 4851. For further information on the GRE, please visit the website: www.ets.org/.

- Three letters of recommendation are required. These letters should attest to the applicant's academic preparation and capability for advanced studies. (There are no standard recommendation forms.) Please send signed and sealed original letters with other supporting documents in one envelope to: Engineering Graduate Admissions, Santa Clara University, 500 El Camino Real, Santa Clara, CA 95053.

Please Note: International students requiring an F-1 student visa must submit financial statements showing adequate funds for tuition, fees, and living expenses for the entire program. Accepted students will be mailed an I-20 Request Form with their acceptance letter. This form and the financial documents must be returned to the Engineering Graduate Programs Admissions Office no earlier than 90 days before classes begin.

ADMISSION DEFERRALS

Any student who has been admitted to a degree program and wishes to defer that admission must submit a request, in writing, to the Engineering Graduate Programs Admissions Office prior to the beginning of the quarter.

OPEN UNIVERSITY

For those who want to update their skills and learn new technologies without the commitment of earning a graduate degree, Open University allows students to enroll in graduate-level classes. Individuals who have applied to a degree program can get a head start by enrolling in classes while they wait for admission to a degree program.

For admission, applicants must submit the following materials:

- A completed online Application for Admission to Engineering Graduate Programs, including a nonrefundable $60 application fee
- Official transcript from every university attended* to:

Engineering Graduate Programs
Guadalupe Hall
Santa Clara University
500 El Camino Real
Santa Clara, CA 95053-0583
Email: GradEngineer@scu.edu
Phone: 408-554-4313
Fax: 408-554-4323

**Please Note: All applicants with degrees from universities outside of the United States must also submit a transcript evaluation report from Educational Credential Evaluators (ECE) or World Education Services (WES). The report must include a course-by-course evaluation which verify a GPA (based on a 4.0 scale), and the U.S. equivalence of each educational credential.*

For additional information, please refer to the ECE or WES websites: www.ece.org or www.wes.org. (There is no exception to this requirement.)

If students wish to apply to a degree program at a later date, they must follow the same procedure, and submit the same supporting documentation required of degree-seeking applicants, except that the application fee is waived. A maximum of 16 units may apply toward the degree if the courses are in the same discipline to which the student is accepted. The general GRE test requirement for admission to the master's degree program will be waived if the student has completed a set of required courses in the department to which they are applying, and has earned a GPA of 3.5 or higher. A list of these courses can be found on the Graduate Engineering website: . www.scu.edu/engineering/academic-programs/waiving-the-gre/

Please Note: Santa Clara University does not issue F-1 visas to applicants who wish to enter directly into this program.

Please Note: Open University students are not eligible to enroll in undergraduate classes.

READMISSION

An application for readmission is required of students whose enrollment in the School of Engineering lapses for three consecutive quarters. Applicants for readmission must submit transcripts of the latest graduate work completed in other university programs, together with official transcripts of study completed elsewhere since their previous enrollment.

After successfully completing advanced degree requirements at Santa Clara University, a student must reapply if interested in taking graduate engineering courses. None of the courses used to satisfy requirements for the first degree can be applied to any other subsequent degree.

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Academic Information

ENGINEERING HONOR CODE

The Engineering Honor Code is a long-standing Santa Clara tradition. Instituted at the request of engineering students, the code states: All students taking courses in the School of Engineering agree, individually and collectively, that they will not give or receive unpermitted aid in examinations or other coursework that is to be used by the instructor as the basis of grading. Students and teachers cooperate and share responsibilities under the code. Teachers are responsible for making clear what aid is permissible and for using procedures that minimize temptations to violate the code. Students are responsible for behaving honorably, for actively ensuring that others as well as themselves uphold the code, and for being responsive to violations. Students dominate the administration of the code, and they take full responsibility for trying cases of alleged violations and for recommending penalties. Alleged violations should be reported to the Office of the Dean.

THE GRADUATE CORE

The Graduate Core is a set of requirements that is common to all departments in the School of Engineering. The Core promotes an educational philosophy that goes far beyond narrow specialization and emphasizes a global and societal orientation. It also reflects the fact that we live in an increasingly complex world, in which engineers must continually deepen their understanding of the interdisciplinary environment in which they operate.

Students will be required to take a course in each of the following three areas of the Core (for a minimum of 6 units):

1. Emerging Topics in Engineering
2. Engineering and Business/Entrepreneurship
3. Engineering and Society

Emerging Topics in Engineering

- AMTH 308 Theory of Wavelets
- AMTH 351 Quantum Computing
- AMTH 367 Mathematical Finance
- AMTH 387 Cryptology
- BIOE 256/ENGR 256 Introduction to Nanobioengineering
- CENG 213 Sustainable Materials
- CENG 215 Sustainable Structural Engineering
- CENG 219 Designing for Sustainable Construction

- CENG 282 Introduction to Building Information Modeling
- ~~COEN 331 Wireless and Mobile Networks~~
- ~~COEN 389 Energy-Efficient Computing~~
- ELEN 280/MECH 287 Introduction to Alternative Energy Systems
- ELEN 285 Introduction to the Smart Grid
- ENGR 260 Nanoscale Science and Technology
- ENGR 262 Nanomaterials
- ENGR 273 Sustainable Energy and Ethics
- ENGR 337 Sustainability and Green Information Technology
- ENGR 371 Space Systems Design and Engineering I
- ENGR 372 Space Systems Design and Engineering II
- MECH 234 Combustion Technology
- MECH 268 Computational Fluid Dynamics I
- MECH 295 Fire Dynamics (Special Topic)

Engineering and Business/Entrepreneurship

- AMTH 367 Mathematical Finance
- CENG 208 Engineering Economics and Project Finance
- CENG 282 Infrastructure Project Management
- COEN 287 Software Development Process Management
- ENGR 302 Managing in the Multicultural Environment
- ENGR 304 Building Global Teams
- ENGR 336 Engineering for the Developing World
- ENGR 338 Mobile Applications for Emerging Markets

This requirement can also be satisfied by taking any 2-unit course in Engineering Management (EMGT)

Engineering and Society

- BIOE 210 Ethical Issues in Bioengineering
- CENG 208 Engineering Economics and Project Finance
- COEN 250 Information Security Management
- COEN 288 Software Ethics
- ELEN 217 Chaos Theory, Metamathematics, and the Limits of Science: An Engineering Perspective on Religion
- ENGR 261 Nanotechnology and Society
- ENGR 272 Energy Public Policy
- ENGR 273 Sustainable Energy and Ethics
- ENGR 302 Managing in the Multicultural Environment

- ENGR 303 Gender and Engineering
- ENGR 304 Building Global Teams
- ENGR 306 Engineering and the Law
- ENGR 310 Engineering Ethics
- ENGR 330 Law, Technology, and Intellectual Property
- ENGR 334 Energy, Climate Change, and Social Justice
- ENGR 336 Engineering for the Developing World
- ENGR 340 Distributed & Renewable Energy for the Developing World
- ENGR 341 Innovation, Design and Spirituality
- ENGR 342 3D Print Technology and Society
- ENGR 343 Science, Religion and the Limits of Knowledge
- ENGR 349 Topics in Frugal Engineering

Note 1: Although certain courses (such as ENGR 302, ENGR 304, ENGR 336, and AMTH 367 for example) may appear in multiple categories, they cannot be used to satisfy more than one Core requirement. Students are encouraged to periodically check the graduate engineering website for updates regarding new courses in these areas, www.scu.edu/engineering/graduate

Note 2: Core requirements cannot be waived, and no substitutions will be approved.

CLASSES

Classes are taught in the following timeslots: 7:10-9:00 a.m., 5:10-7:00 p.m., and 7:10-9:00 p.m., Monday through Friday with some Saturday and/or Sunday offerings; 2-unit courses meet one day per week, and four unit courses meet two days per week. All students are expected to attend the first class meeting of the quarter. Failure to do so can result an academic withdrawal from the course.

STANDARDS OF SCHOLARSHIP

Only courses in which the student has earned assigned grades of A, B, or C, with plus (+) or minus (-) variations, may be counted for the master's or Ph.D. degree. The student must earn a 3.0 average in the approved 45 units required for the completion of the M.S. degree or the approved 72 units required for the Ph.D. degree. Only credits, not grade points, are transferred from other institutions. A cumulative GPA of less than 2.6 after the completion of 16 units may result in dismissal from the graduate program.

Please note: Only classes with assigned grades of C- or higher will count toward the completion of the certificates, M.S. or Ph.D. degrees.

GRADING SYSTEM

The grades A, B, C, and D may be modified by (+) or (-) suffixes, except that the grade of A may not be modified by a (+). Grade point values per unit are assigned as follows: A = 4.0; A- = 3.7; B+ = 3.3; B = 3.0; B- = 2.7; C+ = 2.3; C = 2; C- = 1.7; D+ = 1.3; D = 1.0; D- = 0.7. F= 0., I (incomplete), P (pass), NP (no pass), and W (withdrawn) are all assigned zero points. Unit credit, but not grade point credit, is awarded when the grade of P is assigned. The P (pass) and NP (no pass) options are not available in engineering management courses.

The University also uses the following marks: AUD (audit), I (incomplete), N (continuing work), NP (not passed), NS (no show), and W (withdrawn). No unit credit or grade point value is granted for any of these marks.

Please note: Only classes with assigned grades of C- or higher will count toward the completion of the certificates, M.S. or Ph.D. degrees.

NONGRADED COURSES

Courses such as seminars (with the exception of COEN 400 and ELEN 200), Co-ops, etc., are limited to a total of four units and must be approved by the student's advisor.

Please Note: Co-op units may not be used toward the completion of a degree.

INCOMPLETE GRADES

A student's work may be reported incomplete if due to illness or other serious circumstance some essential portion of the coursework remains unfinished after the final examination, or if the thesis has not been completed. An incomplete (I) becomes a failure (F) unless the unfinished work is completed to the satisfaction of the instructor and proper notice is filed with the registrar within four weeks from the beginning of the next scheduled quarter, not including summer session. Makeup work must be in the hands of the instructor no later than the end of the third week so that the instructor can meet the four-week submission deadline.

AUDITING COURSES

A student may take courses with a grading basis of "audit" but need to keep in mind the following:

- The current graduate tuition rate of $928.00 per unit + the $150.00 engineering fee will be charged.
- No grade points or credit will be earned so the class cannot be counted toward the completion of a certificate, M.S. or Ph.D.
- A student will need to register for the class, then send an email to the Director of Records requesting that the grading basis be changed to "Audit": lmjocewicz@scu.edu
- The last day to request to audit a course is at the end of the first week of instruction.

REPEATING COURSES

A student may, with the permission of the department, repeat a course in which a grade of C or lower was received on the first attempt. All grades, whether received on the first or second attempt, will be used in computing overall student performance. The units from a course may be counted only once in fulfilling graduation requirements.

WITHDRAWAL FROM COURSES

Students may change their course registration as stated in the Academic Calendar. Withdrawal from any course may be accomplished up to the 7th Friday of the term. After the fourth week of the quarter, a withdrawal will be recorded as W on the transcript. After the tenth Friday, an emergency that qualifies may be handled as an incomplete (I). Dropping a course without formal withdrawal will result in a grade of F. Deadlines are strictly adhered to and will result in loss of tuition refund.

PROGRAM OF STUDIES

During the first quarter of enrollment, a student whose objective is an M.S. degree should meet with a faculty advisor to discuss the program of studies and future coursework. The advisor-approved program of studies, including any transfer units, must be submitted to Engineering Graduate Programs before the end of the first quarter of enrollment. Variations from the approved program of studies may be made only with the written approval of the advisor and the filing of the proper forms.

A maximum of 16 quarter units earned in a SCU nondegree status and nine quarter units of graduate-level transfer credit from an accredited university may be applied toward graduation upon approval of the academic advisor. B.S./M.S. students can transfer up to 20 units from their undergraduate program as long as the units were not used toward their undergraduate degree. All units must be included on the Program of Studies.

Please Note: Extension and continuing education units are not accepted for transfer.

COURSES TRANSFERRED FROM SANTA CLARA UNIVERSITY

M.S. students who have an undergraduate degree from Santa Clara University can transfer up to 12 units of eligible graduate level coursework into the program.

- Only those courses completed with a C grade or better will be eligible for transfer.
- The units may not have been used for another degree.
- Since these courses were taken at SCU, the grades will count toward the overall grade point average.

COURSES TRANSFERRED FROM OTHER INSTITUTIONS

All M.S. students have the option to transfer a maximum of six semester or nine quarter units of graduate level coursework from an accredited institution into their degree program with their advisor's approval. All Ph.D. students have the option to transfer a maximum of 12 semester or 18 quarter units of graduate level coursework from an accredited institution into their degree program with their advisor's approval. Please keep the following in mind when transferring units:

- Only those courses completed with a C grade or better will be eligible for transfer.
- Extension, continuing education, and online courses may not be transferred.
- The units may not have been used for another degree.
- Only the credit will transfer, but not grades so your overall grade point average will be based on coursework completed at Santa Clara University only.
- An official transcript and course syllabus is required for verification of the units by the student's advisor and Engineering Graduate Programs.

In order to transfer units into a degree program, please follow this procedure:

- Include those units you wish to transfer in the "Transfer Credit" section of the Program of Studies form and include the Institution Name, Course Number and Title, Grade, Units*, Year and (if applicable) the SCU equivalent course. If no equivalent course is listed the transfer credit will be processed as general transfer credit. (*Note that 1 semester unit is equivalent to 1.5 quarter units. Please put the quarter unit value on your Program of Studies so that the final total will be correct.)
- Have your academic advisor sign the Program of Studies form and submit it to Engineering Graduate Programs.

PETITION FOR GRADUATION

It is a student's responsibility to file a petition for graduation no later than the last day to petition for graduate degrees as indicated in the Academic Calendar. The petition to graduate will only be accepted through online submission and may be found on the graduate engineering website under current students resources www.scu.edu/engineering/graduate

Please Note: Eligibility to participate in the June Commencement ceremony will be based on the completion of all requirements by the end of the spring quarter. If you still have units or a thesis to complete after the spring quarter, participation in the ceremony will be delayed until the following June.

COOPERATIVE EDUCATION OPTION

The objective of cooperative education is to provide students with the opportunity, through the interaction of study and work experience, to enhance their academic knowledge, to further their personal work experience, and to learn about working with people. The Cooperative Education option integrates classroom work with practical industrial experience. It alternates or parallels periods of college education with periods of practical training in industry. The industrial training is related to the field of study in which the student is engaged and often is diversified to afford a wide range of experience. To qualify for this study option, students must complete at least 24 units at Santa Clara University.

International students who wish to pursue this option through curricular practical training (CPT) must enroll in ENGR 288. This class can be taken during the first quarter of CPT, or before the training begins. Those who plan to start (or continue) their CPT after they have taken ENGR 288 must enroll in ENGR 289 (which can be taken for credit up to four times).**

*** Note 1: the units associated with engr 288 and engr 289 are additional to the units that are required by the department.*

**** Note 2: engr 288 is not offered in the summer quarter*

CONCURRENT ENROLLMENT

Concurrent Enrollment means that a student is enrolled in two places at the same time. An international student at Santa Clara University may be given permission to engage in Concurrent Enrollment provided the student meets the following USCIS requirements:

- Combined enrollment amounts to a full course of study
- The student has been granted permission from a faculty advisor to enroll at another college (advisor must sign Concurrent Enrollment Form)
- Must receive written approval from DSO at International Student Services
- The student is making normal progress at Santa Clara and is not in danger of probation or disqualification
- The coursework at the other school is NOT vocational and will be accepted for fulfilling degree requirements at SCU

For more information, please contact the International Student Services Office at 408-554-4318 or refer to website: www.scu.edu/globalengagement/international-students

NON-ENROLLMENT PERIOD

Students in the Master's program are expected to enroll in at least one unit for the fall, winter and spring quarters. Those who do not wish to do so must submit a leave of absence form or a withdrawal form to the Graduate Services office. A leave of absence form is required if a student plans to miss one or two quarters, while any longer absence requires a withdrawal form. Students who wish to resume their Master's studies after withdrawing from the program must apply for readmission, and obtain the signatures of their academic advisor and the department chair.

Students are required to complete their degree within six years from their original admit term date. The six year time frame includes quarters during which a student was not enrolled. Note that students who miss one or more quarters and fail to submit the appropriate form(s) will be discontinued automatically, and will have to reapply to the Master's program. They will need to follow the same procedure as students who withdrew from the program.

WITHDRAWAL FROM THE UNIVERSITY

Withdrawal from the University is not officially complete until students clear all of their financial obligations with the Bursar's Office. Students on deferments or a Federal Perkins Loan must also clear their financial obligations with the Credit Counseling Office.

STUDENT RECORDS

University policy relating to student records complies with the Family Educational Rights and Privacy Act of 1974 (FERPA). Accordingly, the University may release directory information to any person on request, unless a student requests in writing that directory information be kept confidential. A student's directory information is designated as follows:

1. Name
2. Address, telephone number (campus, local and/or permanent), email
3. Date and place of birth
4. Dates of attendance, full-time/part-time status, major field of study, classification, expected graduation date, degrees, and honors received
5. Photographic image
6. Most recent previous educational institution attended
7. Participation in officially recognized activities, including intercollegiate athletics
8. Name, height, and weight of participants on intercollegiate athletic teams

During the registration period and throughout the academic year, students may request in writing, through the Office of the Registrar, that directory information be kept confidential. Once filed, the request remains in effect until the beginning of the next academic year, or a shorter period, if designated by the student.

Certain records are excluded by the law from inspection, specifically those created or maintained by a physician, psychiatrist, or psychologist in connection with the treatment or counseling of a student. Parents' financial information, including statements submitted with scholarship applications, is also excluded by law from inspection. Third parties may not have access to educational records or other information pertaining to students without the written consent of the particular student about whom the information is sought.

Former or current borrowers of funds from any Title IV student loan program should note carefully that requests for nondisclosure of information will have no effect on preventing Santa Clara University from releasing information pertinent to employment, enrollment status, current address, and loan account status to a school lender, subsequent holder, guarantee agency, U.S. Department of Education, or an authorized agent.

Students have the right to inspect and review their educational records at the following offices:

1. Official academic records, including application forms, admissions transcripts, letters of acceptance, and a student's permanent academic record are on file and maintained in the Office of the Registrar.
2. Working academic files are also maintained by the deans in their respective offices.
3. Records related to students' nonacademic activities are maintained in the Office of Student Life.
4. Records relating to students' financial status with the University are maintained in the various student financial services offices.

Students have the right to request the amendment of their educational records to ensure that they are not inaccurate, misleading, or otherwise in violation of the student's privacy or other rights. Students may direct complaints regarding academic records to the dean of the college or school in which they are enrolled or to the University Registrar. In addition, students have the right to file with the U.S. Department of Education a complaint concerning alleged failures by Santa Clara University to comply with the requirements of FERPA. Written complaints should be directed to the Family Policy Compliance Office, U.S. Department of Education, 400 Maryland Ave., S.W., Washington, D.C. 20202-5902. Detailed information can be found on the Family Compliance Office website:
www.ed.gov/policy/gen/guid/fpco/index.html.

Copies of Santa Clara University's student records policy are available from the Student Records Office, Walsh Administration Building.

CAMPUS SECURITY AND CRIME STATISTICS ACT

The U.S. Department of Education requires universities that receive Title IV funding to disclose certain information, including institutional graduation rates, athlete graduation rates, financial assistance awarded, and crime statistics. Information presented in compliance with the Jeanne Clery Disclosure of Campus Security Policy and Campus Crime Statistics Act is made available to assist current and potential students and employees in making informed decisions regarding their attendance or employment with Santa Clara University. To view the Santa Clara University reports, please refer to the Campus Safety Services website: www.scu.edu/university-operations/campus-safety/

A paper copy of the report may be obtained by writing to Campus Safety Services, Santa Clara University, 500 El Camino Real, Santa Clara, CA 95053.

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Financial Information

FINANCIAL RESPONSIBILITY

Students assume responsibility for all costs incurred as a result of enrolling at Santa Clara University and agree to abide by applicable University policies and procedures. Students may designate a third party (e.g. spouse) to be an authorized user for the purpose of reviewing student account/billing information and remitting payment on the student's behalf. However, it is ultimately the student's responsibility to make sure all financial obligations are completed by the published deadlines.

Students receive monthly billing statements electronically via a third-party vendor that are accessible through University eCampus. Billing notification will be sent to the student's assigned SCU gmail address and to the e-mail address of any authorized user. Students also may forward their billing statement electronically to any third party they authorize for remittance. Information on a student's account cannot be provided to any third party until a completed Family Educational Rights and Privacy Act (FERPA) form, authorizing its release by the student, is on file with the University. This form is available online via the students eCampus.

Students are obligated to pay the applicable tuition and fees associated with their enrollment status by the published payment deadline. Students enrolling after the initial billing of any quarter may be required to pre-pay for tuition before enrollment is granted. Registered students who do not withdraw formally from the University are responsible for all tuition and fees assessed to their accounts as well as any penalty charges incurred for nonpayment. Nonattendance does not relieve the student of his or her obligation to pay tuition and fees.

More helpful information, including detailed instructions on santa clara university's billing and payment procedures, are located at: www.Scu.Edu/bursar

FINANCIAL TERMS AND CONDITIONS

Students are required to accept the financial terms and conditions outlined by the University in order to continue their enrollment at SCU. Students will be prompted to accept the terms and conditions, on an annual basis, upon their login to ecampus. Students will not have access to their Student Center until they have read and agreed to the information contained on the page(s) prompted. By accepting SCU's financial terms and conditions, students are agreeing to pay for services rendered by the University and to abide by all policies and procedures as published.

TUITION AND FEES

Tuition, per quarter unit, for all courses $928
Graduate Design Center and Student Association (AGES) fee $150

Per quarter, for each student enrolled in School of Engineering courses; includes Association of Graduate Engineering Students (AGES) fee.

MANDATORY HEALTH INSURANCE

Annual graduate student health insurance fee $2896

Santa Clara University requires all students taking two or more classes to have health insurance. Students may either enroll in the University-sponsored health insurance plan or complete the online waiver form each academic year with the student's own health insurance information. For details on completing the waiver or on-line insurance enrollment option go to: www.scu.edu/cowell and click on Student Health Insurance.

Graduate students who have medical insurance other than the University-sponsored plan will be billed a $90 health center fee for each quarter they visit the Cowell Health Center. Graduate students enrolled in the University plan may use the health center at any time. The health center fee is included in the cost of the insurance premium.

OTHER FEES

Non-refundable application fee, per application $60
Non-refundable Enrollment Deposit (will be credited toward student's account once enrollment is posted) $300
Late registration fee.....$100
Course drop/swap fee (per course) $50
Late payment fee $100
Ph.D. thesis microfilming.....$45
Parking permits (per year) $350
Parking permits (N permit)after 4:30p.m. only (per year).....$175

BILLING AND PAYMENT PROCEDURES

Students assume responsibility for all costs incurred as a result of enrollment at Santa Clara University and agree to abide by applicable University policies and procedures.

Students may designate a third party (e.g., parent, spouse) to be an authorized payer for their student account. That individual is authorized by the student to have access to his or her billing statements and to make payments on the student's behalf. Once authorization is arranged, the authorized payer will be notified via the email address provided by the student verifying their access to view and pay a student's bill online.

Students receive monthly bills electronically via a third-party vendor that are accessible through University e-campus. A billing notification will be sent to the student's University email address and to the email address of any payer authorized by the student. Students may also forward their student account statements electronically to any third party they authorize for remittance. Information on a student's account cannot be provided to any third party payer unless a completed Family Educational Rights and Privacy Act form authorizing its release by the student is on file with the University.

Students are obligated to pay the applicable tuition and fees associated with their enrollment status by the published payment deadline. Students enrolling after the initial billing of any term may be required to pre-pay for tuition before enrollment is granted. **Registered students who do not withdraw formally from the University are responsible for all tuition and fees assessed to their account as well as any penalty charges incurred for nonpayment. Nonattendance does not relieve the student of his or her obligation to pay tuition and fees.**

More helpful information, including detailed instructions on Santa Clara's billing and payment procedures, is located at the website: www.scu.edu/bursar.

Graduate Programs Billing Dates and Deadlines

The following dates are the initial payment deadlines for each quarter:

Fall 2016	Billing available August 1; payment due August 21
Winter 2017	Billing available December 1; payment due December 21
Spring 2017	Billing available March 1; payment due March 21
Summer 2017	Billing available May 1; payment due May 21

PAYMENT METHODS

Santa Clara University offers the following payment methods to students to assist with their financial obligations:

Payment by Electronic Check

A student or authorized user may make online payments by authorizing a fund transfer directly from his/her personal checking or savings account through the SCU pay system. Students will login to eCampus to complete their transaction; authorized users will login to a separate URL provided at the time their access is created.

Payment by Mail

Payment by personal or cashier's check for student account charges can be mailed to: SCU Payment Processing, PO Box 550, Santa Clara, CA. 95052-0550. It is extremely important to include a copy of the student's billing statement to ensure accurate and timely posting.

Payment in Person

Payments for student account charges may be made in person by personal/cashier's check, money order or cash at the Enrollment Service Center in the Admissions & Enrollment Services Building. The University is not able to accept any electronic form of payment, including debit or credit cards. However, there are computer kiosks located in the Enrollment Services Center for the convenience of students and payers who wish to make electronic payments.

International Payment by Wire Transfer

International students may submit payment quickly and securely by going to www.flywire.com/scu. Students are able to benefit from excellent exchange rates and payment can usually be made in the student's home currency.

PAYMENT PLANS

Students have the option to enroll in a term monthly payment plan for tuition and housing costs to assist with budgeting needs. Students must be in good financial standing to enroll in a payment plan. There is a modest fee to enroll in a plan, however no interest or additional fees are charged as long as payment is received per the agreement. All payments are remitted electronically. The first is due upon enrollment and students authorize the University to extract remaining payments from their designated bank account.

Please note: This option is not a deferral for students with financial aid. All aid will be applied to the student's account and any remaining balance can be placed on a payment plan. More information can be found on the Bursar's Office webpage.

DELINQUENT PAYMENTS

If all charges on a student's account have not been cleared by payment, financial aid, or loan disbursement, a late payment fee will be assessed to the student's account and a hold will be placed on the student's record. A hold on a student's record prevents the release of transcripts or diplomas, access to any registration services, and may limit access to other University services. Students who have unpaid accounts at the University or who defer payment without approval are subject to dismissal from the University. All unpaid balances will accrue ten percent interest per annum on the balance remaining from the date of default in accordance with California state law.

Delinquent student accounts may be reported to one or more of the major credit bureaus and may be forwarded to an outside collection agency or an attorney for assistance in recovering the debt owed to the University. The student is responsible for all costs incurred to collect outstanding debt, including but not limited to accrued interest, late fees, court costs, collection fees, and attorney fees. All outstanding bills and costs of collection incurred by the University must be paid in full prior to a student re-enrolling at the University.

BILLING DISPUTES

If a student believes there is an error on his or her billing statement, a written explanation should be forwarded to: Santa Clara University, Bursar's Office, 500 El Camino Real, Santa Clara, CA 95053-0615. The Bursar's Office must receive written correspondence within 60 days from the billing statement date on which the error appeared. Communication can be made by telephone, but doing so will not preserve the student's rights.

Communication should include the student's name, SCU identification number, the amount in question, and a brief explanation. Payment for the amount in question is not required while the investigation is in progress. An adjustment will be made on the student's account for any incorrect charges. If the amount in question is found to be valid, payment must be submitted to the Enrollment Services Center immediately upon notification.

TUITION REFUND POLICY

Process - Students may be eligible to receive a refund due to excess financial aid or change in enrollment. Refunds are not provided for an overpayment on an account. The refund process begins after the late registration period of each term. Students must have a credit balance before a request can be processed. Students should enroll in direct deposit, prior to requesting a refund, to obtain their funds quickly and securely. Refunds by check method is delayed significantly. Payment on a students account received by personal check will have a 21-day hold before a refund can be issued; a 5-day hold will be imposed for electronic check payments. More information on the refund criteria and process is located at www.scu.edu/bursar/refund.

Policy - Students who formally withdraw from the University or drop courses are eligible for a tuition refund in accordance with the policies outlined below. No refunds are made for registration fees, student activity fees, or course audit fees.

The effective date used for the determination of any tuition refund is the date on which notification of withdrawal is received by the student's respective Records Office or the date in which the student drops his or her course online—not the last date of attendance. Students who fail to drop a course, even if they do not attend, or fail to notify the University of their intent to withdraw, regardless of the reason, will be responsible to pay all tuition and fee charges.

Neither informing an individual faculty member, an academic department, nor the Dean's Office constitutes an official withdrawal from the University. The official date of withdrawal from the University cannot be backdated prior to the date on which the student submits the applicable withdrawal form or the Records Office receives notification.

Fall, Winter, and Spring Quarters

Students who drop courses or withdraw from the University during fall, winter, or spring term will receive a tuition refund in accordance with the following:

- By the end of the first week of classes – 100% tuition refund, less any applicable fees
- By the end of the second week of classes – 50% tuition refund, less any applicable fees
- By the end of the third week of classes – 25% tuition refund, less any applicable fees
- After the third week of classes – zero tuition refund

Summer

Students who drop courses or withdraw from the university during the summer session term will receive a tuition refund in accordance with the following:

- By the end of day of the second class meeting – 100% tuition, refund less any applicable fees
- By the end of day of the third class meeting – 50% tuition, refund less any applicable fees

Saturday/Sunday Courses/Off Cycle Courses

Students enrolled in a weekend course in which the first class meeting is after the first week of the term must provide written notification, to their respective Records Office, of their intent to withdraw or drop any weekend/off cycle course(s). Failure to comply with this process will result in an irreversible forfeit of tuition.

The following refund schedule applies:

- Students will receive a 100% tuition refund, less any applicable fees, if written notification is received by 5 p.m. on the Tuesday immediately following the first class meeting.
- Students will receive a 50% tuition refund, less any applicable fees, if written notification is received by 5 p.m. on the Tuesday immediately following the second class meeting.

To receive tuition refunds from the Bursar's Office, these course drops must be handled administratively. Students should NOT drop a weekend/off cycle course themselves through ecampus after the first week of the quarter.

Please Note: If you withdraw or drop below half-time status you may no longer be eligible to receive financial aid or student loans. Your account will be adjusted accordingly and the aid returned to the appropriate program. If you have received a refund for these funds, you must reimburse Santa Clara University immediately. For more information on financial aid forfeiture, please visit the Financial Aid website or make an appointment with your financial aid counselor.

One-Unit Courses

Students enrolled in a one-unit course must provide written notification to their respective Records Office of their intent to withdraw or drop any course(s). Failure to comply with this process will result in an irreversible forfeit of tuition.

The following refund schedule applies:

- Students will receive a 100% tuition refund, less any applicable fees, if written notification is received within two business days prior to the first class meeting.
- Students will receive 50% tuition refund, less any applicable fees, after the first class meeting unless the course has only one session, in which case no refund will be granted.

Financial Hardship

Students who withdraw from the University or drop courses due to an illness, injury, or psychological/emotional condition are eligible for a tuition refund in accordance with the schedule above. Tuition insurance may be purchased to cover tuition charges for medically related withdrawals that occur after the first week of the term.

Santa Clara University degree students who withdraw from the University or who are administratively withdrawn from the University after the third week of the term due to a qualifying financial hardship may be eligible for an allocation from the student hardship fund for 25 percent of the tuition charges for that term. Qualifying financial hardships include: (1) death, disabling injury, medical emergency, (2) loss of job by an independent student, (3) medical or other emergency involving a dependent of an independent student, and (4) student deployment for active military duty. The Vice Provost for Student Life or designee, in consultation with the Financial Aid Office, will determine qualifying financial hardships and any allocation from the student hardship fund. Students must submit a request for an allocation from the student hardship fund by the end of the applicable term.

No tuition refunds are made because of curtailed services resulting from strikes, acts of God, civil insurrection, riots or threats thereof, or other causes beyond the control of the University.

TUITION INSURANCE PROTECTION

Students and families may protect themselves, from loss of funds paid toward tuition/fees, by purchasing tuition insurance provided by A.W.G. Dewar Inc. This low cost plan is designed to assist those that have an unexpected withdrawal from the University due to medical reasons. Plan enrollment is available annually or by quarter. Enrollment must be complete before the first day of school to be eligible for insurance benefits. For more information refer to the website: www.collegerefund.com.

EDUCATIONAL TAX CREDITS

Students may be eligible for a higher education tax credit designed to help students and their parents finance the cost of education. Tax credits are based on the amount of qualified tuition and fees, less grants and other tax-free educational assistance, and the taxpayer's adjusted gross income. Students enrolled in an eligible degree program may qualify for a Hope Scholarship Credit or Lifetime Learning Tax Credit. Specific information is available from the Internal Revenue Service.

FINANCIAL AID

Students must be enrolled at least part-time status (4 units) to receive Federal financial aid.

California State Graduate Fellowships

State graduate fellowships are awarded to California residents pursuing a recognized graduate or professional degree who intend to pursue teaching as a career and who have not completed more than four quarters of full-time graduate work as of October 1. Selection is based on state manpower needs, academic performance, and financial need. Applicants should apply using the Free Application for Federal Student Aid (FAFSA), which is available at website: www.fafsa.ed.gov/.

Loans

Students applying for aid may find the most advantageous method of financing their education through loan programs. Among those available to students of the School of Engineering are the Federal Perkins Loan and Federal Stafford Loans through the School as Lender Program. Applicants should apply using the Free Application for Federal Student Aid (FAFSA), which is available at website: www.fafsa.ed.gov/.

Please Note: A student must be a U.S. citizen or eligible non-citizen to qualify for federal sources of financial assistance.

Deadlines

The Financial Aid Office has established deadlines for consideration of the various programs it administers. All students requesting financial aid from the University should contact the Financial Aid Office at the earliest possible date to request specific deadline information and appropriate application materials. Files completed later than February 1 for new recipients and March 2 for current recipients will receive consideration on a funds-available basis. All financial aid deadlines are posted on the Financial Aid website: www.scu.edu/financialaid.

Veterans and Veterans' Dependents Assistance

Santa Clara University is listed by the Department of Veterans Affairs as qualified to receive students under Chapter 33 (Post 9-11 G.I. Bill), Chapter 35 (veteran's dependent son or daughter with parent deceased or 100 percent disabled, widow of any person who died in the service or died of a service-connected disability, or wife of a veteran with a 100 percent service-connected disability); Chapter 31 (Rehabilitation); Chapter 30 (Active Duty Montgomery G.I. Bill). Those interested in attending under any of these chapters should contact the Veterans Administration Office in their locality to determine eligibility for benefits.

Information regarding these programs may be obtained from the Santa Clara University's VA represenative, Laura Moreno in the Office of the Registrar.

Teaching and Research Assistantships

The School of Engineering offers a limited number of teaching and research assistantships providing up to eight units of tuition and, in some cases, a modest stipend. For further information, students are encouraged to contact the associate dean for graduate studies, their faculty advisor, or their academic department.

University-Awarded Aid

Individual graduate schools may grant their students a specific amount of financial aid, per term, in the form of Santa Clara University school scholarships. Once the amount has been determined by the school, the information is sent to the Financial Aid Office for processing. The Financial Aid Office awards the aid and sends an e-mail notification to the student's SCU Groupwise e-mail address only, informing them of their financial aid package and/or any aid revision. Students will be able to see their school scholarship award on e-campus. The award amount will also appear as "anticipated aid" on the student's account to alleviate the assessment of holds/late fees from the Bursar's Office. Generally, financial aid is disbursed to the student's account ten days before the start of classes each term. If eligible, the Bursar's Office will issue refund checks to students reflecting credit balances during the first week of the term.

Return of Federal Title IV Funds

In addition to the institutional refund policy, all students who withdraw completely from the University and who have federal financial aid, including federal student loans, are subject to the return of Title IV funds policy. Under this policy, it is assumed that a student earns his or her aid based on the period of time he or she remains enrolled. Unearned Title IV funds, other than federal work-study, must be returned to the federal aid programs. Unearned aid is the amount of disbursed Title IV aid that exceeds the amount of Title IV aid earned.

During the first 60 percent of the enrollment period, a student "earns" Title IV funds in direct proportion to the length of time he or she remains enrolled. That is, the percentage of time during the period that the student remained enrolled is the percentage of disbursable aid for that period that the student earned. Institutional costs play no role in determining the amount of Title IV funds to which a withdrawn student is entitled.

A student who withdraws after the 60 percent point of the enrollment term earns all Title IV aid disbursed for the period.

Examples of common return of Title IV funds situations are available from the Financial Aid Office.

All funds must be returned to federal programs before being returned to state or institutional aid programs and/or the student. This return of funds allocation will be made in the following specific order and will be applied to all students who have received federal Title IV assistance:

1. Unsubsidized Federal Stafford Loan
2. Subsidized Federal Stafford Loan
3. Federal Perkins Loan
4. Federal Grad PLUS Loan
5. Other federal, state, private, or institutional assistance programs
6. Student

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Graduate Minor in Science, Technology, and Society (STS)

Program Advisor: Dr. Aleksandar Zecevic

PROGRAM DESCRIPTION

The graduate minor in science, technology, and society (STS) is designed to help students gain a deeper understanding of the influence that engineering has on society (and vice versa). Knowledge of this kind has become essential in an increasingly complex and interconnected world, in which purely technical expertise often needs to be supplemented by additional skills. In order to successfully operate in such an environment, engineers must (at the very least) have the ability to communicate clearly, function on interdisciplinary and diverse teams, and make ethically and socially responsible decisions. The minor consists of a Core and a set of electives, and entails a minimum of 12 units of coursework. It is open to all students who are pursuing a master's degree in engineering, regardless of the specific program in which they are enrolled.

The need to develop such skills has been widely recognized in universities around the country, as witnessed by the growing emphasis on interdisciplinary studies in undergraduate engineering curricula. It is unusual, however, to encounter programs of this kind on the graduate level. Most traditional master's programs still focus on specialized technical topics, and offer little insight into how practicing engineers might engage global challenges such as climate change, sustainability, or economic disparity (to name just a few).

The primary purpose of the STS minor is to offer graduate students an opportunity to examine some of these key social issues on an advanced level. The scope of the minor is broad, and includes topics that range from the social impact of new technologies, to applied ethics, sustainability, and religion. As such, it reflects an educational philosophy that goes well beyond narrow specialization and promotes a global and societal orientation. All the courses in this program have a distinctly interdisciplinary flavor, and are designed to develop creativity, innovation, and leadership

PROGRAM REQUIREMENTS

The STS minor consists of a Core and a set of electives, and entails a minimum of 12 units of coursework. The Core courses cover four distinct thematic areas:

- Social and Philosophical Issues in Science and Engineering
- Engineering and Ethics
- Science and Religion
- Sustainability and Engineering

Students will be required to take courses in at least three of the Core areas outlined above (for a minimum of 6 units). The remaining units (up to a total of 12, or more if desired) can be accumulated by taking a combination of electives and additional STS Core courses.

The courses and the different thematic areas to which they belong are listed below. Note that courses that appear in multiple areas can be used to satisfy only one Core requirement (in other words, no "double dipping" is allowed).

Social and Philosophical Issues in Science and Engineering

- ENGR 261 Nanotechnology and Society
- ENGR 272 Energy Public Policy
- ENGR 302 Managing in the Multicultural Environment
- ENGR 303 Gender and Engineering
- ENGR 304 Building Global Teams
- ENGR 332 Emergent Human Systems
- ENGR 333 Forms of Nature
- ENGR 336 Engineering for the Developing World
- ENGR 338 Mobile Applications for Emerging Markets
- ENGR 341 Innovation, Design and Spirituality
- ENGR 342 3D Print Technology and Society

Engineering and Ethics

- COEN 288 Software Ethics
- ENGR 273 Sustainable Energy and Ethics
- ENGR 310 Engineering Ethics
- ENGR 334 Energy, Climate Change, and Social Justice
- ENGR 335 Science, Religion, and Environmental Ethics

Science and Religion

- ELEN 217 Chaos Theory, Metamathematics and the Limits of Knowledge: A Scientific Perspective on Religion
- ENGR 334 Energy, Climate Change, and Social Justice
- ENGR 335 Science, Religion, and Environmental Ethics
- ENGR 341 Innovation, Design and Spirituality

Sustainability and Engineering

- ENGR 271 Energy Conservation
- ENGR 272 Energy Public Policy
- ENGR 273 Sustainable Energy and Ethics

- ELEN 280/MECH 287 Introduction to Alternative Energy Systems
- ELEN 288/COEN 282 Energy Management Systems
- ENGR 334 Energy, Climate Change, and Social Justice
- ENGR 337 Sustainability and Green Information Technology
- ENGR 340 Distributed and Renewable Energy for the Developing World
- ENGR 349 Topics in Frugal Engineering

Admission Procedures

The STS minor option is open to all master's students in the School of Engineering. Those who wish to pursue this minor must submit an application form to the Graduate Services Office by the end of their third quarter at SCU (at the latest), and must have their program of studies approved by the academic advisor for this program (Dr. Aleksander Zecevic). Links to the application form and the program of studies form can be found at the website: www.scu.edu/engineering/graduate

Students who complete all the technical requirements set by their department, as well as an approved set of STS classes, will receive a master's degree with a minor in science technology and society. The degree will be conferred by the department to which the student was originally accepted. Please note that the grades obtained in STS courses will be included in the overall GPA, and will carry the same weight as grades obtained in technical classes.

There are no financial or academic penalties for not completing the minor. Such students will receive the standard master's degree, with no reference to the STS minor.

Financial Aid for the STS Minor

Students who have declared a graduate minor in Science, Technology, and Society (STS) are eligible for a special form of financial aid. The amount of aid is limited to 75% of tuition for up to 12 units (excluding fees). These funds can be applied only to courses taken beyond the 45 units that are required for a Master's degree.

In order to become eligible for this benefit, students must check the appropriate box that pertains to financial aid on the application form. In addition, their program of studies must be approved by the academic advisor for the program (Dr. Aleksandar Zecevic). Financial aid comes into effect once a student completes 45 units of course work, at which point he or she should follow the procedure outlined below:

1. The quarterly tuition must be paid in full, and in the time frame specified by the Bursar's Office.
2. In the second week of each quarter, students must provide the program academic advisor with a list of courses in which they are currently enrolled (this will require official proof of registration).
3. Once the academic advisor establishes that the courses conform to the approved programs of studies (both in the technical and in the STS area), students will receive financial aid in the amount of 75% of their tuition expenses for that quarter (excluding fees).

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Certificate Programs

GENERAL INFORMATION

Certificate programs are designed to provide intensive background in a narrow area at the graduate level. At approximately one-third of the units required for a master's degree, the certificate is designed to be completed in a much shorter period of time. These certificate programs are appropriate for students working in industry who wish to update their skills or for those interested in changing their career path.

INTERDISCIPLINARY

Certificate in Frugal Innovation

Advisors: Dr. Aleksandar Zecevic, Radha Basu

Over the past two decades, global trends have been forcing businesses to adapt to growing consumer bases in Africa, Asia and Latin America, which are in desperate need of low-cost and high-quality solutions to the challenges that they face. The importance of these new "economic realities" is underscored by the fact that emerging markets are expected to exceed 50% of the world's GDP by 2017 (according to IMF estimates). In order to excel professionally in such an environment, engineers will have to be equipped with the knowledge and skillsets to appropriately define, design, and implement solutions that are not merely a "stripping down" of Western products to meet the rising demand. Industry, particularly in the Silicon Valley, is becoming increasingly aware of this fact, and has begun to move toward a 'Triple Bottom Line' approach to business, which integrates environmental, societal and financial considerations. The Certificate in Frugal Innovation is designed to give students the ability and the tools to adapt to this new model, and to expand their understanding of the impact that engineering has on society.

This program is suitable for working professionals in a wide variety of engineering disciplines. To enroll, students must have a B.S in Engineering from an accredited institution, and should maintain a GPA of at least 3.0 in order to receive the certificate.

Program Requirements

The Certificate in Frugal Innovation entails a minimum of 16 units of course work. It consists of an eight unit Core, and a set of electives that are organized into two groups. Students are required to take four units from Group A and another four from Group B, as described below.

Required Core Classes (8 units)

- ENGR 336 Engineering for the Developing World (2 units)
- ENGR 338 Mobile Applications and Instrumentation for Emerging Markets (2 units)
- ENGR 340 Distributed and Renewable Energy for the Developing World (2 units)
- ENGR 341 Innovation, Design and Spirituality (2 units)

Elective Group A (4 units)

- ENGR 273 Sustainable Energy and Ethics (2 units)
- ENGR 304 Building Global Teams (2 units)
- ENGR 342 3D Print Technology and Society (2 units)
- ENGR 349 Special Topics in Frugal Engineering (2 units)

Elective Group B (4 units)

- CENG 219 Designing for Sustainable Construction (4 units)
- COEN 389 Energy Efficient Computing (2 units)
- ELEN 280/MECH 287 Introduction to Alternative Energy Systems (2 units)
- ELEN 288/COEN 282 Energy Management Systems (2 units)
- ENGR 302 Managing in the Multicultural Environment (2 units)
- ENGR 334 Energy, Climate Change, and Social Justice (2 units)

Renewable Energy Certificate

Advisor: Dr. Samiha Mourad

Renewable energy is the fastest-growing sector in California and brings together principles and practices from engineering, environmental science, and economics. Silicon Valley, the home of the world's largest cluster of renewable energy companies and green investors, offers fertile ground to recruit career changers who wish to move into renewable energy and students who want to take advantage of the tremendous career opportunities.

The main goal of this certificate is to introduce students to the field of renewable energy. The intent is to help equip professionals in Silicon Valley with the knowledge that will help them advance in their present career or enter the renewable energy field. To enroll in this certificate an applicant should have a B.S. in Engineering from an accredited school and should maintain a grade point average of 3.0. As with most certificates in the Graduate School of Engineering, the requirement is 17 quarter units. Nine of these units are in Power Systems, four units are in Renewable Energy, with the remaining four units in Sustainability as shown below.

Required Courses (17 units total)

Power Systems (9 Units)

- ELEN 280/MECH 287 Renewable Energy (2 units)
- ELEN 281A Power Systems: Generation (3 units)
- ELEN 285 Introduction to the Smart Grid (2 units)
- ELEN 287 Storage Device Systems (2 units)

Renewable Energy (choose any 4 units)

- ELEN 282 Photovoltaic Devices and Systems (2 units)
- ELEN 284 Design and Fabrication of Photovoltaic Cells (2 units)
- ELEN/MECH 286 Introduction to Wind Energy Engineering (2 units)

Sustainability (choose any 4 units)

- CENG 208 Engineering Economics and Project Finance (2 units)
- ENGR 272 Energy Public Policy (2 units)
- ENGR 273 Sustainable Energy and Ethics (2 units)

COMPUTER ENGINEERING

Certificate in Software Engineering

Advisor: Dr. Rani Mikkilineni

This certificate program places an emphasis on methodologies used in the development of large, complex software. The program is appropriate for anyone who is developing new software, maintaining existing software, or is the technical head of a software development project. In addition to the general requirements, students must have two years of industrial experience in software development and prior coursework in data structures and analysis of algorithms, software engineering, discrete mathematics, and predicate logic.

Required Courses (10 units)

- COEN 260 Truth, Deduction, and Computation (4 units)
- COEN 286 Software Quality Assurance and Testing (2 units)
- COEN 287 Software Development Process Management (2 units)
- COEN 385 Formal Methods in Software Engineering (2 units)
- COEN 386 Software Architectures (2 units)
- COEN 485 Software Engineering Project (2 units)

Elective Courses (Select any 6 units; other courses may be considered if approved in advance)

- COEN 261 Structure and Interpretation of Computer Programs (2 units)
- COEN 275 Object-Oriented Analysis and Design (4 units)
- COEN 276 Software Tools Design (4 units)
- COEN 277 Graphical User Interface Design and Programming (2 units)
- COEN 388 Principles of Computer-Aided Engineering Design (2 units)
- EMGT 332 Software Engineering Economics (2 units)
- EMGT 339 Quality Issues in Managing Software (2 units)
- EMGT 341 Software Project Metrics (2 units)

Certificate in Information Assurance

Advisor: Dr. JoAnne Holliday

The Advanced Studies in Information Assurance Certificate program provides education in information assurance to working professionals in engineering and engineering management. Applicants are expected to have previous coursework in Operating Systems and Networks. In addition, applicants must complete all courses in Group 1, and eight units from Group 2 and additional courses should be chosen from Group 2 or Group 3 for a total of at least 16 units.

Group 1: Required Courses (4 units)

- COEN 250 Information Security Management (2 units)
- COEN 253 Secure Systems Development and Evaluation I (2 units)

Group 2: Select courses from this group (8 units)

- AMTH 387 Cryptology (4 units)
- COEN 225 Secure Coding in C and C++ (2 units)
- COEN 252 & 252L Computer Forensics (5 units)
- COEN 350 Network Security (2 units)
- COEN 351 Internet and E-Commerce Security (3 units)

Group 3: Elective Courses

- COEN 226 Introduction to System Certification and Accreditation (2 units)
- COEN 254 Secure Systems Development and Evaluation II (2 units)
- COEN 286 Software Quality Assurance and Testing (2 units)
- COEN 288 Software Ethics (2 units)
- COEN 352 Advanced Topics in Information Assurance (2 units)
- EMGT 288 Management of Quality Assurance (2 units)
- EMGT 369 E-Commerce Technology Strategy (2 units)
- ENGR 310 Engineering Ethics (2 units)
- ENGR 330 Law, Technology, and Intellectual Property (2 units)

Certificate in Networking

Advisor: Dr. Ahmed Amer

This certificate program is appropriate for working professionals in computer engineering, network engineering, and engineering management, and places an emphasis on the fundamentals and recent developments in computer networking. Students who complete the program may pursue a professional career in computer networking, with the ability to understand, analyze, design, implement, validate, and maintain networked systems.

Applicants must have completed an accredited bachelor's degree program in Computer Science, Computer Engineering, Electrical Engineering, Mathematics or an equivalent field with a strong academic record, and are expected to have prior coursework in data structures, analysis of algorithms, software engineering and operating systems.

Program Requirements: Students must complete a total of 16 units of prescribed coursework with a minimum GPA of 3.0 and a grade of C or better in each course. Certificate requirements substantially equivalent to other coursework completed within the last five years must be replaced by electives approved by the faculty in charge of networking.

Required Courses (8 units)

- COEN 233 Computer Networks (4 units)
- COEN 239 Network Design, Analysis (4 units)

Additional Courses (8 units) from:

- COEN 234, 235, 315, 316, 317, 329, 331, 332, 335, 337, 338, 339, 347, 350, or 351

ELECTRICAL ENGINEERING

ASIC Design and Test

Advisor: Dr. Samiha Mourad

This certificate program has a dual purpose: (a) to strengthen fundamental knowledge of the design process that helps the designer adapt to future innovations in technology; and (b) to introduce the designer to state-of-the-art tools and techniques. Any change in the requirements must be approved by the academic advisor. The program consists of the eight courses listed below:

Required Courses (16 units)

- ELEN 387 VLSI Design I (2 units)
- ELEN 500 Logic Analysis and Synthesis (2 units)
- ELEN 603 Logic Design Using HDL (2 units)
- ELEN 605 High-Level Synthesis (2 units)
- ELEN 608 Design for Testability (2 units)
- ELEN 624 Signal Integrity in IC and PCB Systems (2 units)
- Two electives from ELEN 388, 389, 601, 604, 609, 613, 614 or 620 (2 units each)

Analog Circuit Design

Advisor: Dr. Shoba Krishnan

This certificate provides a background in the basic devices and circuits that are fundamental to analog circuit design. The program will also introduce the student to state-of-the-art analog IC design tools. The program consists of the courses listed below totaling 16 units:

Required Courses (12 units)

- ELEN 252 Analog Integrated Circuits I (2 units)
- ELEN 253 Analog Integrated Circuits II (2 units)
- ELEN 254 Advanced Analog Integrated Circuit Design (4 units)

- ELEN 264 Semiconductor Device Theory I (2 units)
- ELEN 387 VLSI Design I (2 units)

Elective Courses (4 units)

- ELEN 251 Transistor Models for IC Design (2 units)
- ELEN 265 Semiconductor Device Theory II (2 units)
- ELEN 351 RF Integrated Circuit Design (2 units)
- ELEN 352 Mixed Signal IC Design for Data Communications (2 units)
- ELEN 353 Power IC Design (2 units)
- ELEN 388 VLSI Design II (2 units)

Digital Signal Processing Applications

Advisors: Dr. Tokunbo Ogunfunmi, Dr. Sally Wood

This certificate program provides a basic understanding of digital signal processing theory and modern implementation methods as well as advanced knowledge of at least one specific application area. Digital signal processing has become an important part of many areas of engineering, and this certificate prepares students for traditional or novel applications.

Required Courses (10 to 12 units)

- AMTH 210 or AMTH 245 (2 units)
- ELEN 223 Digital Signal Processing System Development (4 units) or ELEN 226 DSP Design in FPGA (2 units)
- ELEN 233E or ELEN 233 and 234 Digital Signal Processing I, II (4 units)
- ELEN 421 Speech Coding I or ELEN 640 Digital Image Processing I (2 units)

Elective Courses (four to six units to make a total of 16 units) may be selected from the list below. Any courses from the required list above that were not selected to meet the requirements may be included in the elective options.

- AMTH 308 Theory of Wavelets (2 units) or AMTH 358 Fourier Transforms (2 units)
- ELEN 241 Introduction to Communications (2 units)
- ELEN 243 Digital Communications Systems (2 units)
- ELEN 244 Information Theory (2 units)
- ELEN 334 Introduction to Statistical Signal Processing (2 units)
- ELEN 422 Speech Coding II (2 units)
- ELEN 431 Adaptive Signal Processing I (2 units)
- ELEN 643 Digital Image Processing II (2 units)

Digital Signal Processing Theory

Advisors: Dr. Tokunbo Ogunfunmi, Dr. Sally Wood

This certificate program provides a firm grounding in fundamentals of digital signal processing (DSP) technology and its applications. It is appropriate for engineers involved with any application of DSP who want a better working knowledge of DSP theory and its applications. A novel feature of the program is a hands-on DSP hardware/software development laboratory course in which students design and build systems for various applications using contemporary DSP hardware and development software.

Required Courses (8 units)

- AMTH 308 Theory of Wavelets (2 units) or AMTH 358 Fourier Transforms (2 units)
- ELEN 233E or ELEN 233 and 234 Digital Signal Processing I, II (4 units)
- ELEN 334 Introduction to Statistical Signal Processing (2 units)

Elective Courses (8 units)

- ELEN 223 Digital Signal Processing System Development (4 units)
- ELEN 226 DSP Design in FPGA (2 units)
- ELEN 235 Estimation I (2 units)
- ELEN 241 Introduction to Communications (2 units)
- ELEN 244 Information Theory (2 units)
- ELEN 336 Detection (2 units)
- ELEN 431 Adaptive Signal Processing I (2 units)
- ELEN 640 Digital Image Processing I (2 units)
- ELEN 641 Image and Video Compression (2 units)
- ELEN 643 Digital Image Processing II (2 units)

Fundamentals of Electrical Engineering

Advisor: Electrical Engineering Department Chair

This certificate has been designed for those individuals who have significant work experience in some area of electrical engineering and wish to take graduate-level courses but may lack some prerequisite knowledge because they have not earned the BSEE degree. This one-year program consists of 16 to 28 units, depending on the background of the individual student, and covers electrical engineering core areas. Eight of these units may be credited toward an MSEE degree after successful completion of the certificate.

The required courses are selected with the help of the program advisor according to the student's background.

- ELEN 21 Introduction to Logic Design (4 units)
- ELEN 33 Digital Systems Architecture (5 units)
- ELEN 50 Electric Circuits I (5 units)

- ELEN 100 Electric Circuits II (5 units)
- ELEN 104 Electromagnetics I (5 units)
- ELEN 110 Linear Systems (5 units) or ELEN 210 (2 units)
- ELEN 115 Electronic Circuits I (5 units) or ELEN 250 (2 units)

Microwave and Antennas

Advisors: Dr. Timothy Healy, Dr. Ramesh Abhari

The purpose of this certificate is to meet the increasing need for the knowledge in microwave, antenna and RF integrated circuits in present electronic products. This program is offered for students who have a B.S. in Electrical Engineering. The students are expected to have had knowledge of multivariate calculus and preferably partial differential equations.

The curriculum consists of 16 units: Two required courses (4 units) and the 12 units of elective courses listed below:

Required Courses (4 units)

- ELEN 201 or 202 Electromagnetic Field Theory I or II (2 units each)
- ELEN 701 Microwave System Architecture (2 units)

Elective Courses (12 units)

- RF Circuits ELEN 351, 354 (2 units each)
- Laboratory oriented ELEN 705, 726 (3 units)
- Passive components ELEN 706 (4 units)
- Active components ELEN 711, 712 (2 units each)
- Antennas ELEN 715, 716 (2 units each)

Substitutions for these courses are only possible with the approval of the certificate advisor and the chair.

MECHANICAL ENGINEERING

Controls

The Controls Certificate is intended for working engineers in mechanical and closely related fields of engineering. The certificate will provide a foundation in contemporary control theory and methods. The Controls Certificate covers classical and modern control systems and analysis. Specialization in digital control, mechatronics, robotics, or aerospace applications is possible with a suitable choice of electives. Completion of the certificate will allow the student to design and analyze modern control systems.

Required Courses (8 units)

- MECH 217 Introduction to Control (2 units)
- MECH 218 Guidance and Control I (2 units)
- MECH 323 Modern Control Systems I (2 units)
- MECH 324 Modern Control Systems II (2 units)

Elective Courses (8 units)

- AMTH 245 Linear Algebra I (2 units)
- AMTH 246 Linear Algebra II (2 units)
- CENG 211 Advanced Strength of Materials (4 units)
- MECH 207 Advanced Mechatronics I (2 units)
- MECH 208 Advanced Mechatronics II (2 units)
- MECH 209 Advanced Mechatronics III (2 units)
- MECH 219 Guidance and Control II (2 units)
- MECH 329 Introduction to Intelligent Control (2 units)
- MECH 355, 356 Adaptive Control I, II (2 units each)
- MECH 429, 430 Optimal Control I, II (2 units each)

Dynamics

The Dynamics Certificate is intended for working engineers in mechanical and related fields of engineering. The certificate will provide a fundamental and broad background in engineering dynamics. The Dynamics Certificate includes a strong foundational base in dynamics and applications in optimization, robotics, mechatronics, or dynamics of aircraft or spacecraft (depending on the chosen elective courses). Completion of the certificate will allow the student to formulate and solve the complex dynamics problems that arise in such fields as robotics and space flight.

Required Courses (16 units)

- MECH 205, 206 Aircraft Flight Dynamics I, II (2 units each)
- MECH 214, 215 Advanced Dynamics I, II (2 units each)
- MECH 305, 306 Advanced Vibrations I, II (2 units each)
- MECH 431, 432 Spacecraft Dynamics I, II (2 units each)

Materials Engineering

The Materials Engineering Certificate is intended for working engineers in mechanical, materials, or manufacturing engineering. The certificate will provide either an upgrade in materials understanding, or advanced study in a particular aspect of the subject. Completion of the certificate will allow the student to develop a deeper understanding of materials and their applications in design and manufacturing.

Required Courses (12 units)

- MECH 281 Fracture Mechanics and Fatigue (2 units)
- MECH 330 Atomic Arrangements, Defects, and Mechanical Behavior (2 units)
- MECH 331 Phase Equilibria and Transformations (2 units)
- MECH 332 Electronic Structure and Properties (2 units)
- MECH 333 Experiments in Materials Science (2 units)
- MECH 345 Modern Instrumentation and Control (2 units)

Elective Courses (4 units)

- AMTH 210 Introduction to Probability I and AMTH 211 Continuous Probability (2 units each)
- AMTH 217 Design of Scientific Experiments and AMTH 219 Analysis of Scientific Experiments (2 units each)
- CENG 211 Advanced Strength of Materials (4 units)
- ENGR 260 Nanoscale Science and Technology (2 units)
- ENGR 262 Nanomaterials (2 units)
- MECH 334 Elasticity (2 units)
- MECH 350 and 351 Composite Materials I and II (2 units each)

Mechanical Design Analysis

The Mechanical Design Analysis Certificate is intended for working engineers in mechanical or structural engineering. The certificate will provide a succinct upgrade in knowledge and skills that will allow the student to gain a deeper understanding of CAD and FEA principles and practices. Completion of the certificate will allow the student to pursue more advanced design and analysis tasks.

Required Courses (12 units)

- CENG 205 Finite Element Methods I (2 units)
- CENG 206 Finite Element Methods II (2 units)
- CENG 207 Finite Element Methods III (2 units)
- MECH 325 Computational Geometry for Computer-Aided Design and Manufacture (2 units)
- MECH 334 Elasticity (2 units)
- MECH 415 Optimization in Mechanical Design (2 units)

Elective Courses (4 units)

- AMTH 220 Numerical Analysis I (2 units)
- AMTH 221 Numerical Analysis II (2 units)
- AMTH 308 Mathematical Modeling I (2 units)
- AMTH 309 Mathematical Modeling II (2 units)
- AMTH 370 Optimization Techniques I (2 units)
- AMTH 371 Optimization Techniques II (2 units)
- CENG 211 Advanced Strength of Materials (4 units)
- CENG 214 Theory of Elasticity (4 units)
- CENG 222 Advanced Structural Analysis (4 units)
- MECH 268 Computational Fluid Mechanics I (2 units)
- MECH 269 Computational Fluid Mechanics II (2 units)

Mechatronics Systems Engineering

The Mechatronics Systems Engineering Certificate is intended for working engineers in mechanical engineering and related fields. The certificate program introduces students to the primary technologies, analysis techniques, and implementation methodologies relevant to the detailed design of electro-mechanical devices. Completion of the certificate will allow the student to develop systems that involve the sensing, actuation and control of the physical world. Knowledge such as this is vital to engineers in the modern aerospace, robotics and motion control industries.

Required Courses (8 units)

- MECH 207 Advanced Mechatronics I (2 units)
- MECH 208 Advanced Mechatronics II (2 units)
- MECH 209 Advanced Mechatronics III (2 units)
- MECH 217 Introduction to Control (2 units)

Elective Courses (8 units)

- MECH 218 Guidance and Control I (2 units)
- MECH 219 Guidance and Control II (2 units)
- MECH 275A Design for Competitiveness (2 units)
- MECH 310 Advanced Mechatronics IV (2 units)
- MECH 311 Modeling and Control of Telerobotic Systems (4 units)
- MECH 315 Advanced Digital Control Systems I (2 units)
- MECH 316 Advanced Digital Control Systems II (2 units)
- MECH 323 Modern Control Systems I (2 units)
- MECH 324 Modern Control Systems II (2 units)
- MECH 329 Intelligent Control (2 units)
- MECH 337 Robotics I (2 units)
- MECH 338 Robotics II (2 units)
- MECH 339 Robotics III (2 units)
- MECH 345 Modern Instrumentation (2 units)

An independent study or Capstone project would be suitable as one of the electives. In addition, other courses may serve as electives at the discretion of the program advisor.

Thermofluids

The Thermofluids Certificate is intended for working engineers in mechanical, chemical, or a closely related field of engineering. The certificate will provide fundamental theoretical and analytic background, as well as exposure to modern topics and applications. Specialization in fluid mechanics, thermodynamics, or heat transfer is possible with suitable choice of electives. Completion of the certificate will allow the student to design heat transfer and fluid solutions for a range of modern applications.

Required Courses (12 units)

- MECH 228 Equilibrium Thermodynamics (2 units)
- MECH 236 Conduction Heat Transfer (2 units)
- MECH 238 Convective Heat Transfer I (2 units)
- MECH 240 Radiation Heat Transfer (2 units)
- MECH 266 Fundamentals of Fluid Mechanics (2 units)
- MECH 270 Viscous Flow I (2 units)

Elective Courses (4 units)

- MECH 202 Mathematical Methods in Mechanical Engineering (4 units)
- MECH 225 Gas Dynamics I (2 units)
- MECH 226 Gas Dynamics II (2 units)
- MECH 230 Statistical Thermodynamics (2 units)
- MECH 239 Convective Heat Transfer II (2 units)
- MECH 241 Radiation Heat Transfer II (2 units)
- MECH 242 Nanoscale Heat Transfer (2 units)
- MECH 268 Computational Fluid Mechanics I (2 units)
- MECH 269 Computational Fluid Mechanics II (2 units)
- MECH 271 Viscous Flow II (2 units)
- MECH 288 Energy Conversion I (2 units)
- MECH 289 Energy Conversion II (2 units)

8

Department of Applied Mathematics

Senior Lecturer: Stephen A. Chiappari *(Chair)*
Renewable Term Lecturer: Aaron Melman

MASTER OF SCIENCE PROGRAM

The Applied Mathematics Program is open to those students who have earned a B.S. degree in engineering, science, or mathematics, provided that the student has completed a program in undergraduate mathematics that parallels the program of the mathematics major at Santa Clara University. The undergraduate program at Santa Clara includes calculus and differential equations, abstract algebra, linear algebra, advanced calculus and/or real analysis; and a minimum of five upper-division courses chosen from the areas of analysis, complex variables, partial differential equations, numerical analysis, logic, probability, and statistics.

Courses for the master's degree must result in a total of 45 units. These units may include courses from other fields with permission of the Applied Mathematics Department advisor. A minimum of 12 quarter units must be in 300-level courses.

Concentration in Mathematical Finance within the Master of Science in Applied Mathematics.

In addition to its freestanding master's degree program, the Department of Applied Mathematics offers a concentration in mathematical finance within its master's degree program. Specific course requirements change from time to time. For further information, please consult with the chair of the department.

COURSE DESCRIPTIONS

Undergraduate Courses

AMTH 106. Differential Equations

First-order linear differential equations, systems of linear differential equations, homogeneous systems of linear differential equations with constant coefficients, the Laplace transform, the solution of differential equations by Laplace transform. *Prerequisite: MATH 14.* (4 units)

AMTH 108. Probability and Statistics

Definitions of probability, sets, sample spaces, conditional and total probability, random variables, distributions, functions of random variables, sampling, estimation of parameters, testing hypotheses. *Prerequisite: MATH 14.* (4 units)

AMTH 112. Risk Analysis in Civil Engineering

Set theory and probability, random variables, conditional and total probability, functions of random variables, probabilistic models for engineering analysis, statistical inference, hypothesis testing. *Prerequisite: MATH 14.* (4 units)

AMTH 118. Numerical Methods

Numerical solution of algebraic and transcendental equations, finite differences, numerical differentiation and integration, and solution of ordinary differential equations. Solution of representative problems on the digital computer. *Prerequisites: AMTH 106 or MATH 22 and COEN 44 or 45.* (4 units)

AMTH 120. Engineering Mathematics

Review of ordinary differential equations (ODEs) and Laplace transform, vector calculus, linear algebra, orthogonal functions and Fourier Series, partial differential equations (PDEs), and introduction to numerical solutions of ODEs. *Cross-listed with MECH 120. Prerequisites: AMTH 106 and COEN 45.* (4 units)

AMTH 194. Peer Educator in Applied Mathematics

Peer educators in applied mathematics work closely with a faculty member to help students understand course material, think more deeply about course material, benefit from collaborative learning, feel less anxious about testing situations, and help students enjoy learning. *Prerequisite: Instructor approval.* (2 units)

Graduate Courses

All 200-level applied mathematics courses are assumed to be first-year graduate courses. The minimum preparation for these courses is a working knowledge of calculus and a course in differential equations. A course in advanced calculus is desirable. The 300-level courses are graduate courses in mathematics that should be taken only by students who have completed several 200-level courses.

AMTH 200. Advanced Engineering Mathematics I

Method of solution of the first, second, and higher order differential equations (ODEs). Integral transforms including Laplace transforms, Fourier series and Fourier transforms. *Cross-listed with MECH 200. Prerequisite: AMTH 106 or equivalent.* (2 units)

AMTH 201. Advanced Engineering Mathematics II

Method of solution of partial differential equations (PDEs) including separation of variables, Fourier series and Laplace transforms. Introduction to calculus of variations. Selected topics from vector analysis and linear algebra. *Cross-listed with MECH 201. Prerequisite: AMTH/MECH 200.* (2 units)

AMTH 202. Advanced Engineering Mathematics

Method of solution of first, second, and higher order ordinary differential equations, Laplace transforms, Fourier series, and Fourier transforms. Method of solution of partial differential equations, including separation of variables, Fourier series, and Laplace transforms. Selected topics in linear algebra, vector analysis, and calculus of variations. *Also listed as MECH 202. Prerequisite: AMTH 106 or equivalent.* (4 units)

AMTH 210. Probability I

Definitions, sets, conditional and total probability, binomial distribution approximations, random variables, important probability distributions, functions of random variables, moments, characteristic functions, joint probability distributions, marginal distributions, sums of random variables, convolutions, correlation, sequences of random variables, limit theorems. The emphasis is on discrete random variables. (2 units)

AMTH 211. Probability II

Continuation of AMTH 210. A study of continuous probability distributions, their probability density functions, their characteristic functions, and their parameters. These distributions include the continuous uniform, the normal, the beta, the gamma with special emphasis on the exponential, Erlang, and chi-squared. The applications of these distributions are stressed. Joint probability distributions are covered. Functions of single and multiple random variables are stressed, along with their applications. Order statistics. Correlation coefficients and their applications in prediction, limiting distributions, the central limit theorem. Properties of estimators, maximum likelihood estimators, and efficiency measures for estimators. P*rerequisite: AMTH 210.* (2 units)

AMTH 212. Probability I and II

Combination of AMTH 210 and 211. (4 units)

AMTH 214. Engineering Statistics I

Frequency distributions, sampling, sampling distributions, univariate and bivariate normal distributions, analysis of variance, two- and three-factor analysis, regression and correlation, design of experiments. *Prerequisite: Solid background in discrete and continuous probability.* (2 units)

AMTH 215. Engineering Statistics II

Continuation of AMTH 214. *Prerequisite: AMTH 214.* (2 units)

AMTH 217. Design of Scientific Experiments

Statistical techniques applied to scientific investigations. Use of reference distributions, randomization, blocking, replication, analysis of variance, Latin squares, factorial experiments, and examination of residuals. Prior exposure to statistics useful but not essential. *Prerequisite: Solid background in discrete and continuous probability.* (2 units)

AMTH 219. Analysis of Scientific Experiments

Continuation of AMTH 217. Emphasis on the analysis of scientific experiments. The theory of design of experiments so that maximal information can be derived. *Prerequisites: AMTH 211 or 212 and 217.* (2 units)

AMTH 220. Numerical Analysis I

Solution of algebraic and transcendental equations, finite differences, interpolation, numerical differentiation and integration, solution of ordinary differential equations, matrix methods with applications to linear equations, curve fittings, programming of representative problems. (2 units)

AMTH 221. Numerical Analysis II

Continuation of AMTH 220. *Prerequisite: AMTH 220.* (2 units)

AMTH 222. Design and Analysis of Scientific Experiments

Combination of AMTH 217 and AMTH 219. *Prerequisite: AMTH 211 or 212.* (4 units)

AMTH 225. Vector Analysis I

Algebra of vectors. Differentiation of vectors. Partial differentiation and associated concepts. Integration of vectors. Applications. Basic concepts of tensor analysis. (2 units)

AMTH 226. Vector Analysis II

Continuation of AMTH 225. *Prerequisite: AMTH 225.* (2 units)

AMTH 230. Differential Equations with Variable Coefficients

Solution of ordinary differential equations with variable coefficients using power series and the method of Frobenius. Solution of Legendre differential equation. Orthogonality of Legendre polynomials, Sturm-Liouville differential equation. Eigenvalues and Eigenfunctions. Generalized Fourier series and Legendre Fourier series. (2 units)

AMTH 231. Special Functions and Laplace Transforms

Review of the method of Frobenius in solving differential equations with variable coefficients. Gamma and beta functions. Solution of Bessel's differential equation, properties and orthogonality of Bessel functions. Bessel Fourier series. Laplace transform, basic transforms, and applications. *Prerequisite: AMTH 230.* (2 units)

AMTH 232. Biostatistics

Statistical principles used in bioengineering; distribution-based analyses and Bayesian methods applied to biomedical device and disease testing; methods for categorical data, comparing groups (analysis of variance), and analyzing associations (linear and logistic regression). Special emphases on computational approaches used in model optimization, test-method validation, sensitivity analysis (ROC curves), and survival analysis. *Also listed as BIOE 232. Prerequisite: AMTH 108, BIOE 120, or equivalent.* (2 units)

AMTH 232L. Biostatistics Laboratory

Laboratory for AMTH 232. *Also listed as BIOE 232L. Co-requisite: AMTH 232.* (1 unit)

AMTH 235. Complex Variables I

Algebra of complex numbers, calculus of complex variables, analytic functions, harmonic functions, power series, residue theorems, application of residue theory to definite integrals, conformal mappings. (2 units)

AMTH 236. Complex Variables II

Continuation of AMTH 235. *Prerequisite: AMTH 235.* (2 units)

AMTH 240. Discrete Mathematics for Computer Science

Relations and operation on sets, orderings, combinatorics, recursion, logic, method of proof, and algebraic structures. (2 units)

AMTH 245. Linear Algebra I

Vector spaces, transformations, matrices, characteristic value problems, canonical forms, and quadratic forms. (2 units)

AMTH 246. Linear Algebra II

Continuation of AMTH 245. *Prerequisite: AMTH 245.* (2 units)

AMTH 247. Linear Algebra I and II

Combination of AMTH 245 and 246. (4 units)

AMTH 256. Applied Graph Theory I

Elementary treatment of graph theory. The basic definitions of graph theory are covered; the fundamental theorems are explored. Subgraphs, complements, graph isomorphisms, and some elementary algorithms make up the content. *Prerequisite: Mathematical maturity.* (2 units)

AMTH 257. Applied Graph Theory II

Extension of AMTH 256. Networks, Hamiltonian and planar graphs are covered in detail. Edge colorings and Ramsey numbers may also be covered. *Prerequisite: AMTH 256.* (2 units)

AMTH 258. Applied Graph Theory I and II

Combination of AMTH 256 and AMTH 257. *Prerequisite: Mathematical maturity.* (4 units)

AMTH 297. Directed Research

By arrangement. *Prerequisite: Permission of the chair of applied mathematics. May be repeated for credit with permission of the chair of applied mathematics.* (1–8 units)

AMTH 299. Special Problems

By special arrangement. (1–2 units)

AMTH 308. Theory of Wavelets

Construction of Daubechies' wavelets and the application of wavelets to image compression and numerical analysis. Multi resolution analysis and the properties of the scaling function, dilation equation, and wavelet filter coefficients. Pyramid algorithms and their application to image compression. *Prerequisites: Familiarity with MATLAB or other high-level language, Fourier analysis, and linear algebra.* (2 units)

AMTH 313. Time Series Analysis

Review of forecasting methods. Concepts in time series analysis; stationarity, auto-correlation, Box-Jenkins. Moving average and auto-regressive processes. Mixed processes. Models for seasonal time series. *Prerequisite: AMTH 211 or 212.* (2 units)

AMTH 315. Matrix Theory I

Properties and operations, vector spaces and linear transforms, characteristic root; vectors, inversion of matrices, applications. *Prerequisite: AMTH 246 or 247.* (2 units)

AMTH 316. Matrix Theory II

Continuation of AMTH 315. *Prerequisite: AMTH 315.* (2 units)

AMTH 318. Advanced Topics in Wavelets

An overview of very recent developments in the theory and application of wavelets. Study of a new generation of wavelet-like objects, such as beamlets, which exhibit unprecedented capabilities for the compression and analysis of 3D data. The beamlet framework consists of five major components: The beamlet dictionary, a dyadic ally organized library of line segments over a range of locations, orientations, and scales. The beamlet transform, a collection of line integrals of the given 3D data along the line segments in the beamlet dictionary. The beamlet pyramid, the set of all beamlet transform coefficients arranged in a hierarchical data structure according to scale. The beamlet graph, the graph structure in which vertices correspond to voxel corners of the underlying 3D object, and the edges correspond to beamlets connecting pairs of vertices. The beamlet algorithms, to extract information from the beamlet graph consistent with the structure of the beamlet graph. Study of each component in detail. Implementation issues. Selected applications in the areas of computer graphics, pattern recognition, and data compression. P*rerequisite: AMTH 308.* (2 units)

AMTH 340. Linear Programming I

Basic assumptions and limitations, problem formulation, algebraic and geometric representation. Simplex algorithm and duality. (2 units)

AMTH 341. Linear Programming II

Continuation of AMTH 340. Network problems, transportation problems, production problems. *Prerequisite: AMTH 340.* (2 units)

AMTH 342. Linear Programming

Combination of AMTH 340 and 341. (4 units)

AMTH 344. Linear Regression

The elementary straight-line "least squares least-squares fit;" and the fitting of data to linear models. Emphasis on the matrix approach to linear regressions. Multiple regression; various strategies for introducing coefficients. Examination of residuals for linearity. Introduction to nonlinear regression. *Prerequisite: AMTH 211 or 212.* (2 units)

AMTH 351. Quantum Computing

Introduction to quantum computing, with emphasis on computational and algorithmic aspects. *Prerequisite: AMTH 246 or 247.* (2 units)

AMTH 358. Fourier Transforms

Definition and basic properties. Energy and power spectra. Applications of transforms of one variable to linear systems, random functions, communications. Transforms of two variables and applications to optics. *Prerequisites: Calculus sequence, elementary differential equations, fundamentals of linear algebra, and familiarity with MATLAB (preferably) or other high-level programming language.* (2 units)

AMTH 360. Advanced Topics in Fourier Analysis

Continuation of AMTH 358. Focus on Fourier analysis in higher dimensions, other extensions of the classical theory, and applications of Fourier analysis in mathematics and signal processing. *Prerequisite: AMTH 358 or instructor approval.* (2 units)

AMTH 362. Stochastic Processes I

Types of stochastic processes, stationarity, ergodicity, differentiation and integration of stochastic processes. Topics chosen from correlation and power spectral density functions, linear systems, band-limit processes, normal processes, Markov processes, Brownian motion, and option pricing. *Prerequisite: AMTH 211 or 212 or instructor approval.* (2 units)

AMTH 363. Stochastic Processes II

Continuation of AMTH 362. *Prerequisite: AMTH 362 or instructor approval.* (2 units)

AMTH 364. Markov Chains

Markov property, Markov processes, discrete-time Markov chains, classes of states, recurrence processes and limiting probabilities, continuous-time Markov chains, time-reversed chains, numerical techniques. *Prerequisite: AMTH 211 or 212 or 362 or ELEN 233 or 236.* (2 units)

AMTH 367. Mathematical Finance

Basic principles of finance and economic investments. Random processes with white noise. Topics in control theory, optimization theory, stochastic analysis, and numerical analysis. Mathematical models in finance. Financial derivatives. Software to implement mathematical finance models. *Also listed as FNCE 696 and as MATH 125. Prerequisites: Mathematical maturity at least at the level of junior mathematics majors; knowledge of mean, variance, binomial and normal random variables, and the central limit theorem; or instructor approval.* (4 units)

AMTH 370. Optimization Techniques I

Optimization techniques with emphasis on experimental methods. One-dimensional search methods. Multidimensional unconstrained searches: random walk, steepest descent, conjugate gradient, variable metric. *Prerequisites: Ability to program in some computer language and AMTH 246 or 247.* (2 units)

AMTH 371. Optimization Techniques II

Optimization problems in multidimensional spaces involving equality constraints and inequality constraints by gradient and nongradient methods. Special topics. *Prerequisite: AMTH 370.* (2 units)

AMTH 372. Semi-Markov and Decision Processes

Semi-Markov processes in discrete and continuous time, continuous-time Markov processes, processes with an infinite number of states, rewards, discounting, decision processes, dynamic programming, and applications. *Prerequisite: AMTH 211 or 212 or 362 or 364 or ELEN 233 or 236.* (2 units)

AMTH 374. Partial Differential Equations I

Relation between particular solutions, general solutions, and boundary values. Existence and uniqueness theorems. Wave equation and Cauchy's problem. Heat equation. (2 units)

AMTH 375. Partial Differential Equations II

Continuation of AMTH 374. *Prerequisite: AMTH 374.* (2 units)

AMTH 376. Numerical Solution of Partial Differential Equations

Numerical solution of parabolic, elliptic, and hyperbolic partial differential equations. Basic techniques of finite differences, finite volumes, finite elements, and spectral methods. Direct and iterative solvers. *Prerequisites: Familiarity with numerical analysis, linear algebra, and MATLAB.* (2 units)

AMTH 377. Design and Analysis of Algorithms

Advanced topics in design and analysis of algorithms: amortized and probabilistic analysis; greed technique; dynamic programming; max flow/matching. Intractability: lower bounds; P, NP, and NP completeness; branch-and-bound; backtracking. Current topics: primality testing and factoring; string matching. *Also listed as COEN 279. Prerequisite: Familiarity with data structures.* (4 units)

AMTH 379 Advanced Design and Analysis of Algorithms

Amortized and probabilistic analysis of algorithms and data structures: disjoint sets, hashing, search trees, suffix arrays and trees. Randomized, parallel, and approximation algorithms. *Also listed as COEN 379. Prerequisite: AMTH 377/ COEN 279.* (4 units)

AMTH 387. Cryptology

Mathematical foundations for information security (number theory, finite fields, discrete logarithms, information theory, elliptic curves). Cryptography. Encryption systems (classical, DES, Rijndael, RSA). Cryptanalytic techniques. Simple protocols. Techniques for data security (digital signatures, hash algorithms, secret sharing, zero-knowledge techniques). *Prerequisite: Mathematical maturity at least at the level of upper-division engineering students.* (4 units)

AMTH 388. Advanced Topics in Cryptology

Topics may include advanced cryptography and cryptanalysis. May be repeated for credit if topics differ. *Prerequisite: AMTH 387.* (2 units)

AMTH 397. Master's Thesis

By arrangement. Limited to master's students in applied mathematics. (1–9 units)

AMTH 399. Independent Study

By arrangement. *Prerequisite: Instructor approval.* (1–4 units)

9

Department of Bioengineering

Professor: Yuling Yan *(Department Chair)*
Associate Professor: Zhiwen (Jonathan) Zhang
Assistant Professors: Ismail Emre Araci, Prashanth Asuri, Unyoung (Ashley) Kim, Biao (Bill) Lu
Lecturer: Maryam Mobed-Miremadi
Adjunct Faculty: Eric Chan, Paul Davison, Brian Green, Ying Hao, Gary Li, Sathish Manickam, Menahem Nassi, Gerardo Noriega, Stephanie Norman, Janet Warrington

OVERVIEW

Bioengineering is the fastest-growing area of engineering and holds the promise of improving the lives of all people in very direct and diverse ways. Bioengineering focuses on the application of electrical, chemical, mechanical, and other engineering principles to understand, modify, or control biological systems. As such the curriculum teaches principles and practices at the interface of engineering, medicine and the life sciences. The Department of Bioengineering currently offers a M.S. degree program with a focus on biodevice engineering, biomaterials and tissue engineering, and biomolecular engineering.

A number of faculty offer research projects to bioengineering students that are engaging and involve problem-solving at the interface of engineering, medicine and biology.

Dr. Yan's current research focuses on basic and translational aspects of human voice that include the development of new imaging modalities to study laryngeal dynamics and function, with associated methods in the analysis and modeling of human voice production. She is also participating in a multi-PI project, funded by NIH, on the development of optical switch probes and novel detection and image analyses of this novel class of probe for applications in high contrast imaging within living cells and tissues.

Dr. Zhang is currently engaged in research on several NIH-funded projects spanning protein engineering to drug discovery.

Dr Araci's research goals are directed toward the development and application of novel microfluidic and optofluidic technologies for biology and medicine. His work is focused on two major areas: i) implantable and miniaturized devices for telemedicine and ii) single molecule protein counting.

Dr. Asuri's research interests involve integrating tools and concepts from biomaterials engineering, biotechnology, and cell biology to explore the role of biomaterial properties such porosity, matrix stiffness, etc. on protein structure and function and in regulating cell fate.

Dr. Kim investigates the application of integrated microfluidic systems for multiple applications in diagnostics as well as experimental science.

Dr. Lu's research focuses on medical translations of protein engineering that includes protein therapeutics and drug delivery as well as molecular sensor and imaging technology.

Dr. Mobed-Miremadi's research interests are in the areas of mesoscience specifically the interface of cellular engineering/chemical engineering, bio-device development based on membrane-based therapies and bio-fabrication.

DEGREE PROGRAM

The bioengineering graduate program at Santa Clara University is designed to accommodate the needs of students interested in advanced study in the areas of medical devices/bioinstrumentation and molecular and cellular bioengineering. An individual may pursue the degree of Master of Science (M.S.), either as a full-time or part-time student, through a customized balance of coursework, directed research and/or thesis research. Students are also required to supplement their technical work with coursework on other topics that are specified in the graduate engineering core curriculum.

Master of Science in Bioengineering

To be considered for admission to the graduate program in bioengineering, an applicant must meet the following requirements:

- A bachelor's degree in bioengineering or related areas from an ABET accredited four-year B.S. degree program, or its equivalent
- An overall grade point average (GPA) of at least 3.0 (based on a 4.0 maximum scale)
- Graduate Record Examination (GRE)-general test
- For students whose native language is not English, Test of English as a Foreign Language (TOEFL) or the International English Language Testing Systems (IELTS) exam scores are required before applications are processed.

Applicants who have taken graduate-level courses at other institutions may qualify to transfer a maximum of nine quarter units of approved credit to their graduate program at Santa Clara University.

Upon acceptance, or conditional acceptance, to the graduate program in bioengineering, a student will be required to select a graduate advisor (full-time faculty member) from within the Department of Bioengineering. The student's advisor will be responsible for approving the student's course of study. Any changes to a student's initial course of study must have the written approval of the student's advisor.

To qualify for the degree of Master of Science in Bioengineering, students must complete a minimum of 45 quarter units, including required core and elective courses, within the School of Engineering. Required and elective courses for the bioengineering programs are provided below. Students undertaking thesis work are required to engage in research that results, for example, in the development of a new method or approach to solve a bioengineering relevant problem, or a technical tool, a design criteria, or a biomedical application. This work should be documented in a journal publication, conference, or research report, and must also be included in a Master's thesis. Alternatively, students may elect to take only courses to fulfill the requirement for the M.S. degree.

Course requirements

- Graduate Core (minimum six units including BIOE 210 Bioethics) (See descriptions in Chapter 4, Academic Information)
- Applied Mathematics (4 units)

  Select from AMTH 200, 201, 202, 210, 211 (or consult with advisor)

- Bioengineering Core (15 units)

  Students must take six units from one of the three primary focus areas, four units from other focus areas, three units from biostatistics (BIOE 232 L&L) and two quarter research seminar units (BIOE 200, 2 x 1 unit)
- Three primary focus areas are:

1. Biomolecular Engineering	BIOE 280, 282, 286, 300, or 301
2. Biomaterials and Tissue Engineering	BIOE 208, 240, 269, 273, 278
3. BioDevice Engineering	BIOE 207, 208, 209, 245 268, 270, 275, 276

- Bioengineering Technical Electives (11–20 units)

Select from the approved list of Technical Elective (TE) graduate level courses. Students who pursue the thesis option will obtain nine units from thesis work, and thus 11 TE units are required; for those who pursue the course work only, 20 TE units are required. Directed research may count as a maximum of six TE units. Total: 45 Units

Alternative elective graduate courses may be taken subject to approval from the student's advisor. Courses used to meet the 45-unit minimum total for the Master of Science in Bioengineering degree cannot include courses that were used to satisfy a previous undergraduate degree program requirement. This includes cross-listed undergraduate courses at Santa Clara University and/or their equivalent courses at other institutions. If some required courses in the SCU graduate bioengineering program have been completed prior to graduate-level matriculation at SCU, additional elective courses will be required to satisfy the minimum unit total requirement as necessary.

Ph.D. in Electrical Engineering

The departments of Electrical Engineering and Bioengineering are collaborating to offer a Ph.D. in interdisciplinary topics related to Bioengineering. Faculty from both departments will co-advise the Ph.D. students and the degree will be awarded by the Department of Electrical Engineering.

Bioengineering Laboratory Facilities:

The ***Anatomy & Physiology Laboratory*** provides a full range of activities to study human anatomy and organ function. Through computational modeling, organ dissection, and design projects, students will develop essential skills in conceiving and implementing engineering solutions to medical problems.

The ***Bioimaging/Image and Signal Analysis Laboratory*** carries out basic and translational research on voice. Current research in the laboratory includes the development of imaging modalities to study laryngeal dynamics and function, and novel approaches for image/biosignal-based analysis and assessment of voice pathologies. The lab also supports the development of new detection and analytical methods using optical probes for applications in high-contrast fluorescence imaging in cells and tissues.

The ***Biological Micro/Nanosystems Laboratory*** supports research and teaching activities in the broad areas of microfluidics/biosensing. Utilizing microfluidic technologies, spectroscopy, and microfabrication techniques, we develop innovative microfluidic platforms for applications in basic biology, diagnostics, and cellular engineering.

The ***Biomaterials Engineering Laboratory*** focuses on the use of hydrogels to develop in vitro platforms that explore the role of in vivo like microenvironmental cues on controlling protein structure and function and regulating cell fate. The lab also supports the design and characterization of biomaterial nanocomposites for applications in tissue engineering.

The ***Biomolecular Engineering Laboratory*** conducts "bioengineering towards therapy." The idea is to engineer novel materials (particularly proteins and peptides) and devices and apply them to study basic biological and medical questions that ultimately lead to drug discovery and disease diagnosis.

The ***Biophotonics & Bioimaging Laboratory*** supports research and teaching on portable imaging systems for wearable/implantable biosensors as well as on optical coherence tomography (OCT) probes for stereotactic neurosurgery. The time lapse fluorescence microscopy setup is used for measuring enzyme activity and single cell protein expression at the single molecular level.

The ***Biosignals Laboratory*** provides a full range of measurement and analysis capabilities including electrocardiography (ECG), electroencephalography (EEG), and electromyography (EMG) measurement system, vocal signal recording, and analysis software.

The ***Micro-devices & Microfluidics Laboratory*** focuses on the fabrication and testing of microfluidic devices for biomedical research and teaching. The soft-lithography room is equipped with necessary instruments (e.g., mixer, spinner, plasma cleaner) to build micro-devices using a wide variety of materials and processes. Multiple microfluidic test setups (i.e., computer controlled solenoid valves and microscopes) allow several tests to be run simultaneously.

The ***Tissue Engineering Laboratory*** supports research and teaching activities related to mammalian cell and tissue culture. Activities include but are not limited to 2D and 3D mammalian cell culture, investigation of the role of biophysical cues on cancer cell migration and response to drugs, and genetic manipulation of mammalian cells.

COURSE DESCRIPTIONS

Undergraduate Courses

BIOE 100. Bioengineering Research Seminar

A series of one-hour seminars will be presented by guest professors and researchers on their particular research topics in bioengineering or related fields. Students are required to attend four to five seminars and submit a one-page report summarizing the presentation for each seminar. May be repeated for credits. *Also listed as BIOE 200. Prerequisite: Sophomore standing or higher. P/NP grading.* (1 unit)

BIOE 107. Medical Device Product Development

The purpose of this course is to provide background information and knowledge to start or enhance a career in medical device product development. Discusses medical device examples, product development processes, regulation, industry information, and intellectual property. *Also listed as EMGT 307. Prerequisite: BIOE 10.* (2 units)

BIOE 108. Biomedical Devices: Role of Polymers

This course is designed to highlight the role of polymers play in the design and fabrication of various medical devices ranging from simple intravenous drip systems to complex cardiac defibrillator implants and transcatheter heart valves. Topics include polymer basics, biocompatibility, biodegradation and other tangentially related topics such as regulatory body approvals and intellectual property. *Also listed as BIOE 208.* (2 units)

BIOE 111. Bioengineering Innovation and Design

Introduces bioengineers to healthcare and medical device technology innovation for advanced and emerging markets. Students in the course will work as teams on problem identification and assessment, iterative value proposition design, as well as concept and business model development. *Prerequisite: BIOE 10.* (2 units)

BIOE 115. Fundamentals of Cell Culture

This course will introduce the basic concepts and fundamentals of mammalian cell culture techniques and its application in tissue engineering. *Prerequisite: BIOL 25/BIOE 22. Co-requisite: BIOE 115L.* (1 unit)

BIOE 115L. Fundamentals of Cell Culture Laboratory

Laboratory for BIOE 115. *Co-requisite: BIOE 115.* (1 unit)

BIOE 120. Experimental Methods in Bioengineering

This course will cover the principles of data representation, analysis, and experimental designs in bioreactors, biomaterials, and medical devices. Topics include error analysis, modeling, normality testing, hypothesis testing, and design of experiments. Special emphases will be placed on the interpretation of data from high-throughput assays used in "omics"/tissue engineering, and formulation designs used for optimal drug delivery. *Prerequisite: MATH 14.* (4 units)

BIOE 140. Biomaterials Engineering and Characterization

This course will cover the fundamental principles of soft biomaterials characterization in terms of mechanical and rheological properties related to biocompatibility. Areas of focus in the lab include study and fabrication of implantable hydrogels for eukaryotic cell immobilization in scaffolds and microscapsules, cytotoxicity measurements in the engineered micro-environment and nutrient diffusion visualized by fluorescence microscopy. *Also listed as BIOE 240. Prerequisite: CHEM 13.* (2 units)

BIOE 140L. Biomaterials Engineering and Characterization Laboratory

Laboratory for BIOE 140. *Also listed as BIOE 240L. Co-requisite: BIOE 140.* (1 unit)

BIOE 153. Biomaterials Science

An introduction into materials used for medical devices. Focus areas include materials science, biology, biochemistry, practical aspects of biomaterials, industry literature, and applications. *Prerequisite: CHEM 13.* (4 units)

BIOE 154. Introduction to Biomechanics

Engineering mechanics and applications in the analysis of human body movement, function, and injury. Review of issues related to designing devices for use in, or around, the human body including safety, biocompatibility, ethics, and Food and Drug Administration (FDA) regulations. *Prerequisites: BIOE 10, PHYS 33.* (4 units)

BIOE 155. Biological Transport Phenomena

The transport of mass, momentum, and energy are critical to the function of living systems and the design of medical devices. This course develops and applies scaling laws and the methods of continuum mechanics to biological transport phenomena over a range of length and time scales. *Also listed as BIOE 215. Prerequisites: BIOE 10, PHYS 33, AMTH 106.* (4 units)

BIOE 157. Introduction to Biofuel Engineering

This course will cover the basic principles used to classify and evaluate biofuels in terms of thermodynamic and economic efficiencies as well as environmental impact for resource recovery. Special emphases will be placed on emerging applications namely microbial fuel cell technology and photo-bioreactors. *Also listed as BIOE 257/ ENGR 257. Prerequisites: BIOE 21 or BIOL 21, CHEM 13, PHYS 33.* (2 units)

BIOE 161. Bioinstrumentation

Transducers and biosensors from traditional to nanotechnology; bioelectronics and measurement system design; interface between biological system and instrumentation; data analysis; clinical safety. Laboratory component will include traditional clinical measurements and design and test of a measurement system with appropriate transducers. *Also listed as BIOE 211 and ELEN 161. Prerequisites: BIOE 10, BIOE 21 (or BIOL 21), ELEN 50. Co-requisite: BIOE 161L.* (4 units)

BIOE 161L. Bioinstrumentation Laboratory

Laboratory for BIOE 161. *Also listed as BIOE 211L and ELEN 161L. Co-requisite: BIOE 161.* (1 unit)

BIOE 162. Biosignals and Systems

Origin and characteristics of bioelectric, bio-optical, and bioacoustic signals generated from biological systems. Behavior and response of biological systems to stimulation. Acquisition and interpretation of signals. Signal processing methods include FFT spectral analysis and time-frequency analysis. Laboratory component will include modeling of signal generation and analysis of signals such as electrocardiogram (ECG), electromyogram (EMG), and vocal sound pressure waveforms. *Also listed as BIOE 212 and ELEN 162. Prerequisites: BIOE 10, AMTH 106, ELEN 50. Co-requisite: BIOE 162L.* (4 units)

BIOE 162L. Biosignals and Systems Laboratory

Laboratory for BIOE 162. *Also listed as BIOE 212L and ELEN 162L. Co-requisite: BIOE 162.* (1 unit)

BIOE 163. Bio-Device Engineering

This course will instruct students with the fundamental principles of bio-device design, fabrication and biocompatibility, and let students experiment with the state-of-the-art bio-devices. Students will gain the hands-on experience with these bio-instruments which are also used in the field. Emphasis is given to the cutting-edge applications in biomedical diagnostics and pharmaceutical drug discovery and development, particularly detection and monitoring interaction, and activity of biomolecules, such as enzymes, receptors, antibody, nucleic acids, and bioanalytes. *Prerequisites: BIOL 25 or BIOE 22 and CHEM 31. Co-requisite: BIOE 163L.* (4 units)

BIOE 163L. Bio-Device Engineering Laboratory

Laboratory for BIOE 163. *Co-requisite: BIOE 163.* (1 unit)

BIOE 167. Medical Imaging Systems

Overview of medical imaging systems including sensors and electrical interfaces for date acquisition, mathematical models of the relationship of structural and physiological information to senor measurements, resolution and accuracy limits based on the acquisition system parameters, impact of the imaging system on the volume being imaged, data measured, and conversion process from electronic signals to image synthesis. Analysis of the specification and interaction of the functional units of imaging systems and the expected performance. Focus on MRI, CT, ultrasound, PET, and impedance imaging. *Also listed as ELEN 167. Prerequisites: BIOE 162/ELEN 162, ELEN 110 or MECH 142.* (4 units)

BIOE 168. Biophotonics and Bioimaging

This course starts with an introduction of optics and basic optical components (e.g. lenses, mirrors, diffraction grating etc). Then focuses on light propagation and propagation modeling to examine interactions of light with biological matter (e.g. absorption, scattering). Other topics that will be covered in this course are; Laser concepts. Optical coherence tomography. Microscopy. Confocal microscopy. Polarization in tissue. Absorption, diffuse reflection, light scattering, Raman spectroscopy. Fluorescence lifetime imaging. *Also listed as BIOE 268. Prerequisite: PHYS 33.* (4 units)

BIOE 168L. Biophotonics and Bioimaging Laboratory

The lab will provide the hands-on experience for basic imaging and microscopy techniques as well as advanced techniques such as fiber-optics and optical coherence tomography. Some of the experiments that will be conducted are: i) measuring the focal length of lenses and imaging using a single lens and a lens system ii) Determining the magnification of optical systems (e.g. of a microscope) iii) Interference in young's double slit and in Michelson configuration iv) Diffraction v) Polarization and polarization rotation. (1 unit)

BIOE 171. Physiology and Anatomy for Engineers

Examines the structure and function of the human body and the mechanisms for maintaining homeostasis. The course will provide a molecular-level understanding of human anatomy and physiology in select organ systems. The course will include lectures, class discussions, case studies, computer simulations, field trips, lab exercises, and team projects. *Prerequisite: BIOE 21 or BIOL 21. Co-requisite: BIOE 171L.* (4 units)

BIOE 171L. Physiology and Anatomy for Engineers Laboratory

Laboratory for BIOE 171. *Co-requisite: BIOE 171.* (1 unit)

BIOE 172. Introduction to Tissue Engineering

Introduces the basic principles underlying the design and engineering of functional biological substitutes to restore tissue function. Cell sourcing, manipulation of cell fate, biomaterial properties and cell-material interactions, and specific biochemical and biophysical cues presented by the extracellular matrix will be discussed, as well as the current status and future possibilities in the development of biological substitutes for various tissue types. *Prerequisite: BIOE 22 or BIOL 25.* (4 units)

BIOE 173. Advanced Topics in Tissue Engineering

Overview of the progress achieved in developing tools, technologies, and strategies for tissue engineering-based therapies for a variety of human diseases and disorders. Lectures will be complemented by a series of student-led discussion sessions and student team projects. *Also listed as BIOE 273. Prerequisite: BIOE 172 (or instructor approval).* (2 units)

BIOE 174. Microfabrication and Microfluidics for Bioengineering Applications

Microfluidics uses principles from a broad range of disciplines including fluid mechanics, material science and optics for miniaturization, and automation of biochemical applications. This course will introduce the basic physical and engineering concepts which have practical importance in microfluidics and will allow better understanding of molecule and cell manipulation in the micro-domain. The course aims to introduce students to the state-of-art applications of various microfluidic techniques (e.g. mLSI, droplet and paper-based), in biological and biomedical research through lectures and discussion of current literature. *Also listed as BIOE 214. Prerequisites: BIOE 10, BIOE 21 or BIOL 21. Co-requisite: BIOE 174L.* (4 units)

174L. Microfabrication and Microfluidics for Bioengineering Applications Laboratory

Multilayer soft-lithography will be taught and integrated microfluidic chips will be built. Basic pressure driven microfluidic chip tests will be performed. A team design project that stresses interdisciplinary communication and problem solving is required in this course. *Also listed as BIOE 214L. Co-requisite: BIOE 174.* (1 unit)

BIOE 175. Biomolecular and Cellular Engineering I

This course will focus on solving problems encountered in the design and manufacturing of biopharmaceutical products, including antibiotics, antibodies, protein drugs and molecular biosensors, with particular emphasis on the principle and application of protein engineering and reprogramming cellular metabolic networks. *Also listed as BIOE 225. Prerequisites: BIOL 25 or BIOE 22 and CHEM 31, or equivalent knowledge and instructor approval, BIOE 153 is recommended. Co-requisite: BIOE 175L.* (4 units)

BIOE 175L. Biomolecular and Cellular Engineering I Laboratory

Laboratory for BIOE 175. *Also listed as BIOE 225L Co-requisite: BIOE 175.* (1 unit)

BIOE 176. Biomolecular and Cellular Engineering II

This course will focus on the principle of designing, manufacturing synthetic materials and their biomedical and pharmaceutical applications. Emphasis of this class will be given to chemically synthetic materials, such as polymers, inorganic and organic compounds. *Also listed as BIOE 226. Prerequisites: BIOL 25 or BIOE 22 and CHEM 31, or equivalent knowledge and instructor approval. BIOE 175 and BIOE 171 is recommended.* (4 units)

BIOE 177L. Advanced Molecular Bioengineering Laboratory

This course is the lab session of BIOE 176. Lab sections are designed for students to experience the concepts of bioprocess engineering and biochemical engineering. *Prerequisite: BIOE 176.* (1 unit)

BIOE 178. Clinical Biomaterials

The objective of this course is to convey the state-of-the-art of biomaterials currently used in medical devices. The course is taught as a series of semi-independent modules on each class of biomaterial, each with examples of medical applications. Students will explore the research, commercial and regulatory literature. In teams of two to four, students will prepare and orally present a design study for a solution to a medical problem requiring one or more biomaterials, covering alternatives and selection criteria, manufacture and use of the proposed medical device, and economic, regulatory, legal and ethical aspects. Students should be familiar with or prepared to learn medical, anatomical and physiological terminology. Written assignments are an annotated bibliography on the topic of the design study and an individually written section of the team's report. Material from lectures and student presentations will be covered on a mid-term quiz and a final examination. *Also listed as BIOE 278 and MECH 256. Prerequisite: BIOE 153 or instructor approval.* (2 units)

BIOE 179. Physiology and Disease Biology

The course will provide a molecular-level understanding of human physiology and disease biology, an overview of cardiovascular disease, diagnostic methods, and treatment strategies. Engineering principles to evaluate the performance of cardiovascular devices and the efficacy of treatment strategies will also be discussed. The course will include lectures, class discussions, case studies, and team projects. *Also listed as BIOE 275. Prerequisites: BIOE 21 and BIOE 22 or BIO 21 and BIO 24 and BIO 25.* (2 units)

BIOE 180. Clinical Trials: Design, Analysis and Ethical Issues

This course will cover the principles behind the logistics of design and analysis of clinical trials from the statistical and ethical perspectives. Topics include methods used for quantification of treatment effect(s) and associated bias interpretation, cross-over designs used in randomized clinical trials and clinical equipoise. *Also listed as BIOE 380. Prerequisites: BIOE 10, AMTH 108 or BIOE 120 or instructor approval.* (4 units)

*BIOE 185. Physiology and Disease Biology II***

The course will provide a molecular-level understanding of physiology and disease biology, an overview of gastrointestinal diseases, and an introduction to medical devices used in the diagnosis and treatment as well as challenges in this field. The course will include lectures, class discussions, case studies, and team projects. *Also listed as BIOE 285. Prerequisite: BIOE 21 (or BIOL 21). BIOE 171 recommended.* (2 units)

BIOE 186. Current and Emerging Techniques in Molecular Bioengineering

The course is designed to introduce basic and practical biotechniques to students with minimum training and background in biomolecular engineering. The basic principles and concepts of modern biotechniques will be illustrated and highlighted by studying real cases in lectures. *Also listed as BIOE 286. Prerequisite: BIOE 22 or BIOL 24.* (2 units)

BIOE 188. Co-op Education

This course is designed to prepare students for the working environment, and enable them to relate their experience in the industry to their academic program. They will then engage in practical work experience related to their academic field of study and career objectives. All students must enroll in BIOE 188 before enrolling in BIOE 189. Students can take BIOE 188 during the first quarter of work experience, or before an internship begins. International students who wish to start (or continue) their CPT after they have taken BIOE 188 must be enrolled in BIOE 189. *Prerequisites: Junior status and cum GPA ≥ 2.75.* (2 units)

BIOE 189. Work Experience and Co-op Technical Report

Credit is given for a technical report on a specific activity, such as a design or research activity, after completing a co-op work assignment. Letter grades will be based on the content and quality of the report. May be taken more than once. *Prerequisites: Junior status, cum GPA ≥ 2.75, and approval of department co-op advisor.* (2 units)

BIOE 192. Junior Design

Establishes a foundation for the Senior Design sequence. Students will be given broad overview of the possible project offerings and will be directed to meet potential project advisors to learn more about their research and previous senior design projects. As a part of this course, students will also be introduced to the necessary 'soft skills,; (e.g. literature review, documentation, market research, experimental design, etc.) as they develop feasible senior design concepts. P/NP grading. *Prerequisite: Junior standing.* (1 unit)

BIOE 194. Design Project I

Specification of an engineering project, selected with the mutual agreement of the student and the project advisor. Complete initial design with sufficient detail to estimate the effectiveness of the project. Initial draft of the project report. *Prerequisite: Senior standing.* (2 units)

BIOE 195. Design Project II

Continued design and construction of the project, system, or device. Second draft of project report. *Prerequisite: BIOE 194.* (2 units)

BIOE 196. Design Project III

Continued design and construction of the project, system, or device. Final report. *Prerequisite: BIOE 195.* (2 units)

BIOE 198. Internship

Directed internship in local bioengineering and biotech companies or research in off-campus programs under the guidance of research scientists or faculty advisors. Required to submit a professional research report. Open to upper-division students. (Variable units)

BIOE 199. Supervised Independent Research

By arrangement. *Prerequisite: Advisor approval.* (1–4 units)

Graduate Courses

BIOE 200. Graduate Research Seminar

Seminar lectures on the progress and current challenges in fields related to bioengineering. P/NP grading. *Also listed as BIOE 100.* (1 unit)

BIOE 207. Medical Device Invention - From Ideas to Business Plan

This course will introduce students to various tools and processes that will improve their ability to identify and prioritize clinical needs, select the best medical device concepts that address those needs, and create a plan to implement inventions. *Also listed as ENGR 207.* (2 units)

BIOE 208. Biomedical Devices: Role of Polymers

This course is designed to highlight the role of polymers play in the design and fabrication of various medical devices ranging from simple intravenous drip systems to complex cardiac defibrillator implants and transcatheter heart valves. Topics include polymer basics, biocompatibility, biodegradation and other tangentially related topics such as regulatory body approvals and intellectual property. *Also listed as BIOE 108.* (2 units)

BIOE 209. Development of Medical Devices in Interventional Cardiology

This course will be an in-depth, case-based review of medical devices that are currently used in clinical practice, meeting the heart patient's medical needs. Directed reading will be assigned and the in-class discussions will focus on bioengineering design considerations including: measurements of physiology vs anatomy, intracoronary blood flow vs pressure, invasive vs non-invasive imaging; as well as, the significant economic challenges facing innovative start-ups developing medical devices within our changing health care delivery system. (2 units)

BIOE 210. Ethical Issues in Bioengineering

This course serves to introduce bioengineering students to ethical issues related to their work. This includes introductions to ethical theories, ethical decision-making, accessibility and social justice concerns, issues in personalized medicine, environmental concerns, and so on. This course will also cover ethical and technical issues related to biomedical devices. (2 units)

BIOE 211. Bioinstrumentation

Transducers and biosensors from traditional to nanotechnology; bioelectronics and measurement system design; interface between biological system and instrumentation; data analysis; clinical safety. Laboratory component will include traditional clinical measurements and design and test of a measurement system with appropriate transducers. *Also listed as BIOE 161 and ELEN 161. Prerequisites: BIOE 10, BIOE 21 (or BIOL 21), ELEN 50. Co-requisite: BIOE 211L.* (4 units)

BIOE 211L. Bioinstrumentation Laboratory

Laboratory for BIOE 211. *Also listed as BIOE 161L and ELEN 161L. Co-requisite: BIOE 211.* (1 unit)

BIOE 212. Biosignals and Systems

Origin and characteristics of bioelectric, bio-optical, and bioacoustic signals generated from biological systems. Behavior and response of biological systems to stimulation. Acquisition and interpretation of signals. Signal processing methods include FFT spectral analysis and time-frequency analysis. Laboratory component will include modeling of signal generation and analysis of signals such as electrocardiogram (ECG), electromyogram (EMG), and vocal sound pressure waveforms. *Also listed as BIOE 162 and ELEN 162. Prerequisites: BIOE 10, AMTH 106, ELEN 50. Co-requisite: BIOE 212L.* (4 units)

BIOE 212L. Biosignals and Systems Laboratory

Laboratory for BIOE 212. *Also listed as BIOE 162L and ELEN 162L. Co-requisite: BIOE 212.* (1 unit)

BIOE 214. Microfabrication and Microfluidics for Bioengineering Applications

Microfluidics uses principles from a broad range of disciplines including fluid mechanics, material science and optics for miniaturization, and automation of biochemical applications. This course will introduce the basic physical and engineering concepts which have practical importance in microfluidics and will allow better understanding of molecule and cell manipulation in the micro-domain. The course aims to introduce students to the state-of-art applications of various microfluidic techniques (e.g. mLSI, droplet and paper-based), in biological and biomedical research through lectures and discussion of current literature. *Also listed as BIOE 174. Prerequisites: BIOE 10, BIOE 21 or BIOL 21. Co-requisite: BIOE 214L.* (4 units)

BIOE 214L. Microfabrication and Microfluidics for Bioengineering Applications Laboratory

Multilayer soft-lithography will be taught and integrated microfluidic chips will be built. Basic pressure driven microfluidic chip tests will be performed. A team design project that stresses interdisciplinary communication and problem solving is required in this course. *Also listed as BIOE 174L. Co-requisite: BIOE 214.* (1 unit)

BIOE 215. Biological Transport Phenomena

The transport of mass, momentum, and energy are critical to the function of living systems and the design of medical devices. This course develops and applies scaling laws and the methods of continuum mechanics to biological transport phenomena over a range of length and time scales. *Also listed as BIOE 155. Prerequisites: BIOE 10, PHYS 33, AMTH 106.* (4 units)

BIOE 225. Biomolecular and Cellular Engineering I

This course will focus on solving problems encountered in the design and manufacturing of biopharmaceutical products, including antibiotics, antibodies, protein drugs and molecular biosensors, with particular emphasis on the principle and application of protein engineering and reprogramming cellular metabolic networks. *Also listed as BIOE 175. BIOE 153 is recommended. Prerequisites: BIOL 25 or BIOE 22 and CHEM 31, or equivalent knowledge and instructor approval.* (4 units)

BIOE 225L. Biomolecular and Cellular Engineering I Laboratory

Laboratory for BIOE 225. *Also listed as BIOE 175L. Co-requisite: BIOE 225.* (1 unit)

BIOE 226. Biomolecular and Cellular Engineering II

This course will focus on the principle of designing, manufacturing synthetic materials and their biomedical and pharmaceutical applications. Emphasis of this class will be given to chemically synthetic materials, such as polymers, inorganic and organic compounds. *Also listed as BIOE 176. Prerequisites: BIOL 25 or BIOE 22 and CHEM 31, or equivalent knowledge and instructor approval. BIOE 175 and BIOE 171 is recommended.* (4 units)

BIOE 232. Biostatistics

This course will cover the statistical principles used in Bioengineering encompassing distribution-based analyses and Bayesian methods applied to biomedical device and disease testing; methods for categorical data, comparing groups (analysis of variance) and analyzing associations (linear and logistic regression). Special emphases will be placed on computational approaches used in model optimization, test-method validation, sensitivity analysis (ROC curve) and survival analysis. *Also listed as AMTH 232. Prerequisite: AMTH 108 or BIOE 120 or equivalent.* (2 units)

BIOE 232L. Biostatistics Laboratory

Laboratory for BIOE 232. *Also listed as AMTH 232L. Co-requisite: BIOE 232.* (1 unit)

BIOE 240. Biomaterials Engineering and Characterization

This course will cover the fundamental principles of soft biomaterials characterization in terms of mechanical and rheological properties related to biocompatibility. Areas of focus in the lab include study and fabrication of implantable hydrogels for eukaryotic cell immobilization in scaffolds and microscapsules, cytotoxicity measurements in the engineered micro-environment and nutrient diffusion visualized by fluorescence microscopy. *Also listed as BIOE 140. Prerequisite: CHEM 13. Co-requisite: BIOE 240L.* (2 units)

BIOE 240L. Biomaterials Engineering and Characterization Laboratory

Laboratory for BIOE 240. *Also listed as BIOE 140L. Co-requisite: BIOE 240.* (1 unit)

BIOE 241. Advanced Biomaterials Engineering

This course will cover a review of mechanical characterization methods and processing of bio-inert and bio-resorbable materials. Ares of focus in lab include simulated prototyping into a device using CAD-based software followed by 3D printing; and; micro-mechanical testing conducted on tissue phantoms and scaffolds. (2 units)

BIOE 241L. Advanced Biomaterials Engineering Laboratory

Laboratory for BIOE 241. *Co-requisite: BIOE 241.* (1 unit)

BIOE 245. Introductory Biotribology for Orthopedic Implants

This course will provide an introduction to surface mechanics and tribology as applied to biological systems and medical devices, with specific focus on orthopedic tissues and implants. Students will learn about the mechanisms of friction, lubrication, and wear in tissues and considerations for the design of implants to minimize adverse interactions in vivo while maximizing lifespan. Topics will include dry, lubricated, and mixed mode contact and the physiological conditions resulting in each case. Class discussions will primarily center around assigned readings of published literature guided by lecture topics. *Prerequisites: BIOE 240 or BIOE 153, 154, BIOE 21 or BIOE 24.* (2 units)

BIOE 249. Topics in Bioengineering

An introduction to the central topics of bioengineering including physiological modeling and cellular biomechanics (e.g., modeling of the human voice production and speech biomechanics), biomedical imaging, visualizaion technology and applications, biosignals and analysis methods, bioinstrumentation and bio-nanotechnology. *Also listed as ENGR 249.* (2 units)

BIOE 250. Introduction to Bioinformatics and Sequence Analysis

Overview of bioinformatics. Brief introduction to molecular biology including DNA, RNA, and protein. Pairwise sequence alignment. Multiple sequence alignment. Hidden Markov models and protein sequence motifs. Phylogenetic analysis. Fragment assembly. Microarray data analysis. Protein structure analysis. Genome rearrangement. DNA computing. *Also listed as ENGR 250. Prerequisites: AMTH 377, MATH 163 or equivalent and programming experience.* (4 units)

BIOE 256. Introduction to NanoBioengineering

This course is designed to present a broad overview of diverse topics in nanobioengineering, with emphasis on areas that directly impact applications in biotechnology and medicine. Specific examples that highlight interactions between nanomaterials and various biomolecules will be discussed, as well as the current status and future possibilities in the development of functional nanohybrids that can sense, assemble, clean, and heal. *Also listed as ENGR 256.* (2 units)

BIOE 257. Introduction to Biofuel Engineering

This course will cover the basic principles used to classify and evaluate biofuels in terms of thermodynamic and economic efficiencies as well environmental impact for resource recovery. Special emphases will be placed on emerging applications namely Microbial Fuel Cell Technology and Photo-bioreactors. *Also listed as ENGR 257 and BIOE 157. Prerequisites: BIOE 21 or BIOL 21, CHEM 13, PHYS 33.* (2 units)

BIOE 258. Synthetic Biology & Metabolic Engineering

This course covers current topics and trend in the emerging field of synthetic biology. These topics include applying the retro-synthetic analysis approach in classic organic chemistry, identifying and engineering metabolic pathways and mechanisms for bioproduction of antibiotics, biofuel compounds, novel bio-building blocks and non-natural proteins. Genetic regulation of biosynthetic pathways, e.g. genetic circuit will also be discussed. (2 units)

BIOE 260. Selected Topics in Bio-Transport Phenomena

This course will cover the principles of mass and oxygen transport and across extra-corporeal devices and bio-membrane design principles, dialyzers, blood-oxygenators, hollow-fiber based bio-artificial organs and PK/PD. *Prerequisite: BIOE 155 or equivalent. BIOE 232 recommended.* (2 units)

BIOE 261. Omics: Global High-throughput Technologies in Life Sciences Discovery Research

This course provides a practical application focused survey of global high-throughput technologies in life sciences discovery research. The impact of all facets of study design and execution on obtaining valuable molecular insights from genomics, metagenomics, transcriptomics, metabolomics, and proteomics methods will be explored. Strategies for integration and interpretation of data-rich read-outs will be applied to case studies focused on research and development of companion diagnostics. *Prerequisite: BIOE 251.* (2 units)

BIOE 263. Applications of Genome Engineering and Informatics in Mammalian System

Advances in genome engineering technologies offer versatile solutions to systematic interrogation and alteration of mammalian genome function. Among them, zinc finger transcription factor nuclease (ZNF), transcription activator-like effector nuclease (TALEN) and CRSPR-associated RNA-guided Cas9 endonuclease (CRISPR/Cas9) have become major drivers for innovative applications from basic biology to biotechnology. This course covers principles and real cases of genome engineering using either ZFN/TALEN or CRSPR/Cas9-based system. Key applications will be discussed in a comparative fashion to better understand the advantages/disadvantages of each system. In addition, informatics' tools that facilitate the application design, implementation, data analysis will be covered. *Prerequisites BIOE 22 or BIOL 25 or equivalent.* (2 units)

BIOE 266. Advanced Nano-Bioengineering

In Introduction to Nano-bioengineering (BIOE 256), students were introduced to how nanomaterials offer the unique possibility of interacting with biological entities (cells, proteins, DNA, etc) at their most fundamental level. This course will provide a detailed overview of nanobioengineering approaches that support research in life sciences and medicine. Topics will include nanotopographical control of in vivo and in vitro cell fate, miniaturization and parallelization of biological assays, and early diagnosis of human disease. *Prerequisite: BIOE 256.* (2 units)

BIOE 268. Biophotonics and Bioimaging

This course starts with an introduction of optics and basic optical components (e.g. lenses, mirrors, diffraction grating etc). Then focuses on light propagation and propagation modeling to examine interactions of light with biological matter (e.g. absorption, scattering). Other topics that will be covered in this course are; Laser concepts. Optical coherence tomography. Microscopy. Confocal microscopy. Polarization in tissue. Absorption, diffuse reflection, light scattering, Raman spectroscopy. Fluorescence lifetime imaging. Graduate students will prepare a presentation/report on one of the state-of-the-art biophotonics technologies. *Also listed as BIOE 168. Prerequisite: PHYS 33.* (4 units)

BIOE 269. Stem Cell Bioengineering

A majority of recent research in bioengineering has focused on engineering stem cells for applications in tissue engineering and regenerative medicine. The aim of this graduate level course is to illuminate the breadth of this interdisciplinary research area, with an emphasis on engineering approaches currently being used to understand and manipulate stem cells. The course topics will include basic principles of stem cell biology, methods to engineer the stem cell microenvironment, and the potential of stem cells in modern medicine. (2 units)

BIOE 270. Mechanobiology

This course will focus on the mechanical regulation of biological systems. Students will gain an understanding of how mechanical forces are converted into biochemical activity. The mechanisms by which cells respond to mechanical stimuli and current techniques to determine these processes will be discussed. Class discussions will primarily center around assigned readings of published literature guided by lecture topics. *Prerequisite: BIOE 154.* (2 units)

BIOE 273. Advanced Topics in Tissue Engineering

Overview of the progress achieved in developing tools, technologies, and strategies for tissue engineering-based therapies for a variety of human diseases and disorders. Lectures will be complemented by a series of student-led discussion sessions and student team projects. *Also listed as BIOE 173. Prerequisite: BIOE 172 (or instructor approval).* (2 units)

BIOE 275. Physiology and Disease Biology I

The course will provide a molecular-level understanding of human physiology and disease biology, an overview of cardiovascular disease, diagnostic methods, and treatment strategies. Engineering principles to evaluate the performance of cardiovascular devices and the efficacy of treatment strategies will also be discussed. The course will include lectures, class discussions, case studies, and team projects. *Also listed as BIOE 179. Prerequisites: BIOE 21 and BIOE 22 or BIO 21 and BIO 24 and BIO 25.* (2 units)

BIOE 276. Microfluidics and Lab-on-a-Chip

The interface between engineering and miniaturization is among the most intriguing and active areas of inquiry in modern technology. This course aims to illuminate and explore microfluidics and LOC (lab-on-a-chip) as an interdisciplinary research area, with an emphasis on emerging microfluidics disciplines, LOC device design, and micro/nanofabrication. *Prerequisite: BIOE 155 or instructor approval.* (2 units)

BIOE 278. Clinical Biomaterials

The objective of this course is to convey the state-of-the-art of biomaterials currently used in medical devices. The course is taught as a series of semi-independent modules on each class of biomaterial, each with examples of medical applications. Students will explore the research, commercial and regulatory literature. In teams of two to four, students will prepare and orally present a design study for a solution to a medical problem requiring one or more biomaterials, covering alternatives and selection criteria, manufacture and use of the proposed medical device, and economic, regulatory, legal and ethical aspects. Students should be familiar with or prepared to learn medical, anatomical and physiological terminology. Written assignments are an annotated bibliography on the topic of the design study and an individually written section of the team's report. Material from lectures and student presentations will be covered on a mid-term quiz and a final examination. *Also listed as BIOE 178 and MECH 256. Prerequisite: BIOE 153 or instructor approval.* (2 units)

BIOE 280. Special Topics in Bio-therapeutic Engineering

This class will cover current topics on the engineering of biomimetic drugs, particularly protein drugs, and the development of vaccine, therapeutic antibody and biomarkers. *Prerequisite: BIOE 270 or equivalent.* (2 units)

BIOE 282. BioProcess Engineering

This course will cover the principles of designing, production and purification of biologicals using living cells in a large scale and industrial scale, including bio-reactor design. *Prerequisite: BIOE 21, BIOL 21, BIOE 10, AMTH 106 or equivalent.* (2 units)

BIOE 283. BioProcess Engineering II

This course will cover principles of bio-separation processes. Driving forces behind upstream and downstream separation processes from post-culture cell collection to end stage purification will be analyzed. Special emphasis will be placed on scale-up and economics of implementation of additional purification processes vs cost illustrated by the use of Simulink software. *Prerequisite: BIOE 282 or equivalent.* (2 units)

BIOE 285. Physiology and Disease Biology II

The course will provide a molecular-level understanding of physiology and disease biology, an overview of gastrointestinal diseases, and an introduction to medical devices used in the diagnosis and treatment as well as challenges in this field. The course will include lectures, class discussions, case studies, and team projects. *Also listed as BIOE 185. Prerequisite: BIOE 21 (or BIOL 21). BIOE 171 recommended.* (2 units)

BIOE 286. Biotechnology

The course is designed to introduce basic and practical biotechniques to the students with minimum training and background in biomolecular engineering. The basic principles and concepts of modern biotechniques will be illustrated and highlighted by studying the real cases in lectures. *Also listed as BIOE 186. Prerequisite: BIOE 22 or BIOL 24.* (2 units)

BIOE 297. Directed Research

By arrangement. (1–6 units)

BIOE 298. Internship

Directed internship in partner bioengineering/biotech companies or research in off-campus programs under the guidance of research scientists or faculty advisors. Required to submit a professional research report. P/NP grading. (Variable units)

BIOE 300. Antibody Bioengineering

This course will cover major areas of antibody engineering including recent progress in the development of antibody-based products and future direction of antibody engineering and therapeutics. The product concept and targets for antibody-based products are outlined and basic antibody structure, and the underlying genetic organization which allows easy antibody gene manipulation, and the isolation of novel antibody binding sites will be described. Anti-body library design and affinity maturation techniques and deep-sequencing of antibody responses, together with biomarkers, imaging and companion diagnostics for antibody drug and diagnostic applications of antibodies, as well as clinical design strategies for antibody drugs, including phase one and phase zero trial design will be covered. *Prerequisite: BIOE 176 or equivalent.* (2 units)

BIOE 301. Protein Engineering and Therapeutics

Protein-based therapeutics has played an increasingly important role in medicine. Future protein drugs are likely to be more extensively engineered to improve their efficacy in patients. Such technologies might ultimately be used to treat cancer, neurodegenerative diseases, diabetes, and cardiovascular or immune disorders. This course will provide an overview of protein therapeutics and its enabling technology, protein engineering. Topics will cover the following areas of interest: therapeutic bioengineering, genome and druggable genes, classification of pharmacological proteins, advantages and challenges of protein-based therapeutics, principles of recombinant protein design, approaches of protein production, and potential modifications. Specific applications will include drug delivery, gene therapy, vaccination, tissue engineering, and surface engineering. Students will work on teams where they will take examples of concepts, designs, or models of protein therapeutics from literature and determine their potential in specific engineering applications. *Prerequisite: BIOE 176 or equivalent.* (2 units)

BIOE 378. Advanced Biomaterials

The objective of this course is to examine the range of new biomaterials potentially applicable to medical and biotechnology devices. The content will focus on chemistry and fabrication of polymeric biomaterials, surface properties, nano-scale analytical tools, effects of the biological environment and interaction with cells and tissues. In teams of 2 to 4, students will prepare and orally present a design study for a solution to a medical problem requiring one or more biomaterials, using tissue engineering and regenerative approaches. Students should be familiar with or prepared to learn medical, anatomical and physiological terminology. Written assignments are an annotated bibliography drawn from research literature on the topic of the design study and an individually-written section of the team's report. Material from lectures and student presentations will be covered in short quizzes and a final examination. (2 units)

BIOE 380. Clinical Trials: Design, Analysis, and Ethical Issues

This course will cover the principles behind the logistics of design and analysis of clinical trials from the statistical and ethical perspectives. Topics include methods used for quantification of treatment effect(s) and associated bias interpretation, cross-over designs used in randomized clinical trials and clinical equipoise. *Also listed as BIOE 180. Prerequisites: BIOE 10, AMTH 108 or BIOE 120 or instructor approval.* (4 units)

BIOE 397. Master's thesis research

By arrangement. (1–9 units)

BIOE 642. Medical Imaging

Image formation from noninvasive measurements in computerized tomography, magnetic resonance imaging, and other modalities used clinically and in research. Analysis of accuracy and resolution of image formation based on measurement geometry and statistics. Offered in alternate years. *Also listed as ELEN 642. Prerequisites: AMTH 211 and either ELEN 234 or AMTH 358.* (2 units)

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Department of Civil Engineering

Professor Emeritus: E. John Finnemore, P.E.
Wilmot J. Nicholson Family Professor: Sukhmander Singh, P.E., G.E.
Peter Canisius S.J. Professor: Mark Aschheim, P.E. *(Chair)*
Robert W. Peters Professor: Edwin Maurer, P.E.
Professor: Reynaud L. Serrette
Associate Professors: Steven C. Chiesa, P.E., Rachel He
Assistant Professor: Hisham Said
Lecturer: Tonya Nilsson, P.E.

OVERVIEW

The Department of Civil Engineering offers graduate programs in the areas of structural engineering, general civil engineering, and construction management. The focus of the educational effort is on modeling, analysis, and practical methods used to design and construct structures and other civil engineering-related infrastructure systems. As such, many of the courses offered are beneficial to civil and construction engineers and construction managers interested in advancing their knowledge and enhancing their technical skills.

DEGREE PROGRAM

The civil engineering graduate program at Santa Clara University is designed to accommodate the needs of students interested in advanced study. An individual may pursue the degree of master of science (M.S.) as either a full-time or part-time student through a customized balance of coursework, design projects, and directed research. Program participants are also required to supplement their technical work with coursework on project management topics addressed in the graduate engineering core curriculum.

The structural engineering track provides students with an opportunity to effectively link theory and practice by completing a combination of analysis- and design-oriented courses. Options within the structural engineering track allow students to either complete a capstone design project or a faculty-directed research investigation. This program track is aimed at individuals looking to prepare for a career in consulting structural engineering or in structural plan review.

The general civil engineering track has been configured to provide students with additional analytical and design coursework in several related areas of civil engineering. This could potentially include work in water resources engineering, environmental engineering, transportation engineering, and geotechnical engineering. A capstone design or research project with a required sustainability component is used to integrate these different elements. This track is geared towards individuals preparing for a career in land development, municipal engineering, or public works.

The construction engineering and management (CEM) track is designed to prepare students with skills and knowledge required to effectively manage time, cost, safety, quality and sustainability requirements of construction projects. The track has some flexibility to accommodate students with interests in practical applications or research investigations. This track is designed for students with career objectives of managing building or heavy construction projects for contractors, owners, and developers.

Master of Science in Civil Engineering

To be considered for admission to the graduate program in civil engineering, an applicant must meet the following requirements:

- A bachelor's degree in civil engineering from an Accreditation Board for Engineering and Technology (ABET)-accredited four-year program or its equivalent
- An overall grade point average (GPA) of at least 2.75 (based on a 4.0 maximum scale)
- Graduate Record Examination (GRE) general test
- For students whose native language is not English, Test of English as a Foreign Language (TOEFL) or the International English Language Testing Systems (IELTS) exam scores are required before applications are processed.
- In very rare cases, applicants not meeting the above requirements may be given conditional acceptance into the M.S. program. A formal acceptance may then be given upon the successful completion of a defined course of studies.

Applicants who have taken graduate-level courses at other institutions may qualify to transfer a maximum of nine quarter units of approved credit to their graduate program at Santa Clara University.

Upon acceptance or conditional acceptance to the graduate program in civil engineering, a student will be required to select a graduate advisor (full-time faculty member) from within the Department of Civil Engineering. The student's advisor will be responsible for approving the student's course of study. Any changes to a student's initial course of study must have the written approval of the student's advisor.

To qualify for the degree of Master of Science in Civil Engineering, the students must complete a minimum of 45 quarter units, including elective and required core courses, within the School of Engineering. Required and elective courses for the structural engineering, general civil engineering, and construction management tracks are provided below. Students may elect to do a design project or research project. Students undertaking a design project would apply a new technique or method in the analysis or design of a structure, system, or element, and this must be documented in a design report. Students undertaking a research project would develop a new technique, method, component, or design criteria, and this must be documented in a conference or journal publication or report.

Course requirements are as follows:

	Structural Engineering Track	**General Civil Engineering Track**	**Construction Engineering and Management Track**
Required Technical Coursework	CENG 205 (2) CENG 206 (2) CENG 222 (4) CENG 233* (4) CENG 234 (4) CENG 236 (4) CENG 237 (4) **(24 units)**	CENG 237 (4) CENG 249 (4) CENG 260 (3) **(11 units)**	CENG 218 (3) CENG 284 (3) CENG 286 (4) CENG 287 (4) CENG 292 (3) **(17 units)**
Elective Technical Coursework	**7 units from:** CENG 207 (2) CENG 213 (4/5) CENG 215 (4/5) CENG 218 (3) CENG 220 (4) CENG 231 (4) CENG 232 (2) CENG 238 (4) CENG 239 (2) CENG 240 (2) CENG 241 (2) CENG 244 (2) CENG 246 (4) CENG 292 (3) CENG 293 (2 – 4) CENG 295 (4 – 6) CENG 297 (2 – 4)	**14 units from:** CENG 217 (4) CENG 218 (3) CENG 219^ (4) CENG 238 (4) CENG 242 (4) CENG 247 (4) CENG 250 (4) CENG 251 (4) CENG 256 (3) CENG 258 (4) CENG 259 (3) CENG 261 (3) CENG 262 (3) CENG 263 (4) CENG 293 (2 – 4) CENG 295 (4 – 6) CENG 297 (2 – 4)	**12 units from:** CENG 219^ (4) CENG 249 (4) CENG 256 (3) CENG 281 (3) CENG 282 (2) CENG 288 (4) CENG 289 (3) EMGT 289 (2) EMGT 292 (2) CENG 293 (2 – 4) CENG 295 (4 – 6) CENG 297 (2 – 4) EMGT 255 (2) EMGT 295 (2) EMGT 330 (2) EMGT 335 (2) ENGR 329^ (3) MGMT 3503 (3) MGMT 3538 (3)
Applied Mathematics	**4 units from:** AMTH 210 (2) & 211 (2) AMTH 214 (2) & 215 (2) AMTH 220 (2) & 221 (2) AMTH 245 (2) & 246 (2)	**8 units from:** AMTH 210 (2) & 211 (2) AMTH 214 (2) & 215 (2) AMTH 220 (2) & 221 (2) AMTH 245 (2) & 246 (2)	**4 units from:** AMTH 210 (2) & 211 (2) AMTH 214 (2) & 215 (2) AMTH 370 (2) & 371 (2) AMTH 367 (4)
Project Management, Leadership, and Communications	**4 units from:** CENG 282 (2) EMGT 255^ (2) EMGT 271^ (2) EMGT 330^ (2) EMGT 335^ (2)	**6 units from:** CENG 282 (2) EMGT 255^ (2) EMGT 271^ (2) EMGT 330^ (2) EMGT 335^ (2) ENGR 329^ (3)	**6 units from:** EMGT 270 (2) EMGT 271^ (2) EMGT 319 (2) EMGT 320 (2) EMGT 329 (2) EMGT 349 (2) MGMT 3532 (3)
Graduate Core	A total of 6 units from pre-approved courses		

Units are shown in parentheses. No more than 6 units from CENG 293, 295, and 297 may be used to satisfy degree requirements. Taking Required Technical Course(s) that repeat previously taken course(s) is discouraged; in such cases, Elective Technical course(s) may be substituted. Program plans may deviate from these requirements with Department approval.

* Replace with CENG 246 if a timber design course was taken previously.

^ May simultaneously satisfy a Graduate Core requirement, thereby allowing additional Elective Technical units to be taken.

° The MGMT 501 prerequisite is waived for students in the Construction Management track.

Upon the approval of the student's advisor, alternative elective courses may be taken. Courses used to satisfy the 45-unit minimum total for the Master of Science in Civil Engineering degree cannot be used to satisfy any previous undergraduate degree program requirement. This includes cross-listed undergraduate courses at Santa Clara University and/or their equivalent courses at other institutions. Where required courses in the SCU graduate civil engineering programs have been completed prior to graduate-level matriculation at SCU, additional elective courses may be required to satisfy the minimum unit total requirement as necessary.

LABORATORIES

The ***Civil Engineering Laboratories*** contain equipment and facilities to support research and teaching in materials engineering, structural engineering, stress analysis, soil mechanics, geology, transportation engineering and surveying, environmental quality, and hydraulics.

The ***Simulation and Design Laboratory*** maintains Windows-based personal computers that are used extensively in course assignments, design projects and research. Commercial software packages in all the major areas of civil engineering are available on the systems, with full documentation available to students.

The ***Concrete Testing Laboratory*** contains facilities for mixing, casting, curing, and testing concrete cylinders and constructing reinforced concrete test specimens.

The ***Environmental Laboratory*** is equipped with the instrumentation needed for basic chemical and biological characterization of water, wastewater, and air samples. Several pilot-scale treatment systems are also available.

The ***Geology Laboratory*** is equipped with extensive rock and mineral samples, as well as topographic, geologic, and soil maps.

The ***Hydraulics Laboratory*** is shared with the Mechanical Engineering Department. The laboratory contains a tilting flume that can be fitted with various open-channel fixtures.

The ***Soil Mechanics Laboratory*** contains equipment for testing soils in shear, consolidation, and compaction, and for conducting other physical and chemical tests. Field testing and sampling equipment is also available. A complete cyclic triaxial testing system with computer control is used for both research and instructional purposes.

The ***Structures and Materials Testing Laboratory*** is equipped with three universal testing machines and an interim high-bay structural test system. These machines/systems are used for testing a variety of construction materials and assemblies under quasi-static and pseudo-dynamic loading. Complementing this equipment are a series of digital and analog instruments, and high-speed data acquisition and control systems.

The offsite ***Structural Laboratory Annex*** is a high-bay test facility equipped with a closed-loop hydraulic system, modern data acquisition and control system, dedicated frames for beam and columns tests, and instrumentation for displacement, pressure, strain, temperature, and acceleration measurements. The Annex has the capability to test unique building components that incorporate wall/frames and floor systems with heights up to 8.0 meters.

The ***Surveying Laboratory*** has a wide variety of equipment, including automatic levels, digital theodolites, total stations, and GPS-based surveying instruments available for instructional purposes.

The ***Traffic Laboratory*** has electronic volume counters that are used in studies to classify vehicles and measure their speeds in user-specified ranges and periods of time.

COURSE DESCRIPTIONS

Lower-Division Undergraduate Courses

CENG 5. Project Impacts on the Community and the Environment

Introduction to the decision-making concepts and strategies that ultimately determine the feasibility of a proposed development project. Chronological aspects of project planning, evaluation, and implementation. Identification of impacts on the community and the environment. (4 units)

CENG 7. Graphic Communication

Introduction to technical drawing including isometric and multiview drawings, use of sectional views and dimensioning, understanding blueprints and scales. *Co-requisite: CENG 7L.* (3 units)

CENG7L. Graphic Communication Laboratory

Freehand drawing, manual and computer-aided drafting of physical models, construction of models from drawings. *Co-requisite: CENG 7.* (1 unit)

CENG 10. Surveying

The use and care of survey instruments. Principles of topographic mapping, linear measurements, leveling, traverses, curves, boundary, and public surveys. *Co-requisite: CENG 10L.* (3 units)

CENG 10L. Laboratory for CENG 10

Field work using common surveying instrumentation and equipment. *Co-requisite: CENG 10.* (1 unit)

CENG 15. Computer Applications in Civil Engineering

Solution techniques for civil engineering problems using common computer software. Introduction to matrix analysis, graphical and numerical solution methods, regression analysis, and linear optimization using some of the basic features in spreadsheet and math analysis programs to aid engineering solutions. Introduction to Visual Basic programming. A paper and presentation on an analytical topic developed with analytical tools used in the course. *Co-requisites: CENG 15L and CENG 41.* (2 units)

CENG 15L. Laboratory for CENG 15

Hands-on work using analytical tools contained in common software programs to solve problems, and written and oral communication of solutions. *Co-requisite: CENG 15.* (1 unit)

CENG 20. Geology

Development and formation of geologic materials. Significance of structure, landform, erosion, deposition. Stream and shoreline processes. Surface water. *Co-requisite: CENG 20L.* (3 units)

CENG 20L. Laboratory for CENG 20

Identification, examination, and characterization of rock specimens. *Co-requisite: CENG 20.* (1 unit)

CENG 41. Mechanics I: Statics

Resolution and composition of force systems and equilibrium of force systems acting on structures and mechanisms. Distributed forces. Friction. Moments of inertia. *Prerequisite: PHYS 31.* (4 units)

CENG 42. Mechanics II: Dynamics

Dynamics of a particle and dynamics of rigid bodies. Work and energy methods. Momentum methods. Kinetics of systems of particles. Introduction to theory of vibrations. *Prerequisite: CENG 41.* (3 units)

CENG 43. Mechanics III: Strength of Materials

Analysis of stresses and strains in machines and structural members. Fundamental study of the behavior and response of statically determinate and indeterminate structural members subjected to axial, flexural, shear, and combined stresses. Introduction to the stability of columns. *Prerequisite: CENG 41. Co-requisite: CENG 43L.* (4 units)

CENG 43L. Laboratory for CENG 43

Laboratory investigations of structural elements subjected to axial load, bending, torsion, combined loading and buckling loads. Laboratory report writing. *Co-requisite: CENG 43.* (1 unit)

CENG 44A. Strength of Materials I

Analysis of stresses and strains in structural members. Fundamental study of the behavior and response of statically determinate structural members subjected to axial, torsional, flexural, shear and combined stresses. Stress transformation, principal stresses, and Mohr's circle. *Prerequisite: CENG 41. Co-requisite: CENG 44AL.* (3 units)

CENG 44AL. Strength of Materials Laboratory

Co-requisite: CENG 44A. (1 unit)

CENG 44B. Strength of Materials II

Continuation of topics covered in CENG 44A. Shear flow and shear center. Indeterminate systems. Introduction to plastic behavior and column stability. *Prerequisite: CENG 44A.* (2 units)

Upper-Division Undergraduate Courses

CENG 115. Civil Engineering Materials

CCENG 115. Civil Engineering Materials Common civil engineering materials, focusing on steel, concrete, and wood, and touching on asphalt and epoxy. Structure and properties of materials, their production processes, and experimental methods used for determining their key properties. Sustainability implications of materials choices. *Prerequisites: CHEM 11 and CENG 44A. Co-requisite: CENG 115L.* (4 units)

CENG 115L. Laboratory for CENG 115

Laboratory testing of steel, concrete, wood, and other, innovative civil engineering construction materials. *Co-requisite: CENG 115.* (1 unit)

CENG 118. Construction Engineering

Introduction to construction roles and responsibilities, construction project phases, building systems, bidding and cost estimating, resource utilization, planning and scheduling, project documentation, safety and quality management. *Also listed as CENG 218. Prerequisite: Junior standing.* (3 units)

CENG 119. Design for Sustainable Construction

Design strategies for sustainable commercial and residential construction. Use of LEED criteria for assessing sustainable construction. Team-based project planning, design, and construction. Economic evaluation of sustainable technologies. Prefabrication. Overall project management. *Also listed as CENG 219. Prerequisite: Junior standing.* (4 units)

CENG 121A. Geotechnical Engineering

Origin, development, and properties of soils. Classification of soils and applications of engineering mechanics to soils as an engineering material. Water in soils. Soil-testing methods. Compaction, stabilization, consolidation, shear strength, and slope stability. *Prerequisites: CENG 20 and 44A. Co-requisite: CENG 121AL.* (3 units)

CENG 121AL. Laboratory for CENG 121

Laboratory examination of soil-testing methods. *Co-requisite: CENG 121.* (1 unit)

CENG 121B. Geotechnical Engineering

Theory and basic factors related to earth pressure, slope stability, and foundations. *Prerequisite: CENG 121A.* (3 units)

CENG 123. Environmental Reaction Engineering

Reaction stoichiometry and kinetics. Reactions of environmental significance. Dynamic and equilibrium system modeling. Reactor configurations and their impact on extent of reaction. *Prerequisites: CHEM 11 or equivalent, AMTH 106, and junior standing.* (3 units)

CENG 123L. Laboratory for CENG 123

Use of experimentation and computer modeling to analyze solutions in aqueous equilibrium. Steady-state and dynamic analysis of reactor systems. *Co-requisite: CENG 123.* (1 unit)

CENG 124. Water Law and Policy

Introduction to the legal and regulatory concepts related to water. Examines rights, policies, and laws, including issues related to water supply and access (water transfers/water markets, riparian and appropriative doctrines), flood control, water pollution and quality (the Clean Water Act, EPA standards, in stream flows for fish), and on-site storm water management/flood control. A focus on California water law and policy is complemented with some national and international case studies. *Cross-listed with CENG 258 and ENVS 124.* (4 units)

CENG 125. Municipal Engineering Design

Various aspects of civil engineering as applied in municipal (public works) design practice. Maps and plats; site layout and earthworks; drainage; streets and utilities. *Prerequisites: CENG 10 and 15. Co-requisite: CENG 125L.* (3 units)

CENG 125L. Laboratory for CENG 125

Development of CAD drawings for the course design project. *Co-requisite: CENG 125.* (1 unit)

CENG 128. Engineering Economics and Business

Time value of money, economic analysis of engineering projects, planning and capital budgeting, rate-of-return analysis, depreciation, cash-flow analysis, organizational behavior, business organization forms, design of organizational structures, financial analysis and management. *Prerequisite: Junior standing.* (3 units)

CENG 132. Structural Analysis

Loads and their distribution in structures. Analysis of statically determinate and indeterminate beams, trusses, and frames. Influence lines for beams and trusses. Analysis of statically indeterminate structures. Modeling and analysis of structures using commercial software programs. A team-based structural analysis project and presentation. *Prerequisite: CENG 44A. Co-requisite: CENG 44B.* (4 units)

CENG 133. Timber Design

Timber structural systems. Design of structural members for tension, compression, bending, and shear. Introduction to shear walls and diaphragm design. Design project. *Also listed as CENG 233. Prerequisite: CENG 148.* (4 units)

CENG 134. Structural Steel Design I

Strength design of structural steel buildings. Design of members for tension, flexure, shear, compression, and combined loading. Introduction to connection design. Design project. *Prerequisite: CENG 148.* (4 units)

CENG 135. Reinforced Concrete Design

Ultimate strength design of reinforced concrete members considering flexure, shear, and axial forces. Anchorage and development of reinforcing bars. *Prerequisite: CENG 148. Co-requisite: CENG 135L.* (4 units)

CENG 135L. Laboratory for CENG 135

Experimental tests of reinforced concrete building components; problem solving and review sessions; field trip(s). *Co-requisite: CENG 135.* (1 unit)

CENG 136. Advanced Concrete Structures

Analysis and design of reinforced-concrete frame and wall structures for gravity and lateral loads; use of strut and tie method for disturbed regions; and introduction to prestressed concrete. *Also listed as CENG 236. Prerequisite: CENG 135.* (4 units)

CENG 137. Earthquake Engineering Design

Introduction to seismic sources, wave propagation, and effects on structures. Spectral representations of demands. Design according to current code provisions, and using simplified pushover methods. *Also listed as CENG 237. Prerequisite: CENG 148.* (4 units)

CENG 138. Geotechnical Engineering Design

Foundation exploration; bearing capacity and settlement analysis; spread foundations; piles and caissons; earth-retaining structures; loads on underground conduits; subsurface construction. *Also listed as CENG 238. Prerequisite: CENG 121.* (4 units)

CENG 138L. Geotechnical Engineering Design Laboratory

Structural design of footings, piles, and retaining walls. *Also listed as CENG 238L. Prerequisite: CENG 135. Co-requisite: CENG 138.* (1 unit)

CENG 139. Groundwater Hydrology

Groundwater occurrence, flow principles, flow to wells, and regional flow. Groundwater contamination, management, and models. Field methods. Field trips. *Also listed as CENG 259. Prerequisite: CENG 141.* (3 units)

CENG 140. Water Resources Engineering

Concepts, analysis, and engineering design related to various aspects of water resources: hydrologic cycle, evaporation, infiltration, precipitation, snow, flood frequency, water supply, and runoff management. Impacts of development, land use, and climate changes on water supply, and importance of these changes to society. Field trips. *Prerequisite: CENG 141 or instructor approval. Co-requisite: CENG 140L.* (4 units)

CENG 140L. Laboratory for CENG 140

Computational exercises for water resources analysis, field trips demonstrating hydrologic monitoring systems and complex regional water management systems. *Co-requisite: CENG 140.* (1 unit)

CENG 141. Fluid Mechanics and Hydraulic Engineering

Fundamentals of fluid behavior with an emphasis on water. Covers basic fluid properties, flow classification, and fluid statics including forces on submerged surfaces. Introduces and applies fundamental relationships: conservation of mass, momentum, and energy. Hydraulic applications include flow in pipes and pipe networks, steady flow in open channels, and hydraulic machinery. Laboratory. *Prerequisite: CENG 41, PHYS 31. Co-requisite: CENG 141L.* (4 units)

CENG 141L. Fluid Mechanics and Hydraulic Engineering Laboratory

Experiments demonstrating the principles of fluid flow and hydraulics for flow in pipes and in open channels. Use of modern data acquisition and writing of formal lab reports. *Co-requisite: CENG 141.* (1 unit)

CENG 142. Water Resources Design

Design of system components for water supply and flood control projects, including storage facilities, closed conduits, open channels, well fields, and pumping systems. *Also listed as CENG 242. Prerequisites: CENG 140 and CENG 141 or instructor approval.* (4 units)

CENG 143. Environmental Engineering

Water and air quality. Water supply and pollution control; air pollution control. Management of solid wastes. *Prerequisites: CHEM 11, MATH 12, and junior standing. Co-requisite: CENG 143L.* (3 units)

CENG 143L. Laboratory for CENG 143

Laboratory analysis of aqueous samples and ideal reactor systems. Analysis of non-point pollution prevention strategies. Solid waste characterization. *Co-requisite: CENG 143.* (1 unit)

CENG 144. Environmental Systems Design

Design of treatment and distribution systems for potable water. Design of collection and treatment systems for water pollution control and wastewater reclamation. *Prerequisites: CENG 141 and 143. Co-requisite: CENG 144.* (3 units)

CENG 144L. Laboratory for CENG 144

Use of commercial software packages to design elements of potable water and wastewater management systems. Oral presentations. *Co-requisite: CENG 144.* (1 unit)

CENG 145. Transportation Engineering Design

Transportation systems analysis and design. Traffic flow. Geometric design of systems. Principles of highway design. Planning, construction, and operation of transportation systems. *Prerequisites: CENG 10 and junior standing.* (4 units)

CENG 146. Design of Cold-Formed Steel Frame Structures

Introduction to the fundamentals of cold-formed steel frame construction. Current design and construction practice. Practical design of members for tension, compression, shear, and torsion. Connection detailing. *Also listed as CENG 246. Prerequisite: CENG 148.* (4 units)

CENG 147. Pavement Design

Paving materials. Geometric and structural design of highways. Urban street layout and details. Layout and design of airport runways. *Also listed as CENG 247. Prerequisites: CENG 115 and 121.* (4 units)

CENG 148. Structural Systems

Structural performance requirements and structural systems; load sources, combinations, and load paths; accommodation of fire, sound, thermal, and mechanical requirements on structural systems; allowable stress and ultimate strength design philosophies; introduction to design of steel and reinforced concrete beams and columns. *Prerequisite: CENG 132. Co-requisite: CENG 148L.* (4 units)

CENG 148L. Structural Systems Laboratory

Simulation and modeling of structural system behavior. Structural drawings/schematics. *Co-requisite: CENG 148.* (1 unit)

CENG 149. Civil Systems Engineering

Introduction to engineering systems analysis and management technologies and their applications to civil engineering problems, such as transportation, assignment, critical path, and maximum flow problems. Topics include linear programming, nonlinear programming, probability and queuing theory, as well as relevant applications to civil engineering problems. *Also listed as CENG 249. Prerequisites: MATH 13 and junior standing.* (4 units)

CENG 150. Traffic Engineering: Design and Operations

Basic characteristics of motor-vehicle traffic, highway and intersection capacity, applications of traffic control devices, traffic data studies, signal design, traffic safety. *Also listed as CENG 250. Prerequisite: CENG 145.* (4 units)

CENG 151. Special Topics in Transportation Engineering

Coverage of special topics in transportation engineering including dynamic traffic flow forecasting, analysis and application of traffic flow patterns, and static and dynamic traffic analysis and modeling for short-term and long-term planning and optimization. *Also listed as CENG 251. Prerequisite: CENG 145.* (4 units)

CENG 160. GIS in Water Resources

Introduction to Geographic Information Systems (GIS) technology with applications in watershed analysis and hydrology. Obtaining and processing digital information for watersheds, mapping terrain, spatial analysis, computing river networks from digital elevation models, preparing data for hydrologic modeling for water supply and flood studies. *Also listed as CENG 260. Prerequisites: Junior standing and experience with Windows directory and file management.* (3 units)

CENG 161. Sustainable Water Resources

Analysis and design of water resource systems, from flood control projects to drinking water supply, as environmental constraints and societal values shift. Includes sustainable and low impact design techniques, climate impacts on water, assessing sustainability, life-cycle economics, and current topics. *Also listed as CENG 261. Prerequisite: CENG 140 or instructor approval.* (3 units)

CENG 162. Computational Water Resources

Use of professional applications software to design and evaluate facility components and systems for water resources engineering projects. *Also listed as CENG 262. Prerequisite: CENG 140, which may be taken concurrently.* (3 units)

CENG 163. Solid Waste Management

Characterization of solid waste streams. Overview of collection, transport, processing, and disposal options. Waste stream reduction and resource recovery strategies. *Also listed as CENG 263.* (4 units)

CENG 182. Introduction to Building Information Modeling

Parametric design and modeling, BIM-based scheduling and estimating, model checking and validation, 4D visualization, green building design, applications in integrated project delivery and facilities management, interoperability, standardization, and web-based collaboration. *Also listed as CENG 282. Prerequisites: CENG 125 and junior standing.* (3 units)

CENG 184. Construction and Contract Administration

Project stakeholders authorities, project organization, compensation schemes, bidding, contracts, quality control, preconstruction operations, project documentation, electronic administration, labor laws and relations, safety, risk and liability sharing, payments and change orders, schedule delay analysis, claims, and disputes, project closeout. *Also listed as CENG 284. Prerequisite: Junior standing.* (3 units)

CENG 186. Construction Planning and Control

Work breakdown structure; work sequencing and logic; activity duration estimates; schedule network representations; critical path method; resources loading, allocation, and leveling; planning of repetitive tasks; cost estimates; time-cost tradeoffs; project cash flow analysis; and, time-cost control. Use of commercial scheduling software. Group project on construction planning. *Also listed as CENG 286. Prerequisite: Junior standing. Co-requisite: CENG 186L.* (3 units)

CENG 186L. Construction Planning and Control Laboratory

Also listed as CENG 286L. Co-requisite: CENG 186. (1 unit)

CENG 187. Construction Operations and Equipment

Earthmoving with dozers, scrappers, and excavators; hauling, compacting and finishing. Piling, lifting; concrete operations, asphalt paving, equipment economics, operations planning using computer simulation, and discrete-event simulation. Group project on construction operations analysis. *Also listed as CENG 287. Prerequisite: Junior standing. Co-requisite: CENG 187L.* (3 units)

CENG 187L. Construction Operations and Equipment Laboratory

Also listed as CENG 287L. Co-requisite: CENG 187. (1 unit)

CENG 188. Co-op Education

Integration of classroom study and practical experience in a planned program designed to give students practical work experience related to their academic field of study and career objectives. The course alternates (or parallels) periods of classroom study with periods of training in industry or government. Satisfactory completion of the work assignment includes preparation of a summary report on co-op activities. P/NP grading. May not be taken for graduate credit. (1–2 units)

CENG 189. Co-op Technical Report

Technical report on a specific activity such as a design or research project, etc., after completing a co-op assignment. Approval of department advisor required. Letter grade based on content and quality of report. May not be taken for graduate credit. *Prerequisite: CENG 188.* (2 units)

CENG 192A. Civil Engineering Project Development

Introduction to problem-solving methodology for the design of civil engineering systems and components. Selection of Capstone Design Project, definition of problem, and conceptual design. *Prerequisite: Junior standing.* (1 unit)

CENG 192B. Elements of Civil Engineering Practice

Further development of problem-solving methodology; introduction to project management. Applications of engineering techniques and procedures to civil engineering design. Schematic designs, alternatives analysis and cost estimates. Preliminary design of critical components or subsystems of Capstone Design Project. Environmental impact assessment. *Prerequisite: CENG 192A. Co-requisite: CENG 192C.* (2 units)

CENG 192C. Professional Development Seminar

Importance of licensing and lifelong learning in the practice of civil engineering. Advanced workshops on topics relevant to Capstone Design Projects. Review of topics covered on FE/EIT professional licensing exam. *Prerequisite: Senior standing or instructor approval.* (1 unit)

CENG 193. Detailed Project Design

Investigation of an approved Capstone Design Project. The design process, including problem formulation, analysis, preliminary design, final design, and plans, is completed. Formal presentation of preliminary and final designs. *Prerequisite: CENG 192B.* (4 units)

CENG 194. Design Project Communication

Completion of design project documentation and public presentation of results. *Prerequisite: CENG 193.* (1 unit)

CENG 197. Special Topics in Civil Engineering

Subjects of current interest. May be taken more than once if topics differ. (1–4 units)

CENG 198. Internship

Time off campus with an engineering organization. Different aspects of work in the assigned professional office. Oral and written reports. *Prerequisites: Senior standing and approval of internship coordinator.* (4–5 units)

CENG 199. Directed Research

Investigation of an approved engineering problem and preparation of a suitable project report. Conferences with faculty advisor are required. *Prerequisite: Junior standing.* (1–5 units)

Graduate Courses

CENG 205. Finite Element Methods I

Introduction to structural and stress analysis problems using the finite element method. Use of matrix methods, interpolation (shape) functions and variational methods. Formulation of global matrices from element matrices using direct stiffness approach. Development of element matrices for trusses, beams, 2D, axisymmetric and 3D problems. Theory for linear static problems and practical use of commercial FE codes. (2 units)

CENG 206. Finite Element Methods II

Isoparametric elements and higher order shape functions for stiffness and mass matrices using numerical integration. Plate and shell elements. Mesh refinement and error analysis. Linear transient thermal and structural problem using finite element approach. Eigenvalue/eigenvector analysis, frequency response and direct integration approaches for transient problems. Application of commercial FE codes. *Prerequisite: CENG 205.* (2 units)

CENG 207. Finite Element Methods III

Solution of nonlinear problems using finite element analysis. Methods for solving nonlinear matrix equations. Material, geometrical, boundary condition (contact) and other types of nonlinearities and applications to solid mechanics. Transient nonlinear problems in thermal and fluid mechanics. Application of commercial FE codes to nonlinear analysis. *Prerequisite: CENG 206.* (2 units)

CENG 208. Engineering Economics and Project Finance

Time value of money, cash-flow, rate of return, and depreciation; financing approaches and sources; applications to large scale energy projects such as wind and solar energy, cogeneration, biomass, and geothermal. (3 units)

CENG 211. Advanced Strength of Materials

Bending of beams with nonsymmetrical cross section. Curved beams. Shear center. Shear flow in open and closed sections. Torsion of open and closed section members. Energy theorems and their applications. Beams on elastic foundations. Beam analysis using Fourier series. Stress analysis of composite materials. (4 units)

CENG 213. Sustainable Materials

Evaluation of material sustainability. Material characteristics, microstructure, and mechanical properties of selected materials such as bamboo, straw, adobe, lime, and reduced cement concretes. Processing and durability considerations. Course project. (3 units)

CENG 213L. Laboratory for CENG 213

Sample preparation and evaluation of mechanical properties in the laboratory. *Co-requisite: CENG 213.* (1 unit)

CENG 215. Sustainable Structural Engineering

Use of sustainable materials in structural design; characteristics and design of systems such as bamboo frames and trusses, straw bale walls, low-cement concrete, and composite barrel vaults. Course project. *Prerequisite: CENG 148 or instructor approval.* (3 units)

CENG 215L. Laboratory for CENG 215

Preparation and testing of structural subassemblies in the laboratory. *Co-requisite: CENG 215.* (1 unit)

CENG 217. Sustainable Infrastructure for Developing Countries

Sustainable options for providing water and energy to communities, adaptation to local resources and constraints, processing and reuse of waste products, transportation alternatives. (4 units)

CENG 218. Construction Engineering

Introduction to construction roles and responsibilities, construction project phases, building systems, bidding and cost estimating, resource utilization, planning and scheduling, project documentation, safety and quality management. *Also listed as CENG 118.* (3 units)

CENG 219. Designing for Sustainable Construction

Design strategies for sustainable commercial and residential construction. Use of LEED criteria for assessing sustainable construction. Team-based project planning, design, and construction. Economic evaluation of sustainable technologies. Prefabrication. Overall project management. *Also listed as CENG 119.* (4 units)

CENG 220. Structural Dynamics

Analysis and behavior of simple linear oscillators. Natural mode shapes and frequencies for distributed and lumped mass systems. Introduction to nonlinear vibrations. (4 units)

CENG 221. Advanced Dynamics

Continuation of CENG 220. Distributed parameter systems. Nonlinear transient dynamics. Dynamic response in the frequency domain. Component mode methods. *Prerequisite: CENG 220.* (2 units)

CENG 222. Advanced Structural Analysis

Advanced methods for the analysis of statically indeterminate and non-conventional structural systems. Explicit modeling of cross-sections and joints in structural systems. Hands-on experience with modern commercial analysis software. (4 units)

CENG 223. Stability of Structures

Energy methods. Elastic stability of columns under axial loads and bending moments. Introduction to inelastic stability analysis of columns. Stability analysis of frames. Stability of flat plates and cylindrical shells. Lateral buckling of beams. (4 units)

CENG 226. Plastic Theory of Structures

Concepts of plastic behavior of structures. Collapse mechanisms for beams and frames. Applications of energy methods in solution procedures. (2 units)

CENG 228. Fracture Mechanics of Solids

Elastic and elastic-plastic fracture criteria. Stress intensity solutions. Metallurgical aspects of toughness. Design and alloy selection. Failure analysis techniques applied to actual engineering problems. (2 units)

CENG 231. Bridge Engineering

An introduction to modern bridge structural systems, bridge loading, bridge deck slab design, girders, and substructure. *Prerequisite: CENG 135.* (4 units)

CENG 232. Masonry Engineering

Design of unreinforced and reinforced masonry structures, including shear-wall and bearing-wall systems. *Prerequisite: CENG 135.* (2 units)

CENG 233. Timber Design

Timber structural systems. Design of structural members for tension, compression, bending, and shear. Introduction to shear walls and diaphragm design. Design project. *Also listed as CENG 133.* (4 units)

CENG 234. Structural Steel Design II

Design of lateral systems, including new and innovative systems, and connections. Introduction to hybrid and composite design. Application of performance-based design requirements for steel structures. *Prerequisite: CENG 134.* (4 units)

CENG 236. Advanced Concrete Structures

Analysis and design of reinforced-concrete and frame-wall structures for gravity and lateral loads; use of strut and tie method for disturbed regions; and introduction to pre-stressed concrete. *Also listed as CENG 136. Prerequisite: CENG 135.* (4 units)

CENG 237. Earthquake Engineering Design

Introduction to seismic sources, wave propagation, and effects on structures. Spectral representations of demands. Design according to current code provisions, and using simplified pushover methods. *Also listed as CENG 137.* (4 units)

CENG 238. Geotechnical Engineering Design

Foundation exploration; bearing capacity and settlement analysis; spread foundations; piles and caissons; earth-retaining structures; loads on underground conduits; subsurface construction. *Also listed as CENG 138. Prerequisite: CENG 121.* (4 units)

CENG 238L. Geotechnical Engineering Design Laboratory

Structural design of footings, piles, and retaining walls. *Also listed as CENG 138L. Prerequisite: CENG 135. Co-requisite: CENG 238* (1 unit)

CENG 239. Earthquake Engineering II

Continuation of CENG 237. Performance-based earthquake engineering. Use of advanced techniques for design of new buildings and rehabilitation of existing buildings to meet clearly delineated seismic performance expectations. Modeling of structural components and use of nonlinear analysis software for static and dynamic analyses. *Prerequisite: CENG 237.* (2 units)

CENG 240. Soil-Structure Interaction

Introduction of soil-structure analysis for evaluating seismic response. Dynamic interaction between the structure and its surrounding soil. Soil-structure interaction models. *Prerequisites: CENG 237 and CENG 238.* (2 units)

CENG 241. Introduction to Blast Analysis

This introductory course will cover well-established procedures and principles used to design structures to resist the effects of accidental explosions. Concepts covered include: design considerations; risk analysis and reduction; acceptable performance criteria; levels of protection; air-blast loading phenomenon, blast loading functions, current state of practice of structural blast analysis, design and detailing requirements. This course is well-suited to practicing engineers who would like to develop their skills in the analysis and design of structures subject to high-intensity loading from blast and fragments. (2 units)

CENG 242. Water Resources Design

Design of system components for water supply and flood control projects, including storage facilities, closed conduits, open channels, well fields, and pumping systems. *Also listed as CENG 142. Prerequisites: CENG 140 and CENG 141 or instructor approval.* (4 units)

CENG 242L. Laboratory for CENG 242

Hands on use of commercial software packages to test water supply and flood control projects. *Co-requisite: CENG 242.* (1 unit)

CENG 244. Progressive Collapse and Structural Integrity

This introductory course will cover well-established procedures and principles used to analyze and subsequently design structures to mitigate the possibility of the progressive collapse. Progressive collapse is defined as a structural collapse which is disproportional in size and severity to collapse initiating damage. Concepts covered in this class include: examples and causes, mechanisms of occurrence of progressive collapse, analysis and modeling principles, current state of practice, design and detailing considerations for steel and concrete moment frame structures, levels of protection and risk reduction concepts; course project. (2 units)

CENG 246. Design of Cold-Formed Steel Frame Structures

Introduction to the fundamentals of cold-formed steel frame construction. Current design and construction practice. Practical design of members for tension, compression, shear, and torsion. Connection detailing. *Also listed as CENG 146. Prerequisite: CENG 148.* (4 units)

CENG 247. Pavement Design

Paving materials. Geometric and structural design of highways. Urban street layout and details. Layout and design of airport runways. *Also listed as CENG 147. Prerequisites: CENG 115 and 121.* (4 units)

CENG 249. Civil Systems Engineering

Introduction to engineering systems analysis and management technologies and their applications to civil engineering problems, such as transportation, assignment, critical path, and maximum flow problems. Topics include linear programming, nonlinear programming, probability and queuing theory, as well as relevant applications to civil engineering problems. *Also listed as CENG 149.* (4 units)

CENG 250. Traffic Engineering: Design and Operations

Basic characteristics of motor-vehicle traffic, highway and intersection capacity, applications of traffic control devices, traffic data studies, signal design, traffic safety. *Also listed as CENG 150. Prerequisite: CENG 145.* (4 units)

CENG 251. Special Topics in Transportation Engineering

Coverage of special topics in transportation engineering including dynamic traffic flow forecasting, analysis and application of traffic flow patterns, and static and dynamic traffic analysis and modeling for short-term and long-term planning and optimization. *Also listed as CENG 151. Prerequisite: CENG 145.* (4 units)

CENG 256. Public Transportation

Evolution of mass transit in the United States. Characteristics of major components of mass transit: bus, light- and rapid-rail transit. Prominent systems of mass transit in selected major U.S. cities. Paratransit systems. Financing and administering of transit and paratransit systems. New technology applications in mass transit. Course requires students to get hands-on experience on one of the major transit systems in the Bay Area as a case study. (3 units)

CENG 258. Water Law and Policy

Introduction to the legal and regulatory concepts related to water. Examines rights, policies, and laws, including issues related to water supply and access (water transfers/water markets, riparian and appropriative doctrines), flood control, water pollution and quality (the Clean Water Act, EPA standards, in stream flows for fish), and on-site storm water management/flood control. A focus on California water law and policy is complemented with some national and international case studies. *Cross-listed with CENG 124 and ENVS 124.* (4 units)

CENG 259. Groundwater Hydrology

Groundwater occurrence, flow principles, flow to wells, and regional flow. Groundwater contamination, management, and modeling. Field methods. Field trips. *Also listed as CENG 139. Prerequisite: CENG 141.* (3 units)

CENG 260. GIS in Water Resources

Introduction to Geographic Information Systems (GIS) technology with applications in watershed analysis and hydrology. Obtaining and processing digital information for watersheds, mapping terrain, spatial analysis, computing river networks from digital elevation models, preparing data for hydrologic modeling for water supply and flood studies. *Also listed as CENG 160.* (3 units)

CENG 261. Sustainable Water Resources

Analysis and design of water resource systems, from flood control projects to drinking water supply, as environmental constraints and societal values shift. Includes sustainable and low impact design techniques, climate impacts on water, assessing sustainability, life-cycle economics, and current topics. *Also listed as CENG 161. Prerequisite: CENG 140 or instructor approval.* (3 units)

CENG 262. Computational Water Resources

Use of professional applications software to design and evaluate facility components and systems for water resources engineering projects. Laboratory. *Also listed as CENG 162. Prerequisites: CENG 140 and 141, which may be taken concurrently.* (3 units)

CENG 263. Solid Waste Management

Characterization of solid waste streams. Overview of collection, transport, processing, and disposal options. Waste stream reduction and resource recovery strategies. *Also listed as CENG 163.* (4 units)

CENG 281. Construction Law for Civil Engineers

Legal aspects of construction procedures. Quantitative methods, case studies and procedures for measuring, analyzing and mitigating the value of change orders and claims. Discussion of key construction topics for the construction professional. General review of contract types, tort law, contract interpretation, liens, claims and disputes. A project term paper is required. (3 units)

CENG 282. Introduction to Building Information Modeling

Parametric design and modeling, BIM-based scheduling and estimating, model checking and validation, 4D visualization, green building design, applications in integrated project delivery and facilities management, interoperability, standardization, and web-based collaboration. *Also listed as CENG 182.* (3 units)

CENG 284. Construction and Contract Administration

Project stakeholders authorities, project organization, compensation schemes, bidding, contracts, quality control, preconstruction operations, project documentation, electronic administration, labor laws and relations, safety, risk and liability sharing, payments and change orders, schedule delay analysis, claims, and disputes, project close-out. *Also listed as CENG 184. Prerequisite: Junior standing.* (3 units)

CENG 286. Construction Planning and Control

Work breakdown structure; work sequencing and logic; activity duration estimates; schedule network representations; critical path method; resources loading, allocation, and leveling; planning of repetitive tasks; cost estimates; time-cost tradeoffs; project cash flow analysis; and, time-cost control. Use of commercial scheduling software. Group project on construction planning. *Also listed as CENG 186. Prerequisite: Junior standing. Co-requisite: CENG 286L.* (3 units)

CENG 286L. Construction Planning and Control Laboratory

Also listed as CENG 186L. Co-requisite: CENG 286. (1 unit)

CENG 287. Construction Operations and Equipment

Earthmoving with dozers, scrappers, and excavators; hauling, compacting and finishing. Piling, lifting; concrete operations, asphalt paving, equipment economics, operations planning using computer simulation, and discrete-event simulation. Group project on construction operations analysis. *Also listed as CENG 187. Prerequisite: Junior standing. Co-requisite: CENG 287.* (3 units)

CENG 287L. Construction Operations and Equipment Laboratory

Also listed as CENG 187L. Co-requisite: CENG 287. (1 unit)

CENG 288. Engineering Decision and Risk Analysis

Risk management, decision trees, fault trees, multi-attribute decision-making, sensitivity analysis, fuzzy numbers, fuzzy logic, optimization, reliability analysis, and Monte-Carlo simulation. Group project on engineering decisions. *Prerequisite: AMTH 108 or instructor approval.* (4 units)

CENG 289. Construction Productivity Analysis

Productivity improvement as applied to construction operations. Quantitative methods and procedures for measuring, analyzing and improving the productivity at construction job sites. (3 units)

CENG 292. Infrastructure Project Management

Management concepts and strategies for civil infrastructure projects. Identification of scope, schedule, and budget. Quality assurance and control. Processes for tracking progress and budget. Examination of actual projects. (2 units)

CENG 293. Graduate Design Project

Design of an approved civil engineering system using new methods and/or materials. A formal design report is required. (1–4 units)

CENG 295. Master's Thesis Research

By special arrangement. Limited to MSCE candidates. (1–7 units)

CENG 297. Directed Research

By special arrangement. (1–7 units)

CENG 299. Independent Study

Special/advanced topics. By special arrangement. (1–6 units)

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Department of Computer Engineering

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OVERVIEW

"Computing sits at the crossroads among the central processes of applied mathematics, science, and engineering. The three processes have equal and fundamental importance in the discipline, which uniquely blends theory, abstraction, and design."

–1989 Task Force Report on the Core of Computer Science prepared by the ACM and the IEEE Computer Society.

The most successful graduates in the field of computing are those who understand computers as systems—not just the design of hardware or software, but also the relationships and interdependencies between them and the underlying theory of computation.

The department offers a variety of degree and certificate programs, including courses that cover the breadth of the discipline, from the engineering aspects of hardware and software design to the underlying theory of computation.

DEGREE PROGRAMS

Students are required to meet with their advisors to define and file a program of study during their first quarter. In general, no credit is allowed for courses that duplicate prior coursework, including courses listed as degree requirements. Students should arrange adjustment of these requirements with their academic advisor when they file their program of study.

With the prior written consent of the advisor, master's students may take a maximum of 12 units of coursework for graduate credit from selected senior-level undergraduate courses.

Master of Science in Computer Science and Engineering (MSCSE)

All students admitted to the MSCSE program are expected to already have competence in the fundamental subjects listed below, as required within an accredited program for a B.S. in Computer Engineering or Computer Science. An applicant without such background (but has completed college level calculus and programming) may still be admitted, provided the deficiencies are corrected by coursework that is in addition to the normal degree requirements

and that is completed within the first year of graduate study. Alternatively, a student may take a similar course at another approved accredited institution. The subjects and corresponding SCU courses that may be used to correct the deficiencies include:

1. Logic design	COEN 21 or COEN 921C
2. Data structures	COEN 12 or COEN 912C
3. Computer organization & assembly language	COEN 20 or ELEN 33 or COEN 920C
4. Discrete math	AMTH 240
5. Probability	AMTH 210

6. One of the following: Differential Equations (AMTH 106), Numerical Analysis (AMTH 220, 221), or Linear Algebra (AMTH 245, 246)
7. One additional advanced programming course or one year of programming experience in industry

The SCU COEN and ELEN courses listed above and AMTH 106 are considered undergraduate-level and may not be used to satisfy the requirements for the M.S. in Computer Science and Engineering. However, students who have satisfied item 6 above, but who have never studied numerical analysis, may use AMTH 220/221 as electives; students who have satisfied item 6 above, but who have never studied linear algebra, may use AMTH 245/246 as electives. Laboratory components are not required for the above courses.

Degree Requirements

1. MSCSE Core
   - COEN 210, 279, and 283
   - Students who have taken one or more of these core courses or their equivalent must, with their advisor's approval, replace said course(s) with elective(s).
2. MSCSE Specialization Tracks

A theory course approved by the advisor in the area of specialization is required. A student must take a minimum of 8 units of COEN 300-899 courses. The following are suggested courses for each area of specialization; suggested courses may be replaced by other graduate courses with advisor's approval.

- Data Science: COEN 240, 272, 280, 281, and one of the following: COEN 241, 242, 266, 317, 380, AMTH 212, 247, and other classes as approved by advisor.
- Software Engineering: COEN 260, 275, 285, 286, 385, and 386
- Information Assurance: COEN 225, 250, 252, 351; AMTH387; and one of the following: COEN 226, 253, 254, or 350
- Multimedia Processing: COEN 201, 202, 238, and 338; and 6 units from AMTH 211, COEN 290, 336, 339, 340, 343, 347, ELEN 241, 244, or 444
- Computer Networks: COEN 233, 239, and at least 12 units from COEN 234, 235, 315, 316 , 317, 329, 331, 332, 335, 337, 338, 339, 347, 350, 351 (at least 6 units of 300-level courses)
- Computer Architecture and Systems: COEN 307, 313, 318, and 320; and 4 units from COEN 203, 204, 207, 208, 218, 301, 303, 319
- Other possible specializations with advisor's approval

3. SCU Engineering Graduate Core Requirements (a minimum of 6 units). See Chapter 4, Academic Information. *Please Note: COEN 288 is required for the Software Engineering track.* ***Graduate Core cannot be waived.***
4. Electives: Sufficient units to bring the total to at least 45. (The maximum number of non-COEN graduate units allowed is 10 units, including those from the Engineering Graduate Core, and courses must be approved by the advisor.)

Please Note: Students wishing to do a thesis (COEN 497) should consult with their academic advisor regarding a modification of these requirements.

Master of Science in Software Engineering (MSSE)

The MSSE degree requires a minimum of 45 quarter units of work. All applicants for the Master of Science in Software Engineering program must have a bachelor's degree from an accredited four-year program. The ideal candidate has completed a bachelor's degree in computer science or computer engineering; however, exceptional candidates who hold a bachelor's degree in another closely related field may apply for consideration if they can clearly demonstrate the ability to perform graduate-level work in software engineering

The program consists of the SCU Engineering Graduate core, a software engineering core, a set of software engineering electives, and a capstone project. Students are allowed to sample courses across diverse software disciplines, including databases, networks, parallel and distributed systems, graphical user interfaces, artificial intelligence, and computer languages. Students must work with their advisor to select 15 units of appropriate software engineering electives. The capstone project comprises three consecutive terms of effort and provides an opportunity for students to apply their technical breadth and the core engineering principles toward the development of a complex, team-oriented software project. Ideally, projects will involve collaboration with industry. The capstone project integrates the engineering knowledge acquired in the core courses with the technical breadth acquired in the diverse electives. Thus, students must complete all requirements of the core prior to registering for the first capstone project course. They must also complete six units of electives prior to registering for the second two units of the capstone course, COEN 485, to ensure the project teams have the appropriate blend of technical background and engineering knowledge.

Degree Requirements

1. SCU Engineering Graduate Core Requirements: (a minimum of 6 units): See Chapter 4, Academic Information.

   Please Note: COEN 288 is required for the M.S. in Software Engineering, and satisfies 2 units of the Engineering Core Requirements. ***Graduate Core cannot be waived.***
2. MSSE Core
   - COEN 260, 275, 285, 286, 385, and 386
3. Software engineering electives
   - 15 units selected with the approval of the academic advisor
4. Software Engineering Capstone Project: COEN 485 (repeated in three consecutive terms for a total of 6 units)
   - Students must complete COEN 286 and 386 before enrolling in COEN 485
   - Students are expected to register for three consecutive quarters of COEN 485
   - Students may not register for more than 2 units of COEN 485 in any one term

5. COEN 288 (also satisfies Engineering Graduate core requirement for Engineering and Society)
6. Electives: Sufficient units to bring the total to at least 45

Please Note: Students should meet with their advisors to define and file their program of study during their first quarter.

Doctor of Philosophy in Computer Science and Engineering

The doctor of philosophy (Ph.D.) degree is conferred by the School of Engineering primarily in recognition of competence in the subject field and the ability to investigate engineering problems independently, resulting in a new contribution to knowledge in the field. The work for the degree consists of engineering research, the preparation of a thesis based on that research, and a program of advanced study in engineering, mathematics, and related physical sciences. The student's work is directed by the department, subject to the general supervision of the School of Engineering. See Chapters 2 and 3, Academic Programs and Requirements and Admissions, for details on admission and general degree requirements. The following departmental information augments the general requirements.

Preliminary Exam

A preliminary written exam is offered at least once per year by the School of Engineering as needed. The purpose is to ascertain the depth and breadth of the student's preparation and suitability for Ph.D. work.

Faculty Advisor

The student and his or her advisor jointly develop a complete program of study for research in a particular area. The complete program of study (and any subsequent changes) must be filed with the Engineering Graduate Programs Office and approved by the student's doctoral committee. Until this approval is obtained, there is no guarantee that courses taken will be acceptable toward the Ph.D. course requirements.

Doctoral Committee

After passing the Ph.D. preliminary exam, a student requests his or her thesis advisor to form a doctoral committee. The committee consists of at least five members, each of which must have earned a doctoral degree in a field of engineering or a related discipline. This includes the student's thesis advisor, at least two other current faculty members of the student's major department at Santa Clara University, and at least one current faculty member from another appropriate academic department at Santa Clara University. The committee reviews the student's program of study, conducts an oral comprehensive exam, conducts the dissertation defense, and reviews the thesis. Successful completion of the doctoral program requires that the student's program of study, performance on the oral comprehensive examination, dissertation defense, and thesis itself meet with the approval of all committee members.

Time Limit for Completing Degree

All requirements for the doctoral degree must be completed within eight years following initial enrollment in the Ph.D. program. Extensions will be allowed only in unusual circumstances and must be recommended in writing by the student's doctoral committee, and approved by the dean of engineering in consultation with the Graduate Program Leadership Council (GPLC)

Engineer's Degree in Computer Science and Engineering

The program leading to the engineer's degree is particularly designed for the education of the practicing engineer. The degree is granted on completion of an approved academic program and a record of acceptable technical achievement in the candidate's field of engineering. The academic program consists of a minimum of 45 units beyond the master's degree. Courses are selected to advance competence in specific areas relating to the engineering professional's work. Evidence of technical achievement must include a paper principally written by the candidate and accepted for publication by a recognized engineering journal prior to the granting of the degree. A letter from the journal accepting the paper must be submitted to the Office of the Dean, School of Engineering. In certain cases, the department may accept publication in the proceedings of an appropriate conference.

Admission to the program will generally be granted to those students who demonstrate superior ability in meeting the requirements for their master's degree. Normally, the master's degree is earned in the same field as that in which the engineer's degree is sought. Students who have earned a master's degree from Santa Clara University must file a new application (by the deadline) to continue work toward the engineer's degree. A program of study for the engineer's degree should be developed with the assistance of an advisor and submitted during the first term of enrollment.

CERTIFICATE PROGRAMS

Certificate programs are designed to provide intensive background in a narrow area at the graduate level. At roughly one-third of the units of a master's degree program, the certificate is designed to be completed in a much shorter period of time. These certificate programs are appropriate for students working in industry who wish to enhance their skills in an area in which they already have some background knowledge.

For more specific application and admissions information, please refer to the website at: www.scu.edu/engineering/graduate.

Students must receive a minimum grade of C in each course and an overall GPA of 3.0 or better to earn a certificate of completion.

Continuation for a Master's Degree: All Santa Clara University courses applied to the completion of a certificate program earn graduate credit that may also be applied toward a graduate degree. Students who wish to continue for such a degree must submit a separate application and satisfy all normal admission requirements. The general GRE test requirement for graduate admission to the master's degree will be waived for students who complete a certificate program with a GPA of 3.5 or better.

Certificate in Software Engineering

Advisor: Dr. Rani Mikkilineni

This certificate program places an emphasis on methodologies used in the development of large, complex software. The program is appropriate for anyone who is developing new software, maintaining existing software, or is the technical head of a software development project. **In addition to the general requirements, students must have two years of industrial experience in software development and prior coursework in data structures and analysis of algorithms, software engineering, discrete mathematics, and predicate logic.**

Required Courses (12 units)

- COEN 260 Truth, Deduction, and Computation (4 units)
- COEN 286 Software Quality Assurance and Testing (2 units)
- COEN 287 Software Development Process Management (2 units)
- COEN 385 Formal Methods in Software Engineering (2 units)
- COEN 386 Software Architectures (2 units)

Elective Courses (Select any 4 units; other courses may be considered if approved in advance)

- COEN 261 Structure and Interpretation of Computer Programs (2 units)
- COEN 275 Object-Oriented Analysis and Design (4 units)
- COEN 276 Software Tools Design (4 units)
- COEN 277 Graphical User Interface Design and Programming (2 units)
- COEN 388 Principles of Computer-Aided Engineering Design (2 units)
- EMGT 332 Software Engineering Economics (2 units)
- EMGT 339 Quality Issues in Managing Software (2 units)
- EMGT 341 Software Project Metrics (2 units)

Certificate in Information Assurance

Advisor: Dr. JoAnne Holliday

The Advanced Studies in Information Assurance Certificate program provides education in information assurance to working professionals in engineering and engineering management. Applicants are expected to have previous coursework in Operating Systems and Networks. In addition, applicants must complete all courses in Group 1, and eight units from Group 2 and additional courses should be chosen from Group 2 or Group 3 for a total of 16 units.

Group 1: Required Courses (4 units)

- COEN 250 Information Security Management (2 units)
- COEN 253 Secure Systems Development and Evaluation I (2 units)

Group 2: Select any 8 units

- AMTH 387 Cryptology (4 units)
- COEN 225 Secure Coding in C and C++ (2 units)
- COEN 252 Computer Forensics and COEN 252L (5 units)
- COEN 350 Network Security (2 units)
- COEN 351 Internet and E-Commerce Security (3 units)

Group 3: Elective Courses

- COEN 226 Introduction to System Certification and Accreditation (2 units)
- COEN 254 Secure Systems Development and Evaluation II (2 units)
- COEN 286 Software Quality Assurance and Testing (2 units)
- COEN 288 Software Ethics (2 units)
- COEN 352 Advanced Topics in Information Assurance (2 units)
- EMGT 288 Management of Quality Assurance (2 units)
- EMGT 369 E-Commerce Technology Strategy (2 units)
- ENGR 310 Engineering Ethics (2 units)
- ENGR 330 Law, Technology, and Intellectual Property (2 units)

Certificate in Networking

Advisor: Dr. Ahmed Amer

This certificate program is appropriate for working professionals in computer engineering, network engineering, and engineering management, and places an emphasis on the fundamentals and recent developments in computer networking. Students who complete the program may pursue a professional career in computer networking, with the ability to understand, analyze, design, implement, validate, and maintain networked systems.

Applicants must have completed an accredited bachelor's degree program in Computer Science, Computer Engineering, Electrical Engineering, Mathematics or an equivalent field with a strong academic record, and are expected to have prior coursework in data structures, analysis of algorithms, software engineering and operating systems.

Program Requirements: Students must complete a total of 16 units of prescribed coursework with a minimum GPA of 3.0 and a grade of C or better in each course. Certificate requirements substantially equivalent to other coursework completed within the last five years must be replaced by electives approved by the faculty in charge of networking.

Required Courses (8 units)

- COEN 233 Computer Networks (4 units)
- COEN 239 Network Design, Analysis (4 units)

Additional Courses (8 units) from:

- COEN 234, 235, 315, 316, 317, 329, 331, 332, 335, 337, 338, 339, 347, 350, or 351

LABORATORIES

The ***ASIC Testing Laboratory*** supports research conducted by graduate students from the departments of Electrical Engineering and Computer Engineering. Computer-aided testing packages from industry and the public domain are used in projects such as fault modeling and analysis. Projects include design for Test on RTL-level for digital and mixed signal circuits and design for reliability based on the defect-based testing.

The ***Digital Systems Laboratory*** (operated jointly with the Department of Electrical Engineering) provides complete facilities for experiments and projects ranging in complexity from a few digital integrated circuits to FPGA-based designs. The laboratory also includes a variety of development systems to support embedded systems and digital signal processing.

The ***Green Computing Laboratory*** is devoted to energy-efficient computing, i.e., the study and analysis of energy consumption in operating systems and networks and the development of energy-aware software.

The ***Multimedia Compression Laboratory*** supports research in video coding (compression and decompression).

The ***Wireless Networks Laboratory*** is shared by Computer Engineering and Electrical Engineering. The lab carries out research projects on the lower three layers of wireless networks. Current projects include: 1) Efficient scheduling of user traffic in cellular networks using smart antennas, 2) Algorithms for turn-key base stations in cellular networks, and 3) Changes to the MAC protocol in 802.11 based ad-hoc networks.

The ***Sustainable Computing Laboratory*** is dedicated to research in systems software and data storage technologies. The projects it supports focus on durable, scalable, and efficient solutions to computing problems, and the application of systems software technologies to broader sustainability problems.

The ***Software Engineering Research Laboratory*** is a dedicated facility not only for the support of various research activities aimed at developing engineering techniques and tools that help produce and validate high-quality software, but also for developing applications using leading-edge technologies.

The ***Parallel Processing Laboratory*** pursues research in fundamental problems in parallel processing, multi-core CPUs, and many-core GPUs programming and parallelizing compilers.

The ***Data Science Laboratory*** is devoted to the extraction of knowledge from data and to the theory, design and implementation of information systems to manage, retrieve, mine, and utilize data.

COURSE DESCRIPTIONS

Please Note: Depending on enrollment, some courses may not be offered every year.

Lower-Division Undergraduate Courses

COEN 10. Introduction to Programming

Overview of computing. Introduction to program design and implementation: problem definition, functional decomposition, and design of algorithm programming in PHP and C: variables, data types, control constructs, arrays, strings, and functions. Program development in the Linux environment: editing, compiling, testing, and debugging. *Credit is not allowed for more than one introductory class such as COEN 10, COEN 44, CSCI 10, or OMIS 30. Co-requisite: COEN 10L.* (4 units)

COEN 10L. Introduction to Programming Laboratory

Co-requisite: COEN 10. (1 unit)

COEN 11. Advanced Programming

The C Language: structure and style. Types, operators, and expressions. Control flow. Functions. Pointers, arrays, and strings. Structures and dynamic memory allocation. I/O and file processing. Special operators. Recursion and threads. The Unix environment. *Prerequisites: Previous programming experience and/or a grade of C- or better in an introductory computer programming course such as COEN 10, CSCI 10, or OMIS 30. Co-requisite: COEN 11L.* (4 units)

COEN 11L. Advanced Programming Laboratory

Co-requisite: COEN 11. (1 unit)

COEN 12. Abstract Data Types and Data Structures

Data abstraction: abstract data types, information hiding, interface specification. Basic data structures: stacks, queues, lists, binary trees, hashing, tables, graphs; implementation of abstract data types in the C language. Internal sorting: review of selection, insertion, and exchange sorts; quicksort, heapsort; recursion. Analysis of run-time behavior of algorithms; Big-O notation. Introduction to classes in C++. *Credit not allowed for more than one introductory data structures class, such as COEN 12 or CSCI 61. Prerequisite: A grade of C- or better in either COEN 11 or COEN 44. Co-requisite: COEN 12L. Recommended co-requisite: COEN 19 or MATH 51.* (4 units)

COEN 12L. Abstract Data Types and Data Structures Laboratory

Co-requisite: COEN 12. (1 unit)

COEN 19. Discrete Mathematics

Relations and operations on sets, orderings, elementary combinatorial analysis, recursion, algebraic structures, logic, and methods of proof. *Also listed as MATH 51.* (4 units)

COEN 20. Introduction to Embedded Systems

Introduction to computer organization: CPU, registers, buses, memory, I/O interfaces. Number systems: arithmetic and information representation. Assembly language programming: addressing techniques, arithmetic and logic operations, branching and looping, stack operations, procedure calls, parameter passing, and interrupts. C language programming: pointers, memory management, stack frames, interrupt processing. *Prerequisite: A grade of C- or better in COEN 11 or CSCI 60. Co-requisite: COEN 20L. Recommended co-requisite or prerequisite: COEN 12 or CSCI 61.* (4 units)

COEN 20L. Embedded Systems Laboratory

Co-requisite: COEN 20. (1 unit)

COEN 21. Introduction to Logic Design

Boolean functions and their minimization. Designing combinational circuits, adders, multipliers, multiplexers, decoders. Noise margin, propagation delay. Bussing. Memory elements: latches and flip-flops; timing; registers; counters. Programmable logic, PLD, and FPGA. Use of industry quality CAD tools for schematic capture and HDL in con-junction with FPGAs. *Also listed as ELEN 21. Co-requisite: COEN 21L.* (4 units)

COEN 21L. Logic Design Laboratory

Also listed as ELEN 21L. Co-requisite: COEN 21. (1 unit)

COEN 29. Current Topics in Computer Science and Engineering

Subjects of current interest. May be taken more than once if topics differ. (4 units)

COEN 44. Applied Programming in C

Computer programming in C, including input/output, selection structures, loops, iterative solutions, function definition and invocation, macros, pointers, memory allocation, and top-down design. Programming of elementary mathematical operations. Applications to engineering problems. *Prerequisite: MATH 13. Co-requisite: COEN 44L.* (4 units)

COEN 44L. Applied Programming in C Laboratory

Laboratory for COEN 44. *Co-requisite: COEN 44.* (1 unit)

COEN 45. Applied Programming in MATLAB

Computer programming in MATLAB, including input/output, selection structures, loops, iterative solutions, function definition and invocation, top-down design. Programming of elementary mathematical operations. Applications to engineering problems. *Prerequisite: MATH 13. Co-requisite: COEN 45L.* (4 units)

COEN 45L. Applied Programming in MATLAB Laboratory

Laboratory for COEN 45. *Co-requisite: COEN 45.* (1 unit)

COEN 60. Introduction to Web Technologies

Overview of the Internet and World Wide Web technologies and practices. Introduction to basic markup language, style sheet language, server-side scripting language, and website design. Emerging web applications. *Co-requisite: COEN 60L.* (4 units)

COEN 60L. Introduction to Web Technologies Laboratory

Laboratory for COEN 60. *Co-requisite: COEN 60.* (1 unit)

COEN 70. Formal Specification and Advanced Data Structures

Specification, representation, implementation, and validation of data structures; object-oriented design and programming in a strongly typed language with emphasis on reliable reusable software; formal specification of data structures (e.g. graphs, sets, bags, tables, environments, trees, expressions, graphics); informal use of specifications to guide implementation and validation of programs; guidelines and practice in designing for and with reuse. *Prerequisites: A grade of C- or better in either COEN 12 or CSCI 61 and in either COEN 19 or MATH 51. Co-requisite: COEN 70L.* (4 units)

COEN 70L. Formal Specification and Advanced Data Structures Laboratory

Laboratory for COEN 70. *Co-requisite: COEN 70.* (1 unit)

Upper-Division Undergraduate Courses

COEN 120. Real Time Systems

Overview of real-time systems: classification, design issues and description. Finite state machines and statecharts. Robot programming: odometry and the use of sensors. Real-time programming languages, real-time kernels and multi-threaded programming. Unified Modeling Language for the design of real-time applications. Performance analysis. *Prerequisite: A grade of C- or better in either COEN 12 or CSCI 61. Co-requisite: COEN 120L.* (4 units)

COEN 120L. Real Time Systems Laboratory

Laboratory for COEN 120. *Co-requisite: COEN 120.* (1 unit)

COEN 122. Computer Architecture

Overview of computer systems. Performance measurement. Instruction set architecture. Computer arithmetic. CPU datapath design. CPU control design. Pipelining. Data/control hazards. Memory hierarchies and management. Introduction of multiprocessor systems. Hardware description languages. Laboratory project consists of a design of a CPU. *Prerequisites: A grade of C- or better in either COEN 20 or ELEN 33 and in either COEN 21 or ELEN 21. Co-requisite: COEN 122L.* (4 units)

COEN 122L. Computer Architecture Laboratory

Laboratory for COEN 122. *Co-requisite: COEN 122.* (1 unit)

COEN 123. Mechatronics

Introduction to behavior, design, and integration of electromechanical components and systems. Review of appropriate electronic components/circuitry, mechanism configurations, and programming constructs. Use and integration of transducers, microcontrollers, and actuators. *Also listed as ELEN 123 and MECH 143. Prerequisites: ELEN 50 with a grade of C– or better and COEN 11 or 44. Co-requisite: COEN 123L.* (4 units)

123L. Mechatronics Laboratory

Laboratory for COEN 123. *Also listed as ELEN 123L and MECH 143L. Co-requisite: COEN 123.* (1 unit)

COEN 127. Advanced Logic Design

Contemporary design of finite-state machines as system controllers using MSI, PLDS, or FPGA devices. Minimization techniques, performance analysis, and modular system design. HDL simulation and synthesis. *Also listed as ELEN 127. Prerequisite: COEN 21. Co-requisites: COEN 127L and ELEN 115.* (4 units)

COEN 127L. Advanced Logic Design Laboratory

Also listed as ELEN 127L. Co-requisite: COEN 127. (1 unit)

COEN 129. Current Topics in Computer Science and Engineering

Subjects of current interest. May be taken more than once if topics differ. (4 units)

COEN 145. Introduction to Parallel Programming

Concept of parallelism, thread programming, thread/process synchronization, synchronization algorithms and language constructs, shared-memory versus message-passing. Parallel programming concept, performance metrics, overview of parallel architectures, evaluation of parallel algorithms, data parallel programming, shared-memory, and message-passing parallel programming. Case studies on application algorithms. Hands-on lab on multi-core CPUs and many-core GPUs. *Prerequisites: A grade of C- or better in COEN 11 and 122. Co-requisite: COEN 145L.* (4 units)

COEN 145L. Introduction to Parallel Programming Laboratory

Laboratory for COEN 145. *Co-requisite: COEN 145.* (1 unit)

COEN 146. Computer Networks

Data Communication: circuit and packet switching, latency and bandwidth, throughput/delay analysis. Application Layer: client/ server model, socket programming, Web, e-mail, FTP. Transport Layer: TCP and UDP, flow control, congestion control, sliding window techniques. Network Layer: IP and routing. Data Link Layer: shared channels, media access control protocols, error detection and correction. Mobile computing and wireless networks. Network security. Laboratory consists of projects on software development of network protocols and applications. *Prerequisite: A grade of C- or better in either COEN 12 or CSCI 61. Co-requisite: COEN 146L. Recommended co-requisite or prerequisite: AMTH 108 or MATH 122.* (4 units)

COEN 146L. Computer Networks Laboratory

Laboratory for COEN 146. *Co-requisite: COEN 146.* (1 unit)

COEN 148. Computer Graphics Systems

Interactive graphic systems. Graphics primitives, line and shape generation. Simple transforming and modeling. Efficiency analysis and modular design. Interactive input techniques. Three-dimensional transformations and viewing, hidden surface removal. Color graphics, animation, real-time display considerations. Parametric surface definition and introduction to shaded-surface algorithms. Offered in alternate years. *Prerequisite: MATH 53 ; a grade of C- or better in either COEN 12 or CSCI 61.* (4 units)

COEN 150. Introduction to Information Security

Overview of information assurance. Legal and ethical issues surrounding security and privacy. Malware and other threats. Authentication and authorization. Risk management and other related topics. *Prerequisite: Junior standing.* (4 units)

COEN 152. Introduction to Computer Forensics

Procedures for identification, preservation, and extraction of electronic evidence. Auditing and investigation of network and host system intrusions, analysis and documentation of information gathered, and preparation of expert testimonial evidence. Forensic tools and resources for system administrators and information system security officers. Ethics, law, policy, and standards concerning digital evidence. *Prerequisite: A grade of C- or better in either COEN 12 or CSCI 61 and in COEN 20. Co-requisite: COEN 152L.* (4 units)

COEN 152L. Introduction to Computer Forensics Laboratory

Laboratory for COEN 152. *Co-requisite: COEN 152.* (1 unit)

COEN 160. Object-Oriented Analysis, Design and Programming

Four important aspects of object-oriented application development are covered: fundamental concepts of the OO paradigm, building analysis and design models using UML, implementation using Java, and testing object-oriented systems. *Prerequisite: A grade of C- or better in COEN 70. Co-requisite: COEN 160L. Co-listed with COEN 275.* (4 units)

COEN 160L. Object-Oriented Analysis, Design and Programming Laboratory

Laboratory for COEN 160. *Co-requisite: COEN 160.* (1 unit)

COEN 161. Web Development

Fundamentals of World Wide Web (WWW) and the technologies that are required to develop web-based applications. Topics cover HTML5, CSS, JavaScript, PHP, MYSQL and XML. *Prerequisite: A grade of C- or better in either COEN 12 or CSCI 61. Co-requisite: COEN 161L.* (4 units)

COEN 161L. Web Development Laboratory

Laboratory for COEN 161. *Co-requisite: COEN 161.* (1 unit)

COEN 162. Web Infrastructure

History and overview of World Wide Web technology. Web protocols. Web Navigation. Web caching and load balancing. P2P, Instant Messaging, and Web Services. Web Servers, Server Farms, and Data Centers. *Prerequisite: A grade of C- or better in COEN 146.* (4 units)

COEN 163. Web Usability

Principles of user-centered design. Principles of human-computer interaction. Fundamental theories in cognition and human factors: information processing, perception and representation, constructivist and ecological theories, Gestalt laws of perceptual organization. Usability engineering: user research, user profiling, method for evaluating user interface, usability testing. Prototyping in user interface: process, methods of evaluating and testing. Inclusive design in user interface design: accessibility issues, compliance with section 508 of Rehabilitation Act. *Prerequisite: A grade of C- or better in COEN 12 or CSCI 61. Co-requisite: COEN 163L.* (4 units)

COEN 163L. Web Usability Laboratory

Laboratory for COEN 163. *Co-requisite: COEN 163.* (1 unit)

COEN 164. Advanced Web Development

Advanced topics in Web Application Development; Development with Web Frameworks (Ruby with Rails), implementing Web services and management of Web security. *Prerequisite: A grade of C- or better in COEN 161 or demonstrated knowledge of Web development technology covered in COEN 161. Co-requisite: COEN 164L.* (4 units)

COEN 164L. Advanced Web Development Laboratory

Laboratory for COEN 164. *Co-requisite: COEN 164.* (1 unit)

COEN 165. Introduction to 3D Animation & Modeling/ Modeling & Control of Rigid Body Dynamics

Mathematical and physical principles of motion of rigid bodies, including movement, acceleration, inertia and collision. Modeling of rigid body dynamics for three-dimensional graphic simulation; controlling the motion of rigid bodies in robotic applications. *Also listed as ARTS 173. Prerequisite: MATH 14, COEN 12 or CSCI 61.* (4 units)

COEN 166. Artificial Intelligence

Philosophical foundations of Artificial Intelligence, problem solving, knowledge and reasoning, neural networks and other learning methods. *Prerequisites: A grade of C- or better in either COEN 12 or CSCI 61 and in either COEN 19 or MATH 51.* (4 units)

COEN 168. Mobile Application Development

Design and implementation of applications running on a mobile platform such as smart phones and tablets. Programming languages and development tools for mobile SDKs. Writing code for peripherals—GPS, accelerometer, touchscreen. Optimizing user interface for a small screen. Effective memory management on a constrained device. Embedded graphics. Persistent data storage. *Co-requisite: COEN 168L. Prerequisite: COEN 20, COEN 70 or equivalent.* (4 units)

COEN 168L. Mobile Application Development Laboratory

Laboratory for COEN 168. *Co-requisite: COEN 168.* (1 unit)

COEN 169. Web Information Management

Theory, design, and implementation of information systems that process, organize, analyze large-scale information on the Web. Search engine technology, recommender systems, cloud computing, social network analysis. *Prerequisite: AMTH 108, MATH 122, COEN 12, CSCI 61 or instructor approval.* (4 units)

COEN 171. Principles of Design and Implementation of Programming Languages

High-level programming language concepts and constructs. Costs of use and implementation of the constructs. Issues and trade-offs in the design and implementation of programming languages. Critical look at several modern high-level programming languages. *Prerequisite: A grade C- or better in COEN 12 or CSCI 61.* (4 units)

COEN 172. Structure and Interpretation of Computer Programs

Techniques used to control complexity in the design of large software systems: design of procedural and data abstractions; design of interfaces that enable composition of well-understood program pieces; invention of new, problem-specific languages for describing a design. *Prerequisites: COEN 19 or MATH 51, COEN 70 or CSCI 61, or instructor approval.* (4 units)

COEN 172L. Structure and Interpretation of Computer Programs Laboratory

Laboratory for COEN 172. *Co-requisite: COEN 172.* (1 unit)

COEN 173. Logic Programming

Application of logic to problem solving and programming; logic as a language for specifications, programs, databases, and queries; separation of logic and control aspects of programs; bottom-up reasoning (forward from assumptions to conclusions) versus top-down reasoning (backward from goals to subgoals) applied to problem solving and programming; nondeterminism, concurrency, and invertibility in logic programs. Programs written and run in Prolog. *Prerequisites: COEN 70 or CSCI 61 and COEN 19 or MATH 51.* (4 units)

COEN 173L. Logic Programming Laboratory

Laboratory for COEN 173. *Co-requisite: COEN 173.* (1 unit)

COEN 174. Software Engineering

Software development life cycle. Project teams, documentation, and group dynamics. Software cost estimation. Requirements of engineering and design. Data modeling, object modeling, and object-oriented analysis. Object-oriented programming and design. Software testing and quality assurance. Software maintenance. *Prerequisite: A grade of C- or better in COEN 12 or CSCI 61. Co-requisite: COEN 174L.* (4 units)

COEN 174L. Software Engineering Laboratory

Laboratory for COEN 174. *Co-requisite: COEN 174.* (1 unit)

COEN 175. Introduction to Formal Language Theory and Compiler Construction

Introduction to formal language concepts: regular expressions and context-free grammars. Compiler organization and construction. Lexical analysis and implementation of scanners. Top-down and bottom-up parsing and implementation of top-down parsers. An overview of symbol table arrangement, run-time memory allocation, intermediate forms, optimization, and code generation. *Prerequisites: A grade of C- or better in COEN 20 and COEN 70. Co-requisite: COEN 175L.* (4 units)

COEN 175L. Introduction to Formal Language Theory and Compiler Construction Laboratory

Laboratory for COEN 175. *Co-requisite: COEN 175.* (1 unit)

COEN 177. Operating Systems

Introduction to operating systems. Operating system concepts, computer organization models, storage hierarchy, operating system organization, processes management, interprocess communication and synchronization, memory management and virtual memory, I/O subsystems, and file systems. Design, implementation, and performance issues. *Prerequisites: A grade of C- or better in either COEN 12 or CSCI 61 and in COEN 20. Co-requisite: COEN 177L.* (4 units)

COEN 177L. Operating Systems Laboratory

Laboratory for COEN 177. *Co-requisite: COEN 177.* (1 unit)

COEN 178. Introduction to Database Systems

ER diagrams and the relational data model. Database design techniques based on integrity constraints and normalization. Database security and index structures. SQL and DDL. Transaction processing basics. *Prerequisite: A grade of C- or better in COEN 12 or CSCI 61. Co-requisite: COEN 178L.* (4 units)

COEN 178L. Introduction to Database Systems Laboratory

Laboratory for COEN 178. *Co-requisite: COEN 178.* (1 unit)

COEN 179. Theory of Algorithms

Introduction to techniques of design and analysis of algorithms: asymptotic notations and running times of recursive algorithms; design strategies: brute-force, divide and conquer, decrease and conquer, transform and conquer, dynamic programming, greedy technique. Intractability: P and NP, approximation algorithms. *Also listed as CSCI 163. Prerequisites: A grade of C- or better in either COEN 12 or CSCI 61 and in either COEN 19 or MATH 51.* (4 units)

COEN 180. Introduction to Information Storage

Storage hierarchy. Caching. Design of memory and storage devices, with particular emphasis on magnetic disks and storage-class memories. Error detection, correction, and avoidance fundamentals. Disk arrays. Storage interfaces and buses. Network attached and distributed storage, interaction of economy and technological innovation. *Also listed as ELEN 180. Prerequisites: A grade of C- or better in either COEN 12 or CSCI 61. Recommended prerequisite: COEN 20.* (4 units)

COEN 188. Co-op Education

Integration of classroom study and practical experience in a planned program designed to give students practical work experience related to their academic field of study and career objectives. The course alternates (or parallels) periods of classroom study with periods of training in industry or government. Satisfactory completion of the work assignment includes preparation of a summary report on co-op activities. P/NP grading. May not be taken for graduate credit. (2 units)

COEN 189. Co-op Technical Report

Credit given for a technical report on a specific activity such as a design or research project, etc., after completing the co-op assignment. Approval of department advisor required. Letter grades based on content and quality of report. May be taken twice. May not be taken for graduate credit. *Prerequisite: COEN 188.* (2 units)

COEN 193. Undergraduate Research

Involves working on a year-long research project with one of the faculty members. Students should register three times in a row for a total of 6 units. Does not substitute for the senior project, which may be a continuation of the research done. Registration requires the faculty member's approval. *Prerequisites: Students must have junior or senior standing and a minimum GPA of 3.0.* (2 units)

COEN 194. Design Project I

Specification of an engineering project, selected with the mutual agreement of the student and the project advisor. Complete initial design with sufficient detail to estimate the effectiveness of the project. Initial draft of the project report. (2 units)

COEN 195. Design Project II

Continued design and construction of the project, system, or device. Initial draft of project report. *Prerequisite: COEN 194.* (2 units)

COEN 196. Design Project III

Continued design and construction of the project, system, or device. Formal public presentation of results. Final report. *Prerequisite: COEN 195.* (2 units)

COEN 199. Directed Research/Reading

Special problems. By arrangement. (1–5 units)

Graduate Courses

Some graduate courses may not apply toward certain degree programs. During the first quarter of study, students should investigate with their faculty advisors the program of study they wish to pursue.

COEN 200. Logic Analysis and Synthesis

Analysis and synthesis of combinational and sequential digital circuits with attention to static, dynamic, and essential hazards. Algorithmic techniques for logic minimization, state reductions, and state assignments. Decomposition of state machine, algorithmic state machine. Design for test concepts. *Also listed as ELEN 500. Prerequisite: COEN 127C or equivalent.* (2 units)

COEN 201. Digital Signal Processing I

Description of discrete signals and systems. Z-transform. Convolution and transfer functions. System response and stability. Fourier transform and discrete Fourier transform. Sampling theorem. Digital filtering. *Also listed as ELEN 233. Prerequisite: ELEN 210 or its undergraduate equivalent of ELEN 110.* (2 units)

COEN 201E. Digital Signal Processing I, II

Same description as COEN 201 and COEN 202 combined. Credit not allowed for both COEN 201/202 and 201E. *Also listed as ELEN 233E. (*4 units)

COEN 202. Digital Signal Processing II

Continuation of COEN 201. Digital FIR and IIR filter design and realization techniques. Multirate signal processing. Fast Fourier transform. Quantization effects. *Also listed as ELEN 234. Prerequisite: COEN 201.* (2 units)

COEN 203. VLSI Design I

Introduction to VLSI design and methodology. Analysis of CMOS integrated circuits. Circuit modeling and performance evaluation supported by simulation (SPICE). Ratioed, switch, and dynamic logic families. Design of sequential elements. Fully-custom layout using CAD tools. *Also listed as ELEN 387. Prerequisite: COEN/ELEN 127 or equivalent.* (2 units)

COEN 204. VLSI Design II

Continuation of VLSI design and methodology. Design of arithmetic circuits and memory. Comparison of semi-custom versus fully custom design. General concept of floor planning, placement and routing. Introduction of signal integrity through the interconnect wires. *Also listed as ELEN 388. Prerequisite: COEN/ELEN 387 or equivalent, or ELEN 153.* (2 units)

COEN 207. SoC (System-on-Chip) Verification

A typical SoC costs tens of millions of dollars and involves tens of engineers in various geographical locations. It also incorporates a large number of heterogeneous IP (intellectual property) cores. A single error may dictate a Fab spin of over a million dollar, and typically costs much more by delaying TTM (time-to-market). Therefore, SoC verification is a major challenge that needs to be mastered by design engineers. This course presents various state-of-the-art verification techniques used to ensure thorough testing of the SoC design. Both logical and physical verification techniques will be covered. Also, the use of simulation, emulation, assertion-based verification, and hardware/ software co-verification techniques will be discussed. *Also listed as ELEN 613. Prerequisites: COEN 200 and COEN 303 or equivalent.* (2 units)

COEN 208. SoC (System-on-Chip) Formal Verification Techniques

With continuous increase of size and complexity of SoC, informal simulation techniques are increasing design cost prohibitively and causing major delays in TTM (time-to-market). This course focuses on formal algorithmic techniques used for SoC verification and the tools that are widely used in the industry to perform these types of verifications. These include both programming languages such as System Verilog, Vera, and e-language. The course also covers the various formal verification techniques such as propositional logic; basics of temporal logic. Theorem proving, and equivalent checking. Industrial-level tools from leading EDA vendors will be used to demonstrate the capabilities of such techniques. *Also listed as ELEN 614. Prerequisites: COEN 200 and COEN 303 or equivalent.* (2 units)

COEN 210. Computer Architecture

Historical perspective. Performance analysis. Instruction set architecture. Computer arithmetic. Datapath. Control unit. Pipelining. Data and control hazards. Memory hierarchy. Cache. Virtual memory. Parallelism and multiprocessor. *Prerequisites: COEN 20 and COEN 21 or equivalent.* (4 units)

COEN 218. Input-Output Structures

I/O architecture overview. I/O programming: dedicated versus memory-mapped I/O addresses. CPU role in managing I/O: Programmed I/O versus Interrupt-Based I/O versus DMA–based I/O. I/O support hardware: interrupt controllers (priority settings, and arbitration techniques), DMA controllers and chip-sets. I/O interfaces: point to point interconnects, busses, and switches. Serial versus parallel interfaces. Synchronous versus asynchronous data transfers. System architecture considerations: cache coherency issues, I/O traffic bandwidth versus latency (requirements and tradeoffs). Error detection and correction techniques. Examples: a high bandwidth I/O device, a parallel I/O protocol, and a serial I/O protocol. *Prerequisite: COEN 210.* (2 units)

COEN 225. Secure Coding in C and C++

Writing secure code in C, C++. Vulnerabilities based on strings, pointers, dynamic memory management, integer arithmetic, formatted output, file I/O. Attack modes such as (stack and heap based) buffer overflow and format string exploits. Recommended practices. *Prerequisites: COEN 210 and experience with coding in C or C++.* (2 units)

COEN 226. Introduction to System Certification and Accreditation

Certification and accreditation of information systems' security provides an objective basis of confidence for approval to operate systems that protect the confidentiality and integrity of valuable information resources. This course provides an overview of the laws, regulations, standards, policies, and processes that govern and provide guidance for certification and accreditation of national security systems. The course introduces the National Information Assurance Certification and Accreditation Process (NIACAP), the DoD Information Technology Certification and Accreditation Process (DITSCAP), and Director of Central Intelligence Directive (DCID) 6/3 for intelligence systems. Also addressed are a variety of personnel, facility, and operational security management (SSM) considerations for such systems. *Prerequisite: COEN 150 or COEN 250. Prerequisite may be waived for students with knowledge of the basics of computer security.* (2 units)

COEN 233. Computer Networks

Fundamentals of computer networks: protocols, algorithms, and performance. Data Communication: circuit and packet switching, latency and bandwidth, throughput/delay analysis. Application Layer: client/server model, socket programming, Web, e-mail, FTP. Transport Layer: TCP and UDP, flow control, congestion control, sliding window techniques. Network Layer: IP and routing. Data Link Layer: shared channels, media access control protocols, error detection and correction. Mobile and wireless networks. Multimedia Networking. Network security. *Prerequisites: COEN 20 or equivalent and AMTH 108 or equivalent.* (4 units)

COEN 234. Network Management

Covers the fundamentals of network management. Management functions and reference models, management building blocks (information, communication patterns, protocols, and management organization), and management in practice (integration issues, service-level management). Prerequisite: COEN 233 or equivalent. (2 units) COEN 235. Client/Server Programming Client/server paradigm in the context of the Web and the Internet. Objects, components, frameworks, and architectures. Current platforms, such as J2EE, CORBA, and .NET. *Prerequisites: Knowledge of Java programming and HTML.* (4 units)

COEN 238. Multimedia Information Systems

Overview and applications of multimedia systems. Brief overview of digital media compression and processing. Operating system support for continuous media applications. System services, devices, and user interface. Multimedia file systems and information models. Presentation and authoring. Multimedia over network. Multimedia communications systems and digital rights management. Knowledge-based multimedia systems. MPEG-7. MPEG-21. *Prerequisites: AMTH 377 and COEN 177 or 283.* (2 units)

COEN 239. Network Design Analysis

Focus on current modeling and analysis of computer networks. Graph theory for networks, queuing theory, simulation methodology, principles and tools for network design, protocol definition, implementation, validation and evaluation. *Prerequisite: COEN 233 or equivalent.* (4 units)

COEN 240. Machine Learning

This course presents an introduction to machine learning, the study of computing systems that improve their performance with experience, including discussions of each of the major approaches. The primary focus of the course will be on understanding the underlying theory and algorithms used in various learning systems. *Prerequisite: AMTH 108 or AMTH 210, MATH 53 or AMTH 246, COEN 179 or 279.* (4 units)

COEN 241. Cloud Computing

Introduction to cloud computing, cloud architecture and service models, the economics of cloud computing, cluster/grid computing, virtualization, big data, distributed file system, MapReduce paradigm, NoSQL, Hadoop, horizontal/vertical scaling, thin client, disaster recovery, free cloud services and open source software, example commercial cloud services, and federation/presence/identity /privacy in cloud computing. *Prerequisites: COEN 12 and COEN 146 or 233.* (4 units)

COEN 242. Big Data

Introduction to Big data. NoSQL data modeling. Large-scale data processing platforms. HDFS, MapReduce and Hadoop. Scalable algorithms used to extract knowledge from Big data. Advanced scalable data analytics platforms. *Prerequisites: AMTH 108 or AMTH 210 and COEN 178 or 280.* (4 units)

COEN 243. Internet of Things

Design principles of the Internet of Things (IoT) and their device and infrastructure-related architectures. Technologies and protocol frameworks aimed at enabling the formation of highly distributed networks with seamlessly connected heterogeneous smart devices. Machine-to-Machine (M2M) communication protocols for smart low power objects such as 6LoWPAN and Constrained Application Protocol (CoAP). Technologies and protocols at the service and application layers, which enable the integration of embedded devices in web-based, distributed applications. *Prerequisites: COEN 12 and COEN 146 or 233.* (4 units)

COEN 250. Information Security Management

Techniques and technologies of information and data security. Managerial aspects of computer security and risk management. Security services. Legal and ethical issues. Security processes, best practices, accreditation, and procurement. Security policy and plan development and enforcement. Contingency, continuity, and disaster recovery planning. Preparation for design and administration of a complete, consistent, correct, and adequate security program. Can be taken in place of MSIS 2625. (2 units)

COEN 252. Computer Forensics

Procedures for identification, preservation, and extraction of electronic evidence. Auditing and investigation of network and host system intrusions, analysis and documentation of information gathered, and preparation of expert testimonial evidence. Forensic tools and resources for system administrators and information system security officers. Ethics, law, policy, and standards concerning digital evidence. *Prerequisite: COEN 20 or equivalent. Co-requisite: COEN 252L.* (4 units)

COEN 252L. Laboratory for COEN 252

Co-requisite: COEN 252. (1 unit)

COEN 253. Secure Systems Development and Evaluation

Software engineering for secure systems. Security models and implementations. Formal methods for specifying and analyzing security policies and system requirements. Development of secure systems, including design, implementation, and other life-cycle activities. Verification of security properties. Resource access control, information flow control, and techniques for analyzing simple protocols. Evaluation criteria, including the Orange and Red books and the Common Criteria, technical security evaluation steps, management, and the certification process. *Prerequisite: COEN 250.* (2 units)

COEN 254. Secure Systems Development and Evaluation II

Formal methods for specifying security policies and systems requirements and verification of security properties. A hands-on course in methods for high-assurance using systems such as PVS from SRI, and the NRL Protocol Analyzer. *Prerequisite: COEN 253 (may be taken concurrently).* (2 units)

COEN 256. Principles of Programming Languages

Some history and comparison of languages. Regular expressions; abstract and concrete syntax; formal grammars and post systems; Peano, structural, and well-founded induction. Algebraic semantics and term rewriting; program specification and verification. Unification and logic programming; lambda calculus, combinators, polymorphism; denotational semantics. *Prerequisites: COEN 70 and AMTH 240.* (4 units)

COEN 259. Compilers

Principles and practice of the design and implementation of a compiler, focusing on the application of theory and trade-offs in design. Lexical and syntactic analysis. Semantic analysis, symbol tables, and type checking. Run-time organization. Code generation. Optimization and data-flow analysis. *Prerequisite: COEN 256 or COEN 283 or COEN 210.* (4 units)

COEN 260. Truth, Deduction, and Computation

Introduction to mathematical logic and semantics of languages for the computer scientist. Investigation of the relationships among what is true, what can be proved, and what can be computed in formal languages for propositional logic, first order predicate logic, elementary number theory, and the type-free and typed lambda calculus. *Prerequisites: COEN 19 or AMTH 240 and COEN 70.* (4 units)

COEN 261. Structure and Interpretation of Computer Programs

Programming in a modern, high-level, functional programming language (i.e., one with functions, or procedures, as first-class objects and facilities for abstract data types). Techniques used to control complexity in the design of large software systems. Design of procedural and data abstractions; design of interfaces that enable composition of well-understood program pieces; invention of new, problem-specific languages for describing a design. *Prerequisites: COEN 19 or AMTH 240 and COEN 70.* (2 units)

COEN 266. Artificial Intelligence

Artificial intelligence viewed as knowledge engineering. Historical perspective. Problems of representation: AI as a problem in language definition and implementation. Introduces representations, techniques, and architectures used to build applied systems and to account for intelligence from a computational point of view. Applications of rule chaining, heuristic search, constraint propagation, constrained search, inheritance, and other problem-solving paradigms. Applications of identification trees, neural nets, genetic algorithms, and other learning paradigms. Speculations on the contributions of human vision and language systems to human intelligence. *Prerequisite: AMTH 240.* (4 units)

COEN 268. Mobile Application Development

Design and implementation of applications running on a mobile platform such as smart phones and tablets. Programming languages and development tools for mobile SDKs. Writing code for peripherals—GPS, accelerometer, touchscreen. Optimizing user interface for a small screen. Effective memory management on a constrained device. Embedded graphics. Persistent data storage. *Prerequisite: COEN 20 or COEN 70 or equivalent.* (4 units)

COEN 271. Automata, Computability, and Complexity

Regular and context-free languages (deterministic, non-deterministic, and pushdown automata). Decidable and undecidable problems, reducibility, recursive function theory. Time and space measures on computation, completeness, hierarchy theorems, inherently complex problems, probabilistic and quantum computation. *Prerequisites: AMTH 240 or equivalent and COEN 179.* (4 units)

COEN 272. Web Search and Information Retrieval

Basic and advanced techniques for organizing large-scale information on the Web. Search engine technologies. Big data analytics. Recommendation systems. Text/Web clustering and classification. Text mining. *Prerequisites: AMTH 108 or AMTH 210, MATH 53 or AMTH 246, and COEN 179 or 279.* (4 units)

COEN 275. Object-Oriented Analysis, Design, and Programming

Four important aspects of object-oriented application development are covered: fundamental concepts of the OO paradigm, building analysis and design models using UML, implementation using Java, and testing object-oriented systems. *Prerequisite: COEN 70.* (4 units)

COEN 277. Graphical User Interface Design and Programming

Core concepts in user interface design, task analysis, principles of good UI design, UI interaction styles, building prototypes and evaluating user interfaces, software architectures for graphical user interfaces. *Prerequisite: COEN 276 or familiarity with a scripting language.* (2 units)

COEN 278. Advanced Web Programming

Advanced topics in Web Application Development; Development with Web Frameworks (Ruby with Rails), implement Web services and management of Web security. *Prerequisites: COEN 60 and 161 or demonstrated proficiency.* (4 units)

COEN 279. Design and Analysis of Algorithms

Techniques of design and analysis of algorithms: proof of correctness; running times of recursive algorithms; design strategies: brute-force, divide and conquer, dynamic programming, branch-and-bound, backtracking, and greedy technique; max flow/matching. Intractability: lower bounds; P, NP, and NP-completeness. *Also listed as AMTH 377. Prerequisite: COEN 12 or equivalent.* (4 units)

COEN 280. Database Systems

Data models. Relational databases. Database design (normalization and decomposition). Data definition and manipulation languages (relational algebra and calculus). Architecture of database management systems. Transaction management. Concurrency control. Security, distribution, and query optimization. *Prerequisites: COEN 12 or Data Structures class and COEN 283 or equivalent.* (4 units)

COEN 281. Pattern Recognition and Data Mining

How does an online retailer decide which product to recommend to you based on your previous purchases? How do bio-scientists decide how many different types of a disease are out there? How do computers rank Web pages in response to a user query? In this course we introduce some of the computational methods currently used to answer these and other similar questions. Topics included are association rules, clustering, data visualization, logistic regression, neural networks, decision trees, ensemble methods, and text mining. *Prerequisites: AMTH 210 and 245 or equivalent, COEN 12 or equivalent.* (4 units)

COEN 282. Energy Management Systems

Energy Management Systems (EMS) is a class of control systems that Electric Utility Companies utilize for three main purposes: Monitoring, Engagement and Reporting. Monitoring tools allow Electric Utility Companies to manage their assets to maintain the sustainability and reliability of power generation and delivery. Engagement tools help in reducing energy production costs, transmissions and distribution losses by optimizing utilization of resources and/or power network elements. The reporting tools help tracking operational costs and energy obligations. *Also listed as ELEN 288.* (2 units)

COEN 283. Operating Systems

Fundamentals of operating systems. Processes, Memory, I/O, and File Systems. Implementation and performance issues. Security, Multimedia Systems, Multiple-processor Systems. *Prerequisites: COEN 12 and 20 or equivalent.* (4 units)

COEN 284. Operating Systems Case Study

Case study of a large multiuser operating system: implementation of different operating system components. Operating system for network and distributed processing systems: naming, resource allocation, synchronization, fault detection and recovery, deadlock. *Prerequisite: COEN 283 or equivalent.* (2 units)

COEN 285. Software Engineering

Systematic approaches to software design, project management, implementation, documentation, and maintenance. Software design methodologies: SA/SD, OOA/OOD. Software quality assurance; testing. Reverse engineering and re-engineering. CASE. Term project. (4 units)

COEN 286. Software Quality Assurance and Testing

Social factors. Configuration management. Software complexity measures. Functional and structuring testing. Test coverage. Mutation testing. Trend analysis. Software reliability. Estimating software quality. Testing OOPs. Confidence in the software. Software quality control and process analysis. Managerial aspects. *Prerequisite: COEN 285.* (2 units)

COEN 287. Software Development Process Management

Management of the software development process at both the project and organization levels. Interrelationship of the individual steps of the development process. Management techniques for costing, scheduling, tracking, and adjustment. *Prerequisite: COEN 285.* (2 units)

COEN 288. Software Ethics

Broad coverage of ethical issues related to software development. Formal inquiry into normative reasoning in a professional context. Application of ethical theories to workplace issues, viz., cost-benefit analysis, externalities, individual and corporate responsibility, quality and authorship of product. Case studies and in-class topics of debate include computer privacy, encryption, intellectual property, software patents and copyrights, hackers and break-ins, freedom of speech and the Internet, error-free code, and liability. (2 units)

COEN 290. Computer Graphics

Raster and vector graphics image generation and representation. Graphics primitives, line and shape generation. Scan conversion anti-aliasing algorithms. Simple transformation, windowing and hierarchical modeling. Interactive input techniques. 3D transformations and viewing, hidden surface removal. Introduction to surface definition with B-spline and Bezier techniques. Surface display with color graphics. *Prerequisites: AMTH 245 and COEN 12.* (4 units)

COEN 296. Topics in Computer Science and Engineering

Various subjects of current interest. May be taken more than once if topics differ. (2–4 units)

COEN 301. High-Level Synthesis

Synthesis strategy. Hardware description language and its applications in synthesis. Cost elimination. Multilevel logic synthesis and optimization. Synthesis methods and systems. Module generation. Timing considerations. Area vs. speed tradeoffs. Design simulation and verification. Heuristic techniques. CAD tools. *Also listed as ELEN 605. Prerequisites: COEN 303 and COEN 200 or 209.* (2 units)

COEN 303. Logic Design Using HDL

Algorithmic approach to design of digital systems. Use of hardware description languages for design specification. Different views of HDL structural, register transfer, and behavioral. Simulation and synthesis of systems descriptions. *Also listed as ELEN 603. Prerequisite: COEN 127 or equivalent.* (2 units)

COEN 304. Semicustom Design with Programmable Devices

Digital circuit design methodologies. Semi-custom implementations. Programmable logic devices classification, technology, and utilization. Software tools synthesis, placement, and routing. Design verification and testing. *Also listed as ELEN 604. Prerequisite: COEN 200 or 209.* (2 units)

COEN 305. VLSI Physical Design

Physical design is the phase that follows logic design, and it includes the following steps that precede the fabrication of the IC logic partitioning: cell layout, floor planning, placement, routing. These steps are examined in the context of very deep submicron technology. Effect of parasitic devices and packaging are also considered. Power distribution and thermal effects are essential issues in this design phase. *Also listed as ELEN 389. Prerequisites: COEN 204/ELEN 388 or equivalent.* (2 units)

COEN 307. Digital Computer Arithmetic

Fixed-point and floating-point number representation and arithmetic. High-speed addition and subtraction algorithms and architectures. Multiplication and division algorithms and architectures. Decimal arithmetic. Serial vs. parallel arithmetic circuits. Residue number arithmetic. Advanced arithmetic processing units. High-speed number crunchers. Arithmetic codes for error detection. VLSI perspective and reliability issues. Signed- digit (SD) representation of signed numbers. *Prerequisite: COEN 210.* (2 units)

COEN 308. Design for Testability

Principles and techniques of designing circuits for testability. Concept of fault models. The need for test development. Testability measures. Ad hoc rules to facilitate testing. Easily testable structures, PLAs. Scan-path techniques, full and partial scan. Built-in self-testing (BIST) techniques. Self-checking circuits. Use of computer-aided design (CAD) tools. *Also listed as ELEN 608. Prerequisite: COEN 200 or equivalent.* (2 units)

COEN 310. Digital Testing with ATE

Identification of design-, manufacturing-, and packaging-induced faults. Static and dynamic electrical tests under normal and stressed conditions. Architecture of different automatic test equipment (ATE) and their corresponding test programming software environments. Test-result logging for statistical process control. *Also listed as ELEN 610. Prerequisites: COEN 200 or 209 and ELEN 250.* (2 units)

COEN 313. Advanced Computer Architecture

Advanced system architectures. Overview of different computer architecture paradigms. Hardware-supported instruction level parallelism, VLIW architectures, multithreaded processors. Performance and correctness issues (coherency, consistency, and synchronization) for different multiprocessor configuration alternatives (UMA, NUMA). SIMD architecture alternatives. Warehouse massive-scale computing. *Prerequisite: COEN 210.* (4 units)

COEN 315. Web Architecture and Protocols

History and overview of World Wide Web technology. Web clients and browsers. State management, session persistence, and cookies. Spiders, bots, and search engines. Web proxies. Web servers and server farms. HTTP and Web protocols. Web caching and content distribution. Load balancing. Web security and firewalls. Web workload and traffic characterization. Future of Web technology. *Prerequisite: COEN 233 or equivalent.* (4 units)

COEN 317. Distributed Systems

Fundamental algorithms for distributed system architectures, inter-process communications, data consistency and replication, distributed transactions and concurrency control, distributed file systems, network transparency, fault tolerant distributed systems synchronization, reliability. *Prerequisites: COEN 233 and 283 or equivalent.* (4 units)

COEN 318. Parallel Computation Systems

Introduction to parallel processing. Parallel system classifications. Parallel computation models and algorithms. Performance analysis and modeling. Interconnection networks. Vector processors. SIMD and MIMD architectures and their hybrid. Systolic arrays. Dataflow architectures. Introduction to parallel languages and parallelizing compilers. *Prerequisites: COEN 210 and AMTH 247 or instructor approval.* (4 units)

COEN 319. Parallel Programming

Concept of concurrency, thread programming, thread/process synchronization, synchronization algorithms and language constructs, shared-memory vs. message-passing. Parallel programming concept, performance metrics, overview of multiprocessor architectures, evaluation of parallel algorithms, data parallel programming, shared-memory and message-passing parallel programming. Case studies on application algorithms. Hands-on lab on multi-core CPUs and many-core GPUs. Case studies of typical problem solutions and algorithms of parallel systems. *Prerequisites: COEN 11 and COEN 210.* (4 units)

COEN 320. Computer Performance Evaluation

Measurement, simulation, and analytic determination of computer systems performance. Workload characterization. Bottleneck analysis tuning. *Prerequisites: COEN 210 and AMTH 211.* (4 units)

COEN 329. Network Technology

Advanced technologies and protocols for broadband LAN, MAN, WAN, L2 VPN, and L3 VPN. Current technologies: tunneling, QoS and security in content delivery, optical networks, support for multimedia communication. Emerging technologies, e.g., Carrier Ethernet. *Prerequisite: COEN 233 or equivalent.* (4 units)

COEN 331. Wireless and Mobile Networks

Coverage of the physical layer: transmission, modulation, and error correction techniques. Spread spectrum schemes including FHSS and DSSS. Satellite and cellular networks. Medium access control in wireless networks: FDMA, TDMA and CDMA; mobile IP; 802.11 wireless LANS; ad hoc networks. Emerging technologies. *Prerequisite: COEN 233 or equivalent.* (4 units)

COEN 332. Wireless/Mobile Multimedia Networks

This course will cover IMS (Internet Protocol Multimedia Subsystem), an architectural framework for providing IP-based real-time traffic, such as voice and video, in wireless networks. IMS aims at the convergence of data, speech, fixed, and mobile networks and provides real-time services on top of the UMTS (Universal Mobile Telecommunication System) packet-switched domain. *Prerequisite: COEN 331.* (4 units)

COEN 335. High-Performance Networking

High-speed networks requirements, i.e., quality of service (QoS). Technologies and protocols for high-speed LAN, MAN, WAN, Layer 2 and Layer 3 switching, giga-bit Ethernet (1GE, 10GE), Q.931 signaling, fibre channel, Ethernet over SONET/ SDH, PoS, fiber optics communications, DWDM, and CWDM. Terabit routers. Emerging technologies: 40GE, 100GE. *Prerequisite: COEN 233 or equivalent.* (2 units)

COEN 337. Internet Architecture and Protocols

In-depth and quantitative study of Internet algorithms, protocols, and services. Topics include: scheduling and buffer/ queue management, flow/congestion control, routing, traffic management, support for multimedia/real-time communication. *Prerequisite: COEN 233 or equivalent.* (4 units)

COEN 338. Image and Video Compression

Image and video compression. Entropy coding. Prediction. Quantization. Transform coding and 2-D discrete cosine transform. Color compression. Motion estimation and compensation. Digital video. Image coding standards such as JPEG. Video coding standards such as the MPEG series and the H.26x series. H.264/ MPEG-4 AVC coding. JCT-VC HEVC coding. Rate-distortion theory and optimization. Visual quality and coding efficiency. Brief introduction to 3D video coding and JCT-3V 3D-HEVC. Applications. *Also listed as ELEN 641. Prerequisites: AMTH 108, AMTH 245 and basic knowledge of algorithms.* (4 units)

COEN 339. Audio and Speech Compression

Audio and speech compression. Digital audio signal processing fundamentals. Non-perceptual coding. Perceptual coding. Psychoacoustic model. High-quality audio coding. Parametric and structured audio coding. Audio coding standards. Scalable audio coding. Speech coding. Speech coding standards. *Also listed as ELEN 639. Prerequisites: AMTH 108, AMTH 245 and COEN 279 or equivalent.* (2 units)

COEN 340. Digital Image Processing I

Digital image representation and acquisition; Fourier, Cosine, Walsh, and wavelet transforms; linear and nonlinear filtering; image enhancement; morphological filtering. *Also listed as ELEN 640. Prerequisite: COEN 202.* (2 units)

COEN 341. Information Theory

Introduction to the fundamental concepts of information theory. Source models. Source coding. Discrete channel without memory. Continuous channel. Alternate years. *Also listed as ELEN 244. Prerequisites: ELEN 241 and AMTH 211.* (2 units)

COEN 343. Digital Image Processing II

Image restoration using least squares methods in image and spatial frequency domain; matrix representations; blind deconvolution; reconstructions from incomplete data; image segmentation methods. *Also listed as ELEN 643. Prerequisite: COEN 340.* (2 units)

COEN 344. Computer Vision I

Introduction to image understanding, psychology of vision, sensor models feature extraction, shape from shading, stereo vision, motion detection and optical flow. *Also listed as ELEN 644. Prerequisite: ELEN 233 or 640.* (2 units)

COEN 345. Computer Vision II

Texture, segmentation, region growing. 2-D geometrical structures and 3-D inference. Syntatic models, object matching, and decision trees. *Also listed as ELEN 645. Prerequisites: COEN 344 and AMTH 211.* (2 units)

COEN 347. Advanced Techniques in Video Coding

Advanced topics in image and video coding. Wavelet transform and compression. Sparse coding. Current and likely future standards such as JPEG 2000, JPEG XT, JPEG PLENO, and HEVC extensions such as SHVC, MV-HEVC, 3D-HEVC, and SCC. Scalable video coding. Multiview and 3D video coding. Screen content coding. High dynamic range. Light-field, point-cloud, and holographic imaging. Distributed video coding. Video communications systems. Congestion control. Rate control. Error control. Transcoding. Other advanced topics. *Prerequisite: COEN 338 or ELEN 641.* (4 units)

COEN 348. Speech Coding I

Review of sampling and quantization. Introduction to digital speech processing. Elementary principles and applications of speech analysis, synthesis, and coding. Speech signal analysis and modeling. The LPC Model. LPC Parameter quantization using Line Spectrum Pairs (LSPs). Digital coding techniques: Quantization, Waveform coding. Predictive coding, Transform coding, Hybrid coding, and Sub-band coding. Applications of speech coding in various systems. Standards for speech and audio coding. *Also listed as ELEN 421. Prerequisite: ELEN 334 or equivalent.* (2 units)

COEN 349. Speech Coding II

Advanced aspects of speech analysis and coding. Analysis-by-Synthesis (AbS) coding of speech, Analysis-as-Synthesis (AaS) coding of speech. Code-excited linear speech coding. Error-control in speech transmission. Application of coders in various systems (such as wireless phones). International standards for speech (and audio) coding. Real-time DSP implementation of speech coders. Research project on speech coding. Introduction to speech recognition. *Also listed as ELEN 422. Prerequisite: ELEN 421.* (2 units)

COEN 350. Network Security

Protocols and standards for network security. Network-based attacks. Authentication, integrity, privacy, non-repudiation. Protocols: Kerberos, Public Key Infrastructure, IPSec, SSH, PGP, secure e-mail standards, etc. Wireless security. Programming required. *Prerequisite: COEN 250 or instructor approval.* (2 units)

COEN 351. Internet and E-Commerce Security

Special security requirements of the Internet. Secure electronic business transactions. E-mail security. CGI scripts, cookies, and certified code. Intrusion prevention strategies. Designing secure e-commerce systems. Agent technologies. Legal requirements for E-Commerce. *Prerequisite: COEN 253. Co-requisite: COEN 351L.* (3 units)

COEN 351L. Laboratory for COEN 351

Co-requisite: COEN 351. (1 unit)

COEN 352. Advanced Topics in Information Assurance

Topics may include advanced cryptology, advanced computer forensics, secure business transaction models, or other advanced topics in information assurance. May be repeated for credit if topics differ. *Prerequisites: AMTH 387 and COEN 250.* (2 units)

COEN 358. Introduction to Parallelizing Compilers

Introduction to parallelizing compiler techniques. Automatic restructuring. Loop transformation. Dependence analysis. Vectorization. Partitioning and scheduling. Data alignment. Data distribution. Algorithm mapping. Parallel code generation. *Prerequisite: COEN 318 or instructor approval.* (4 units)

COEN 359. Design Patterns

Software design patterns and their application in developing reusable software components. Creational, structural, and behavioral patterns are studied in detail and are used in developing a software project. *Prerequisite: COEN 275.* (4 units)

COEN 362. Logic Programming

Application of logic to problem solving and programming; logic as a language for specifications, programs, databases, and queries; separation of the logic and control aspects of programs; bottom-up vs. top-down reasoning applied to problem solving and programming; nondeterminism, concurrency, and invertibility in logic programs. Programs written in Prolog. *Prerequisite: COEN 70 or equivalent.* (2 units)

COEN 376. Expert Systems

Overview of tools and applications of expert systems, as well as the theoretical issues: What is knowledge, can it be articulated, and can we represent it? Stages in the construction of expert systems: problem selection, knowledge acquisition, development of knowledge bases, choice of reasoning methods, life cycle of expert systems. Basic knowledge of representation techniques (rules, frames, objects) and reasoning methods (forward-chaining, backward-chaining, heuristic classification, constraint reasoning, and related search techniques). Requires completion of an expert systems project. *Prerequisite: COEN 366.* (4 units)

COEN 379. Advanced Design and Analysis of Algorithms

Amortized and probabilistic analysis of algorithms and data structures: disjoint sets, hashing, search trees, suffix arrays and trees. Randomized, parallel, and approximation algorithms. *Also listed as AMTH 379. Prerequisite: AMTH 377/COEN 279.* (4 units)

COEN 380. Advanced Database Systems

Database system design and implementation. Disk and file organization. Storage and indexes; query processing and query optimization. Concurrency control; transaction management; system failures and recovery. Parallel and distributed databases. MapReduce. *Prerequisite: COEN 280 or equivalent.* (4 units)

COEN 385. Formal Methods in Software Engineering

Specification, verification, validation. Notations and the models they support. Classes of specification models: algebraic, state machine, model theoretic. Appropriate use of formal methods: requirements, design, implementation, testing, maintenance. Data and program specification and design using Z or any other modern formal method. Case studies. *Prerequisites: COEN 260 or other courses including predicate logic and lambda calculus.* (2 units)

COEN 386. Software Architecture

Understanding and evaluating software systems from an architectural perspective. Classification, analysis, tools, and domain-specific architectures. Provides intellectual building blocks for designing new systems using well-understood architectural paradigms. Examples of actual system architectures that can serve as models for new designs. *Prerequisite: COEN 385.* (2 units)

COEN 389. Energy-Efficient Computing

This course covers energy-efficient software practices. Historically, software has always been written to run faster and faster, and energy has always been considered a plentiful resource. However, it has been shown that computers use a lot of energy, which may not always be so plentiful, leading to the redesign of traditional software solutions in different areas. The focus of the course will be on operating systems, networks, compilers, and programming. *Prerequisites: COEN 233 or equivalent and COEN 283 or equivalent.* (2 units)

COEN 396. Advanced Topics in Computer Science and Engineering

Various subjects of current interest. May be taken more than once if topics differ. See department Web site for current offerings and descriptions. (2–4 units)

COEN 397. Research Seminar in Digital Systems

Advanced topics in digital systems design and test. Themes vary yearly (e.g., memory devices, effect of GaAs on performance and reliability, missing technologies, etc.). Students are expected to investigate current research and practices, and give oral presentations. *Also listed as ELEN 697. Prerequisite: Instructor approval.* (2 units)

COEN 400. Computer Engineering Graduate Seminars

Regularly scheduled seminars on topics of current interest in the field of computer engineering. May apply a maximum of 1 unit of credit from COEN 400 to any graduate degree in the Department of Computer Engineering. Consult department office for additional information. *Prerequisites: GPA of 3.5 or better and completion of 12 or more units at SCU. P/NP grading.* (1–2 units)

COEN 485. Software Engineering Capstone

A capstone course in which the student applies software engineering concepts and skills to a software engineering project. Team projects are strongly encouraged. Projects will cover all aspects of the software life-cycle: specification of requirements and functionality; project planning and scoping; system and user interface definition; analysis of architectural solutions; detailed system design; implementation and integration; testing and quality assurance; reliability, usability, and performance testing, documentation, evolution, and change management. Students enrolled in the MSSE program must complete three one-quarter (preferably consecutive) sections. *Prerequisites: COEN 286 and COEN 386.* (2 units)

COEN 490. Mathematical Reasoning in Computer Science

(Seminar Style) Short introduction to the praxis of mathematical proofs. Students will write and present proofs and papers on instructor-approved topics related to Computer science and engineering. Stress is on mathematical exactness. Maximum enrollment of 10. Enrollment is by preference to Ph.D. students, but is open to other students as space allows. *Prerequisite: Open to Ph.D. students or with instructor approval.* (2 units)

COEN 493. Directed Research

Special research directed by a faculty member. By arrangement. *Prerequisite: Registration requires the faculty member's approval.* (1–6 units per quarter)

COEN 497. Master's Thesis Research

By arrangement. Limited to master's students in computer engineering. (1–9 units per quarter, for a total of at least 8 units)

COEN 498. Ph.D. Thesis Research

By arrangement. Limited to Ph.D. students in computer engineering. (1–15 units per quarter, for a total of 36 units)

COEN 499. Independent Study

Special problems. By arrangement. Limited to computer engineering majors. (1–6 units per quarter)

COEN 912C. Abstract Data Types and Data Structures

Intense coverage of topics related to abstract data types and data structures. Data abstraction: abstract data types, information hiding, interface specification. Basic data structures: stacks, queues, lists, binary trees, hashing, tables, graphs; implementation of abstract data types in the C language. Internal sorting: review of selection, insertion, and exchange sorts; quicksort, heapsort; recursion. Analysis of run-time behavior of algorithms; Big-O notation. Introduction to classes in C++. Not for graduate credit. *Prerequisite: A grade of B or higher in a programming language course.* (2 units)

COEN 920C. Embedded Systems and Assembly Language

Intense coverage of topics related to embedded systems and assembly language. Introduction to computer organization: CPU, registers, buses, memory, I/O interfaces. Number systems: arithmetic and information representation. Assembly language programming: addressing techniques, arithmetic and logic operations, branching and looping, stack operations, procedure calls, parameter passing, and interrupts. C language programming: pointers, memory management, stack frames, interrupt processing. Not for graduate credit. *Prerequisite: A grade of B or higher in a programming language course.* (2 units)

COEN 921C. Logic Design

Intense coverage of topics related to logic design. Boolean functions and their minimization. Designing combinational circuits, adders, multipliers, multiplexers, decoders. Noise margin, propagation delay. Bussing. Memory elements: latches and flip-flops; timing; registers; counters. Programmable logic, PLD, and FPGA. Use of industry quality CAD tools for schematic capture and HDL in conjunction with FPGAs. Not for graduate credit. *Also listed as ELEN 921C.* (2 units)

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Department of Electrical Engineering

Professor Emeritus: Dragoslav D. Siljak
William & Janice Terry Professor: Samiha Mourad
Thomas J. Bannan Professor: Sally L. Wood
Professors: Shoba Krishnan *(Chair)*, Timothy J. Healy, Tokunbo Ogunfunmi, Cary Y. Yang, Aleksandar Zecevic
Assistant Professor: Maryam Khanbaghi
RT Lecturer: Ramesh Abhari

OVERVIEW

The field of electrical engineering covers the design, construction, testing, and operation of electrical components, circuits, and systems. Electrical engineers work with information representation and transmission; advancing integrated circuit design for digital, analog, and mixed systems; new devices and architectures, energy systems and renewable energy; nanotechnology; and all the areas of information circuits and systems that have traditionally supported these efforts. This includes all phases of the digital or analog transmission of information, such as in mobile communications and networks, radio, television, telephone systems, fiber optics, and satellite communications, as well as control and robotics, electric power, information processing, and storage.

The Electrical Engineering Program is supported by the facilities of the University's Academic Computing Center, as well as by the School of Engineering Design Center, which is described in the Facilities section of this bulletin. The department supports 10 major teaching and research laboratories, three additional laboratories used only for teaching, and a laboratory dedicated to the support of senior design projects. The three teaching laboratories cover the fields of electric circuits, electronic circuits, and logic design.

MASTER'S DEGREE PROGRAM AND REQUIREMENTS

The master's degree will be granted to degree candidates who complete a program of studies approved by a faculty advisor. The degree does not require a thesis, but students may include a thesis in their program with up to nine units for their thesis work. The program must include no less than 45 units. In addition, a 3.0 GPA (B average) must be earned in all coursework taken at Santa Clara. Residence requirements of the University are met by completing 36 units of the graduate program at Santa Clara. A maximum of nine quarter units (six semester units) of graduate level coursework may be transferred from other accredited institutions at the discretion of the student's advisor. All units applied toward the degree, including those transferred from other institutions, must be earned within a six-year period.

Students must develop a program of studies with an academic advisor and file the program during their first term of enrollment at Santa Clara. The program of studies must contain a minimum of 31 electrical engineering units and a minimum total of 45 units of graduate-level engineering courses. The number of engineering management courses accepted is restricted to four units.

The program of studies must include the following:

General Core

1. Graduate Core (minimum 6 units) See descriptions in Chapter 4, Academic Information
2. Applied Mathematics (4 units)
3. Electrical Engineering Core – focus area (6 units). Students must select and meet the requirements of one of the three primary focus areas (Systems, Electronics, or Microwave and Communication)
   - ***Systems:*** Choose two courses from ELEN 211, 236, BIOE 251. Choose one course from ELEN 233, 233E, or BIOE 250.
   - ***Electronics:*** Choose one course from each of these three groups: ELEN 252 or 387, ELEN 261 or 264, ELEN 500 or 603.
   - ***Communications and Microwave:*** ELEN 201, 241, 701
4. Electrical Engineering Core – breadth: (4 units) One course must be taken from each of the two areas not selected as the primary focus area. These courses may be selected from the focus area core lists above or, with the approval of the graduate program advisor, from an extended list included in the program of studies form.

Additional graduate courses recommended and approved by the graduate program advisor. Up to 15 units of electives may be selected from the following upper-division undergraduate courses: 112, 118, 127, 130, 133, 160 (Systems); 116, 117, 152, 153, 156, 164 (Electronics); 105, 141, 144 (Communication and Microwave).

These M.S. degree requirements may be adjusted by the advisor based on the student's previous graduate work. Alterations in the approved program, consistent with the above departmental requirements, may be requested at any time by a petition initiated by the student and approved by the advisor.

Students with relevant technical backgrounds may be admitted to the MSEE program without a BSEE from an accredited program. In order to guarantee prerequisites for graduate courses, those students must take sufficient additional courses beyond the 45-unit minimum to ensure coverage of all areas of the undergraduate EE core requirements. A student who has earned a Fundamentals of Electrical Engineering Certificate will have satisfied these background requirements.

Undergraduate Core Courses:

- ELEN 21 Introduction to Logic Design
- ELEN 33 Introduction to Digital Systems Architectures
- ELEN 50 Electric Circuits I
- ELEN 100 Electric Circuits II
- ELEN 104 Electromagnetics I

- ELEN 110 Linear Systems
- ELEN 115 Electronic Circuits I

The advisor will determine which courses must be taken to meet these requirements. Undergraduate core courses will not be included in the 45 units required for the MSEE.

Please Note: In general, no credit will be allowed for courses that duplicate prior coursework, including courses listed above as degree requirements. (However, a graduate-level treatment of a topic is more advanced than an undergraduate course with a similar title.) Students should discuss any adjustments of these requirements with their academic advisor before they file their program of studies. In all cases, prerequisite requirements should be interpreted to mean the course specified or an equivalent course taken elsewhere.

ENGINEER'S DEGREE PROGRAM AND REQUIREMENTS

The program leading to the engineer's degree is particularly designed for the education of the practicing engineer. The degree is granted on completion of an approved academic program and a record of acceptable technical achievement in the candidate's field of engineering. The academic program consists of a minimum of 45 quarter units beyond the master's degree. Courses are selected to advance competence in specific areas relating to the engineering professional's work. Evidence of technical achievement must include a paper principally written by the candidate and accepted for publication by a recognized engineering journal prior to the granting of the degree. A letter from the journal accepting the paper must be submitted to the Office of the Dean, School of Engineering. In certain cases, the department may accept publication in the peer-reviewed proceedings of an appropriate national or international conference.

Electrical engineering courses at the introductory master of science level (e.g., ELEN 210, 211, 212, 230, 231, 236, 241, 250, 261; and AMTH 210, 211, 220, 221, 230, 231, 235, 236, 240, 245, 246) are not generally acceptable in an engineer's degree program of studies. However, with the approval of the advisor, the student may include up to three of these courses in the engineer's degree program. The department also requires that at least 15 units of the program of studies be in topics other than the student's major field of concentration. Candidates admitted to the Electrical Engineering Program who have M.S. degrees in fields other than electrical engineering must include in their graduate programs (M.S. and engineer's degree combined) a total of at least 45 units of graduate-level electrical engineering coursework.

PH.D. PROGRAM AND REQUIREMENTS

The doctor of philosophy (Ph.D.) degree is conferred by the School of Engineering primarily in recognition of competence in the subject field and the ability to investigate engineering problems independently, resulting in a new contribution to knowledge in the field. The work for the degree consists of engineering research, the preparation of a thesis based on that research, and a program of advanced studies in engineering, mathematics, and related physical sciences.

Preliminary Examination

The preliminary examination shall be written and shall include subject matter deemed by the major department to represent sufficient preparation in depth and breadth for advanced study in the major. Only those who pass the written examination may take the oral.

Students currently studying at Santa Clara University for a master's degree who are accepted for the Ph.D. program and who are at an advanced stage of the M.S. program may, with the approval of their academic advisor, take the preliminary examination before completing the M.S. degree requirements. Students who have completed the M.S. degree requirements and have been accepted for the Ph.D. program should take the preliminary examination as soon as possible but not more than two years after beginning the program.

Only those students who pass the preliminary examination shall be allowed to continue in the doctoral program. The preliminary examination may be repeated only once, and then only at the discretion of the thesis advisor.

General Requirements

Thesis Advisor

It is the student's responsibility to obtain consent from a full-time faculty member in the student's major department to serve as his/her prospective thesis advisor.

It is strongly recommended that Ph.D. students find a thesis advisor before taking the preliminary examination. After passing the preliminary examination, Ph.D. students should have a thesis advisor before the beginning of the next quarter following the preliminary examination. Students currently pursuing a master's degree at the time of their preliminary examination should have a thesis advisor as soon as possible after being accepted as a Ph.D. student.

The student and the thesis advisor jointly develop a complete program of studies for research in a particular area. The complete program of studies (and any subsequent changes) must be filed with the Graduate Services Office and approved by the student's doctoral committee. Until this approval is obtained, there is no guarantee that courses taken will be acceptable toward the Ph.D. course requirements.

Doctoral Committee

After passing the Ph.D. preliminary exam, a student requests his or her thesis advisor to form a doctoral committee. The committee consists of at least five members, each of which must have earned a doctoral degree in a field of engineering or a related discipline. This includes the student's thesis advisor, at least two other current faculty members of the student's major department at Santa Clara University, and at least one current faculty member from another appropriate academic department at Santa Clara University. The committee reviews the student's program of study, conducts an oral comprehensive exam, conducts the dissertation defense, and reviews the thesis. Successful completion of the doctoral program requires that the student's program of study, performance on the oral comprehensive examination, dissertation defense, and thesis itself meet with the approval of all committee members.

Residence

The doctoral degree is granted on the basis of achievement, rather than on the accumulation of units of credit. However, the candidate is expected to complete a minimum of 72 quarter units of graduate credit beyond the master's degree. Of these, 36 quarter units may be earned through coursework and independent study, and 36 through the thesis. All Ph.D. thesis units are graded on a Pass/No Pass basis. A maximum of 18 quarter units (12 semester units) may be transferred from other accredited institutions at the discretion of the student's advisor.

Ph.D. students must undertake a minimum of four consecutive quarters of full-time study at the University; spring and fall quarters are considered consecutive. The residency time shall normally be any period between passing the preliminary examination and completion of the thesis. For this requirement, full-time study is interpreted as a minimum registration of eight units per quarter during the academic year and four units during summer session. Any variation from this requirement must be approved by the doctoral committee.

Comprehensive Examinations and Admission to Candidacy

After completion of the formal coursework approved by the doctoral committee, the student shall present his/her research proposal for comprehensive oral examinations on the coursework and the subject of his/her research work. The student should make arrangements for the comprehensive examinations through the doctoral committee. A student who passes the comprehensive examinations is considered a degree candidate. The comprehensive examinations normally must be completed within four years from the time the student is admitted to the doctoral program. Comprehensive examinations may be repeated once, in whole or in part, at the discretion of the doctoral committee.

Thesis Research and Defense

The period following the comprehensive examinations is devoted to research for the thesis, although such research may begin before the examinations are complete. After successfully completing the comprehensive examinations, the student must pass an oral examination on his/her research and thesis, conducted by the doctoral committee and whomever they appoint as examiners. The thesis must be made available to all examiners one month prior to the examination. The oral examination shall consist of a presentation of the results of the thesis and the defense. This examination is open to all faculty members of Santa Clara University, but only members of the doctoral committee have a vote.

Thesis and Publication

At least one month before the degree is to be conferred, the candidate must submit to the Office of the Dean of Engineering two copies of the final version of the thesis describing the research in its entirety. The thesis will not be considered as accepted until approved by the doctoral committee and one or more refereed articles based on it are accepted for publication in a first-tier professional or scientific journal approved by the doctoral committee. All doctoral theses must also be reproduced on microfilm by University Microfilms International, which keeps on deposit the master microfilm copy and responds to requests for copies by individuals and libraries.

Time Limit for Completing Degree

All requirements for the doctoral degree must be completed within eight years following initial enrollment in the Ph.D. program. Extensions will be allowed only in unusual circumstances and must be recommended in writing by the student's doctoral committee, and approved by the dean of engineering in consultation with the Graduate Program Leadership Council.

Additional Graduation Requirements

The requirements for the doctoral degree in the School of Engineering have been made to establish the structure in which the degree may be earned. Upon written approval of the provost, the dean of the School of Engineering, the doctoral committee, and the chair of the major department, other degree requirements may be established. The University reserves the right to evaluate the undertakings and the accomplishments of the degree candidate in total, and award or withhold the degree as a result of its deliberations.

The departments of Electrical Engineering and Bioengineering are collaborating to offer a Ph.D. in interdisciplinary topics related to Bioengineering. Faculty from both departments will co-advise the Ph.D. students and the degree will be awarded by the Department of Electrical Engineering.

CERTIFICATE PROGRAMS

General Information

Certificate programs are designed to provide intensive background in a narrow area at the graduate level. At roughly one-third of the units of a master's degree program, the certificate is designed to be completed in a much shorter period of time. These certificate programs are appropriate for students working in industry who wish to update their skills or those interested in changing their career path. More detail about certificates may be found on the department website.

Admission

To be accepted into a certificate program, the applicant must have a bachelor's degree and meet any additional requirements for the specific certificate. Exceptions based on work experience may be granted for the Certificate in Fundamentals of Electrical Engineering.

Grade Requirements

Students must receive a minimum grade of C in each course and have an overall GPA of 3.0 or better to earn a certificate.

Continuation for a Master's Degree

All Santa Clara University graduate courses applied to the completion of a certificate program earn graduate credit that may also be applied toward a graduate degree. Students who wish to continue for such a degree must submit a separate application and satisfy all normal admission requirements. The general GRE test requirement for graduate admission to the master's degree will be waived for students who complete a certificate program with a GPA of 3.5 or better.

Academic Requirements

ASIC Design and Test

Advisor: Dr. Samiha Mourad

This certificate program has a dual purpose: (a) to strengthen fundamental knowledge of the design process that helps the designer adapt to future innovations in technology; and (b) to introduce the designer to state-of-the-art tools and techniques. The program consists of the eight courses listed below. Any change in the requirements must be approved by the academic advisor.

Required Courses (16 units)

- ELEN 387 VLSI Design I (2 units)
- ELEN 500 Logic Analysis and Synthesis (2 units)
- ELEN 603 Logic Design Using HDL (2 units)

- ELEN 605 High-Level Synthesis (2 units)
- ELEN 608 Design for Testability (2 units)
- ELEN 624 Signal Integrity in IC and PCB Systems (2 units)
- Two electives from ELEN 388, 389, 601, 604, 609, 613, 614 or 620 (2 units)

Analog Circuit Design

Advisor: Dr. Shoba Krishnan

This certificate provides a background in the basic devices and circuits that are fundamental to analog circuit design. The program will also introduce the student to state-of-the-art analog IC design tools. The program consists of the courses listed below totaling 16 units.

Required Courses (14 units)

- ELEN 252 Analog Integrated Circuits I (2 units)
- ELEN 253 Analog Integrated Circuits II (2 units)
- ELEN 254 Advanced Analog Integrated Circuit Design (4 units)
- ELEN 264 Semiconductor Device Theory I (2 units)
- ELEN 387 VLSI Design I (2 units)

Elective Courses (2 units)

- ELEN 251 Transistor Models for IC Design (2 units)
- ELEN 265 Semiconductor Device Theory II (2 units)
- ELEN 351 RF Integrated Circuit Design (2 units)
- ELEN 352 Mixed Signal IC Design for Data Communications (2 units)
- ELEN 353 DC to DC Power Conversion (2 units)
- ELEN 388 VLSI Design II (2 units)

Digital Signal Processing Applications

Advisors: Dr. Tokunbo Ogunfunmi, Dr. Sally Wood

This certificate program provides a basic understanding of digital signal processing theory and modern implementation methods as well as advanced knowledge of at least one specific application area. Digital signal processing has become an important part of many areas of engineering, and this certificate prepares students for traditional or novel applications.

Required Courses (10 to 12 units)

- ELEN 233E or ELEN 233 and 234 Digital Signal Processing I, II (4 units)
- ELEN 223 Digital Signal Processing System Development (4 units) or
  ELEN 226 DSP Design in FPGA (2 units)
- ELEN 421 Speech Coding I or ELEN 640 Digital Image Processing I (2 units)
- AMTH 210 or AMTH 245 (2 units)

Elective Courses (4 to 6 units to make a total of 16 units) may be selected from the list below. Any courses from the required list above that were not selected to meet the requirements may be included in the elective options.

- AMTH 308 Theory of Wavelets (2 units) or
  AMTH 358 Fourier Transforms (2 units)
- ELEN 241 Introduction to Communications (2 units)
- ELEN 243 Digital Communications Systems (2 units)
- ELEN 244 Information Theory (2 units)
- ELEN 334 Introduction to Statistical Signal Processing (2 units)
- ELEN 422 Speech Coding II (2 units)
- ELEN 431 Adaptive Signal Processing I (2 units)
- ELEN 643 Digital Image Processing II (2 units)

Digital Signal Processing Theory

Advisors: Dr. Tokunbo Ogunfunmi, Dr. Sally Wood

This certificate program provides a firm grounding in fundamentals of digital signal processing (DSP) technology and its applications. It is appropriate for engineers involved with any application of DSP who want a better working knowledge of DSP theory and its applications. A novel feature of the program is a hands-on DSP hardware/software development laboratory course in which students design and build systems for various applications using contemporary DSP hardware and development software.

Required Courses (8 units)

- AMTH 308 Theory of Wavelets (2 units) or
  AMTH 358 Fourier Transforms (2 units)
- ELEN 233E or ELEN 233 and 234 Digital Signal Processing I, II (4 units)
- ELEN 334 Introduction to Statistical Signal Processing (2 units)

Elective Courses (8 units)

- ELEN 223 Digital Signal Processing System Development (4 units)
- ELEN 226 DSP Design in FPGA (2 units)
- ELEN 235 Estimation I (2 units)
- ELEN 241 Introduction to Communications (2 units)
- ELEN 244 Information Theory (2 units)
- ELEN 336 Detection (2 units)
- ELEN 431 Adaptive Signal Processing I (2 units)
- ELEN 640 Digital Image Processing I (2 units)
- ELEN 641 Image and Video Compression (2 units)
- ELEN 643 Digital Image Processing II (2 units

Fundamentals of Electrical Engineering

Advisor: Electrical Engineering Department Chair

This certificate has been designed for those individuals who have significant work experience in some area of electrical engineering and wish to take graduate-level courses but may lack some prerequisite knowledge because they have not earned the BSEE degree. This one-year program consists of 16 to 28 units, depending on the background of the individual student, and covers electrical engineering core areas. Eight of these units may be credited toward an MSEE degree after successful completion of the certificate.

The required courses are selected with the help of the program advisor according to the student's background.

- ELEN 21 Introduction to Logic Design (4 units)
- ELEN 33 Digital Systems Architecture (5 units)
- ELEN 50 Electric Circuits I (5 units)
- ELEN 100 Electric Circuits II (5 units)
- ELEN 104 Electromagnetics I (5 units)
- ELEN 110 Linear Systems (5 units) or ELEN 210 (2 units)
- ELEN 115 Electronic Circuits I (5 units) or ELEN 250 (2 units)

Microwave and Antennas

Advisors: Dr. Timothy Healy, Dr. Ramesh Abhari

The purpose of this certificate is to meet the increasing need for the knowledge in microwave, antenna and RF integrated circuits in present electronic products. This program is offered for students who have a B.S. in Electrical Engineering. The students are expected to have had knowledge of multivariate calculus and preferably partial differential equations.

The curriculum consists of 16 units: two required courses (4 units) and 12 units of elective courses listed below:

Required Courses

- ELEN 201 Electromagnetic Field Theory I (2 units)
- ELEN 701 Microwave System Architecture (2 units

Elective Courses

- Signal Integrity and RF Circuits: ELEN 351, 354, 624 (2 units each)
- RF Circuits: ELEN 351, 354 (2 units each)
- Laboratory oriented: ELEN 705, 726 (3 units each)
- Passive components: ELEN 706 (4 units)
- Active components: ELEN 711, 712 (2 units each)
- Antennas: ELEN 715, 716 (2 units each)
- Advanced Electromagnetics: ELEN 202 (2 units)

Substitutions for these courses are only possible with the approval of the certificate advisor and the chair.

ELECTRICAL ENGINEERING LABORATORIES

The Electrical Engineering program is supported by a set of well-equipped laboratories. Some are dedicated solely for lower division courses such as circuits and electronics. In addition the department has a diversity of research and teaching laboratories listed next.

The ***Communications and Microwave Laboratory*** provides a full range of modern measurement capability from 0-22 GHz, including a number of automatic network analyzers and modern spectrum analyzers. It also has extensive computer-aided design and simulation capability, based largely on modern commercial software running on workstations. Interconnection of hardware measurements and computer simulation is stressed.

The ***Digital Systems Laboratory*** (operated jointly with the Department of Computer Engineering) provides complete facilities for experiments and projects ranging in complexity from a few digital integrated circuits to FPGA-based designs. The laboratory also includes a variety of development systems to support embedded systems and digital signal processing.

The ***Electronic Devices Laboratory*** is dedicated to teaching and research topics on electronic devices, materials, and their manufacturing technologies. Current research topics include modeling complex electronic devices using variational methodologies, experimental studies of photovoltaic devices, aging of organic semiconductor films, porous silicon, etc.

The ***Intelligent Control Laboratory*** provides an experimental environment for students in the area of control and system engineering. It includes a computer-controlled robotic system, several servo-experimenters, and a torsional mechanical control system. The equipment provides students with a wide range of qualitative and quantitative experiments for learning the utility and versatility of feedback in computer-controlled systems.

The ***Latimer Energy Laboratory (LEL)*** supports a very wide range of activities relating to photovoltaics (PV), from K-12 outreach through graduate engineering. The laboratory focuses on measurement of solar radiation, measurement and characterization of artificial light sources, study of physical characteristics of PV cells, and electrical characteristics, including I-V curves. Instrumentation includes: pyranometers, VIS-IR spectrometers, metallurgical microscopes, source meters, and related computers.

The ***Nanoelectronics Laboratory*** provides teaching and research facilities for modeling, simulation, and characterization of devices and circuits in the nanoscale. Ongoing research topics include silicon heterostructures, thin dielectrics, high-frequency device and circuit parameter extraction, carbon nanostructures used as electrical interconnect and thermal interface materials, and compact modeling of transistors and interconnects for large-scale circuit simulation. This laboratory is part of the campus-wide Center for Nanostructures, established to conduct, promote, and nurture nanoscale science and technology interdisciplinary research and education activities at the University, and to position the University as a national center of innovation in nanoscience education and nanostructures research.

The ***Image and Video Processing Laboratory*** supports graduate student research on algorithms and implementations for image analysis, image reconstruction and super-resolution, and stereo imaging. Laboratory equipment includes cameras for image acquisition, computational resources, and FPGAs for real-time testing.

The ***Robotics Systems Laboratory*** is an interdisciplinary laboratory specializing in the design, control, and teleoperation of highly capable robotics systems for scientific discovery, technology validation, and engineering education. Laboratory students develop and operate systems that include spacecraft, underwater robots, aircraft, and land rovers. These projects serve as ideal test beds for learning and conducting research in mechatronic system design, guidance and navigation, command and control systems, and human-machine interfaces.

The ***Signal Processing Research Laboratory (SPRL)*** conducts research into theoretical algorithm development in adaptive/nonlinear signal processing, speech/audio/video signal processing, and their applications in communications, biotech, Voice-over-IP networking, and related areas. The lab supports student research in algorithms and real-time implementations on Digital Signal Processors (DSPs) and Field Programmable Gate Arrays (FPGAs). Laboratory equipment includes UNIX workstations, PCs, digital oscilloscopes, video cameras, wireless LAN networking equipment, DSP boards, and FPGA boards.

COURSE DESCRIPTIONS

Lower-Division Undergraduate Courses

ELEN 20. Emerging Areas in Electrical Engineering

Introduction to several important new frontiers in electrical engineering selected from: renewal energy sources and conversion to electricity, energy storage devices and systems, nanoscale science and technology, power electronics, high-speed electronics, and ubiq-uitous wireless and video communications. Course includes laboratory experience and visits to research and production facilities in Silicon Valley companies. (3 units)

ELEN 21. Introduction to Logic Design

Boolean functions and their minimization. Designing combinational circuits, adders, multipliers, multiplexers, decoders. Noise margin, propagation delay. Bussing. Memory elements: latches and flip-flops; timing; registers; counters. Programmable logic, PLD, and FPGA. Use of industry quality CAD tools for schematic capture and HDL in conjunction with FPGAs. *Also listed as COEN 21. Co-requisite: ELEN 21L.* (4 units)

ELEN 21L. Laboratory for ELEN 21

Also listed as COEN 21L. Co-requisite: ELEN 21. (1 unit)

ELEN 33. Digital Systems Architecture

Overview of processor architectures for general purpose processors, special purpose signal processing microprocessors, and FPGA soft core processors; data representation in fixed point, floating point; instruction set architectures; assembly and machine language programming; real-time I/O; introduction to sample data systems. Analog to digital converters and digital to analog converters. *Prerequisites: ELEN 21 with a grade of C– or better, and COEN 11 or 44. Co-requisite: ELEN 33L, COEN 12.* (4 units)

ELEN 33L. Laboratory for ELEN 33

Co-requisite: ELEN 33. (1 unit)

ELEN 50. Electric Circuits I

Physical basis and mathematical models of circuit components and energy sources. Circuit theorems and methods of analysis are applied to DC and AC circuits. *Co-requisite: ELEN 50L, PHYS 33.* (4 units)

ELEN 50L. Laboratory for ELEN 50

Co-requisite: ELEN 50. (1 unit)

Upper-Division Undergraduate Courses

ELEN 100. Electric Circuits II

Continuation of ELEN 50. Sinusoidal steady state and phasors, transformers, resonance, Laplace analysis, transfer functions. Frequency response analysis. Bode diagrams. Switching circuits. *Prerequisite: ELEN 50 with a grade of C– or better or PHYS 70. Co-requisite: ELEN 100L, AMTH 106.* (4 units)

ELEN 100L. Laboratory for ELEN 100

Co-requisite: ELEN 100. (1 unit)

ELEN 104. Electromagnetics I

Vector analysis and vector calculus. The laws of Coulomb, Lorentz, Faraday, and Gauss. Dielectric and magnetic materials. Energy in electric and magnetic fields. Capacitance and inductance. Maxwell's equations. Wave equation. Poynting vector. Wave propagation and reflection. Transmission lines. Radiation. *Prerequisites: PHYS 33 and ELEN 50. Co-requisite: ELEN 104L.* (4 units)

ELEN 104L. Laboratory for ELEN 104

Co-requisite: ELEN 104. (1 unit)

ELEN 105. Electromagnetics II

In-depth study of several areas of applied electromagnetics such as transmission line including transient effects, losses, and signal integrity concepts, plane waves, matching circuits, antenna theory and antenna design. *Prerequisite: ELEN 104. Co-requisite: ELEN 105L.* (4 units)

ELEN 105L. Laboratory for ELEN 105

Co-requisite: ELEN 105. (1 unit)

ELEN 110. Linear Systems

Signals and system modeling. Laplace transform. Transfer function. Convolution. Dis-crete systems and Z-transform. Frequency analysis. Fourier series and transform. Filtering. State-Space models. *Prerequisite: ELEN 100. Co-requisite: ELEN 110L.* (4 units)

ELEN 110L. Laboratory for ELEN 110

MATLAB laboratory/problem sessions. *Co-requisite: ELEN 110.* (1 unit)

ELEN 112. Modern Network Synthesis and Design*

Approximation and synthesis of active networks. Filter design using positive and negative feedback biquads. Sensitivity analysis. Fundamentals of passive network synthesis. Design project. *Prerequisite: ELEN 110. Co-requisite: ELEN 112L.* (4 units)

ELEN 112L. Laboratory for ELEN 112

Co-requisite: ELEN 112. (1 unit)

ELEN 115. Electronic Circuits I

Study of basic principles of operation, terminal characteristics, and equivalent circuit models for diodes and transistors. Analysis and design of diode circuits, transistor amplifiers, and inverter circuits. *Prerequisite: ELEN 50 with a grade of C– or better. Co-requisite: ELEN 115L.* (4 units)

ELEN 115L. Laboratory for ELEN 115

Co-requisite: ELEN 115. (1 unit)

ELEN 116. Electronic Circuits II*

Design and analysis of multistage analog amplifiers. Study of differential amplifiers, current mirrors and gain stages. Frequency response of cascaded amplifiers and gain-bandwidth considerations. Concepts of feedback, stability, and frequency compensation. Design of output stages and power amplifiers. *Prerequisite: ELEN 115. Co-requisite: ELEN 116L.* (4 units)

ELEN 116L. Laboratory for ELEN 116

Co-requisite: ELEN 116. (1 unit)

ELEN 117. Electronic Circuits III*

Design and analysis of BJT and MOSFET analog ICs. Study of analog circuits such as comparators, sample/hold amplifiers, and continuous time switched capacitor filters. Architecture and design of analog to digital and digital to analog converters. Reference and biasing circuits. Study of noise and distortion in analog ICs. *Prerequisite: ELEN 116. Co-requisite: ELEN 117L. (4 units)*

ELEN 117L. Laboratory for ELEN 117

Co-requisite: ELEN 117. (1 unit)

ELEN 118. Fundamentals of Computer-Aided Circuit Simulation*

Introduction to algorithms and principles used in circuit simulation packages (such as SPICE). Formulation of equations for linear and nonlinear circuits. Detailed study of the three different types of circuit analysis (AC, DC, and transient). Discussion of computational aspects, including sparse matrices, Newton's method, numerical integration, and parallel computing. Applications to electronic circuits, active filters, and CMOS digital circuits. Course includes a number of design projects in which simulation software is written in MATLAB and verified using SPICE. *Prerequisites: ELEN 21, with a grade of C– or better; ELEN 100 and 115. Co-requisite: ELEN 118L.* (4 units)

ELEN 118L. Laboratory for ELEN 118

Co-requisite: ELEN 118. (1 unit)

ELEN 119. Current Topics in Electrical Engineering

Subjects of current interest. May be taken more than once if topics differ. (4 units)

ELEN 123. Mechatronics

Introduction to behavior, design, and integration of electromechanical components and systems. Review of appropriate electronic components/circuitry, mechanism configurations, and programming constructs. Use and integration of transducers, micro-controllers, and actuators. *Also listed as MECH 143. Prerequisites: ELEN 50 with a grade of C– or better and COEN 11 or 44. Co-requisite: ELEN 123L.* (4 units)

ELEN 123L. Laboratory for ELEN 123

Also listed as MECH 143L. Co-requisite: ELEN 123. (1 unit)

ELEN 127. Advanced Logic Design*

Contemporary design of finite-state machines as system controllers using MSI, PLDs, or FPGA devices. Minimization techniques, performance analysis, and modular system design. HDL simulation and synthesis. *Also listed as COEN 127. Prerequisite: ELEN 21 with a grade of C– or better. Co-requisites: ELEN 127L and ELEN 115.* (4 units)

ELEN 127L. Laboratory for ELEN 127

Design, construction, and testing of controllers from verbal specs. Use of CAD design tools. *Also listed as COEN 127L. Co-requisite: ELEN 127.* (1 unit)

ELEN 130. Control Systems*

Applications of control systems in engineering. Principle of feedback. Performance specifications: transient and steady-state response. Stability. Design of control systems by frequency and root-locus methods. Computer-controlled systems. State-variable feedback design. Problem sessions. *Prerequisite: ELEN 110. Co-requisite: ELEN 130L.* (4 units)

ELEN 130L Laboratory for ELEN 130

Co-requisite: ELEN 130. (1 unit)

ELEN 131. Introduction to Robotics

Overview of robotics: control, artificial intelligence, and computer vision. Components and structure of robots. Kinematics and dynamics of robot manipulators. Servo-control design, PID control. Trajectory planning, obstacle avoidance. Sensing and vision. Robot intelligence and task planning. *Prerequisite: ELEN 110. Co-requisite: ELEN 131L.* (4 units)

ELEN 131L. Laboratory for ELEN 131

Co-requisite: ELEN 131. (1 unit)

ELEN 133. Digital Signal Processing*

Discrete signals and systems. Difference equations. Convolution summation. Z-transform, transfer function, system response, stability. Digital filter design and implementation. Frequency domain analysis. Discrete Fourier transform and FFT. Audio, video, and communication applications. *Prerequisites: ELEN 110 or both ELEN 50 with a grade of C– or better, and COEN 19. Co-requisite: ELEN 133L.* (4 units)

ELEN 133L. Laboratory for ELEN 133

Laboratory for real-time processing. *Co-requisite: ELEN 133.* (1 unit)

ELEN 134. Applications of Signal Processing*

Current applications of signal processing. *Prerequisite: ELEN 133. Co-requisite: ELEN 134L.* (4 units)

ELEN 134L. Laboratory for ELEN 134

Co-requisite: ELEN 134. (1 unit)

ELEN 139. Special Topics in Signals and Systems

Subjects of current interest. May be taken more than once if topics differ. (4 units)

ELEN 141. Communication Systems*

Modulation and demodulation of communications systems, for both analog and digital systems. Passband and baseband signal modulation and demodulation. Random processes and noise in communication systems and relevant Signal-to-Noise measures. *Prerequisites: ELEN 110 and AMTH 108. Co-requisite: ELEN 141L.* (4 units)

ELEN 141L. Laboratory for ELEN 141

Co-requisite: ELEN 141. (1 unit)

ELEN 144. RF and Microwave Components*

The fundamental characteristics of RF and Microwave components and circuits. Modeling of parasitics and circuit interconnects. Transmission line circuits and network parameters such as scattering and transmission parameters. Study of crosstalk and other noises in high-speed circuits. Design of power dividers, impedance matching circuits, couplers, hybrids and microwave filters. Use of state-of-the-art CAD tools. *Prerequisite: ELEN 104. Co-requisite: ELEN 144L.* (4 units)

ELEN 144L. Laboratory for ELEN 144

Co-requisite: ELEN 144. (1 unit)

ELEN 151. Semiconductor Devices

Properties of materials, crystal structure, and band structure of solids. Carrier statistics and transport; p-n junction statics, I-V characteristics, equivalent circuits, and switching response. Metal-semiconductor contacts, Schottky diodes. MOS field-effect transistors, bipolar junction transistors. *Prerequisite: ELEN 104. Co-requisite: ELEN 151L.* (4 units)

ELEN 151L. Laboratory for ELEN 151

Co-requisite: ELEN 151. (1 unit)

ELEN 152. Semiconductor Devices and Technology*

Continuation of MOS field-effect transistors, bipolar junction transistors, heterjunctions. Principles of silicon IC fabrication processes. Bulk and epitaxial crystal growth, thermal oxidation, diffusion, ion implantation. Process simulation for basic devices. *Prerequisite: ELEN 151. Co-requisite: ELEN 152L.* (4 units)

ELEN 152L. Laboratory for ELEN 152

Co-requisite: ELEN 152. (1 unit)

ELEN 153. Digital Integrated Circuit Design*

Introduction to VLSI design and methodology. Study of basic principles of operation, terminal characteristics, and equivalent circuit models for diodes and transistors. Analysis of CMOS integrated circuits. Circuit modeling and performance evaluation supported by simulation (SPICE). Ratioed, switch, and dynamic logic families; combinational and sequential circuits. Fully-custom and semi-custom design. Physical design: placement and routing. Use of state-of-the-art CAD tools. *Prerequisites: ELEN/ COEN 21 and ELEN 50 with a grade of C– or better. Co-requisite: ELEN 153L.* (4 units)

ELEN 153L. Laboratory for ELEN 153

Co-requisite: ELEN 153. (1 unit)

ELEN 156. Introduction to Nanotechnology*

Introduction to the field of nanoscience and nanotechnology. Properties of nanomaterials and devices. Nanoelectronics: from silicon and beyond. Measurements of nanosystems. Applications and implications. Laboratory experience is an integral part of the course. *Also listed as MECH 156. Prerequisites: PHYS 33 and either PHYS 34 or MECH 15. Co-requisite: ELEN 156L.* (4 units)

ELEN 156L. Laboratory for ELEN 156

Also listed as MECH 156L. Co-requisite: ELEN 156. (1 unit)

ELEN 160. Chaos Theory, Metamathematics and the Limits of Knowledge: A Scientific Perspective on Religion*

Limitations of science are examined in the framework of nonlinear system theory and metamathematics. Strange attractors, bifurcations, and chaos are studied in some detail. Additional topics include an introduction to formal systems and an overview of Godel's theorems. The mathematical background developed in the course is used as a basis for exploring the relationship between science, aesthetics, and religion. Particular emphasis is placed on the rationality of faith. *Also listed as ELEN 217. Prerequisites: AMTH 106 (or an equivalent course in differential equations), and a basic familiarity with MATLAB. Co-requisite: ELEN 160L.* (4 units)

ELEN 160L. Laboratory for ELEN 160

Co-requisite: ELEN 160. (1 unit)

ELEN 161. Bioinstrumentation

Transducers and biosensors from traditional to nanotechnology; bioelectronics and measurement system design; interface between biological system and instrumentation; data analysis; clinical safety. Laboratory component will include traditional clinical measurements and design and test of a measurement system with appropriate transducers. No human or animal subjects will be used. *Also listed as BIOE 161. Prerequisites: BIOE 10, BIOL 21, and ELEN 50. Co-requisite: ELEN 161L.* (4 units)

ELEN 161L. Laboratory for ELEN 161

Also listed as BIOE 161L. Co-requisite: ELEN 161. (1 unit)

ELEN 162. BioSignals and Processing

Origin and characteristics of bioelectric, bio-optical, and bioacoustic signals generated from biological systems. Behavior and response of biological systems to stimulation. Acquisition and interpretation of signals. Signal processing methods include FFT spectral analysis and time-frequency analysis. Laboratory component will include modeling of signal generation and analysis of signals such as electrocardiogram (ECG), electro-glottogram (EGG), and vocal sound pressure waveforms. *Also listed as BIOE 162. Prerequisites: AMTH 106, BIOE 10, and ELEN 50. Co-requisite: ELEN 162L.* (4 units)

ELEN 162L. Laboratory for ELEN 162

Also listed as BIOE 162L. Co-requisite: ELEN 162. (1 unit)

*ELEN 164. Introduction to Power Electronics**

Development of models utilizing semiconductor materials used in high-current and/or high-voltage applications. Models include DC-to-DC converters, AC-to-DC converters, and DC-to-AC inverters. Analysis of power amplifiers. SPICE implementations of models. *Prerequisite: ELEN 115. Co-requisite: ELEN 164L.* (4 units)

ELEN 164L. Laboratory for ELEN 164

Co-requisite: ELEN 164. (1 unit)

ELEN 167. Medical Imaging Systems

Overview of medical imaging systems including sensors and electrical interfaces for data acquisition, mathematical models of the relationship of structural and physiological information to senor measurements, resolution and accuracy limits, and conversion process from electronic signals to image synthesis. Analysis of the specification and interaction of the functional units of imaging systems and the expected performance. Focus on MRI, CT, ultrasound, PET, and impedance imaging. *Also listed as BIOE 167. Prerequisite: BIOE 162 or ELEN 162 or ELEN 110 or MECH 142.* (4 units)

ELEN 180. Introduction to Information Storage

Storage hierarchy. Design of memory and storage devices, with a particular emphasis on magnetic disks and storage-class memories. Error detection, correction, and avoidance fundamentals. Disk arrays. Storage interfaces and buses. Network attached and distributed storage, interaction of economy, and technological innovation. *Also listed as COEN 180. Prerequisites: ELEN 21 or COEN 21, and COEN 20. COEN 122 is recommended.* (4 units)

*ELEN 182. Energy Systems Design**

Introduction to alternative energy systems with emphasis on those utilizing solar technologies; system analysis including resources, extraction, conversion, efficiency, and end-use; project will design power system for a house off or on grid making best use of renewable energy; system design will include power needs, generation options, storage, back-up power. *Prerequisite: ELEN 50.* (4 units)

*ELEN 183. Power Systems Analysis**

Analysis, design, and optimization of power systems for traditional and renewable power generation. *Prerequisite: ELEN 100 or Physics 112.* (4 units)

ELEN 188. Co-op Education

Practical experience in a planned program designed to give students work experience related to their academic field of study and career objectives. Satisfactory completion of the assignment includes preparation of a summary report on co-op activities. P/NP grading. May be taken twice. May not be taken for graduate credit. (2 units)

ELEN 189. Co-op Technical Report

Credit given for a technical report on a specific activity such as a design or research project, etc., after completing the co-op assignment. Letter grades based on content and presentation quality of report. May be taken twice. May not be taken for graduate credit. *Prerequisite: Approval of department co-op advisor.* (2 units)

ELEN 192. Introduction to Senior Design Project

Junior preparation for senior project. An introduction to project requirements and participation in the coordination of the senior conference. Tentative project selection. (2 units)

ELEN 194. Design Project I

Specification of an engineering project, selected with the mutual agreement of the student and the project advisor. Complete initial design with sufficient detail to estimate the effectiveness of the project. Initial draft of the project report. *Co-requisite: ENGL 181.* (2 units)

ELEN 195. Design Project II

Continued design and construction of the project, system, or device. Second draft of project report. *Prerequisite: ELEN 194.* (2 units)

ELEN 196. Design Project III

Continued design and construction of the project, system, or device. Final report. *Prerequisite: ELEN 195.* (1 unit)

ELEN 199. Directed Research/Reading

Investigation of an approved engineering problem and preparation of a suitable project report. Open to electrical engineering majors only. (1–6 units)

**** Eligible for graduate credit in electrical engineering.***

Graduate Courses

Some graduate courses may not apply toward certain degree programs. As early as possible, preferably during the first quarter of study, students are urged to discuss in detail with their faculty advisor the program of study they wish to pursue.

ELEN 200. Electrical Engineering Graduate Seminars

Regularly scheduled seminars on topics of current interest in the fields of electrical engineering and computer engineering. Consult department office for detailed information. P/NP grading. (1 or 2 units)

ELEN 201. Electromagnetic Field Theory I

Time-varying electromagnetic field concepts starting with Maxwell's equations. Development of field theorems. Development of circuit theory from Maxwell's equations. Transmission lines, including transient effects, losses, and coupling. Plane waves, reflection and refraction at interfaces. *Prerequisite: An undergraduate electromagnetic field course.* (2 units)

ELEN 202. Electromagnetic Field Theory II

Solution of boundary value problems in rectangular, cylindrical, and spherical coordinates employing Green's functions. Applications include circular waveguides and resonators, dielectric waveguides and resonators, and antennas. *Prerequisite: ELEN 201.* (2 units)

ELEN 210. Signals, Circuits, and Systems

Continuous and discrete signals. Circuit equations and time response. Laplace transform. Difference equations and discrete systems. Z-transform. Convolution. Transfer function. Frequency response. Fourier series and transform. Matrix representations of circuits and systems. The notion of state. State transition matrix. State and output response. Equivalent to ELEN 110. May not be included in the minimum required units of Electrical Engineering courses. (2 units)

ELEN 211. Modern Network Analysis I

Graph theory and its applications to network matrix equations. Network component magnitude and frequency scaling. Network topology, graph theory, graph matrices, oriented and nonoriented graphs. Fundamental network laws. Topologically dependent matrix equations. Circuit simulation. N Planar and dual graphs. Nondegenerate network state equations. *Prerequisites: AMTH 246 and knowledge of Laplace transforms.* (2 units)

ELEN 216. Modern Network Synthesis and Design

Approximation and synthesis of active networks. Filter design using positive and negative feedback biquads. Sensitivity analysis. Fundamentals of passive network synthesis. Credit not allowed for both 112 and 216. *Prerequisite: ELEN 210 or its undergraduate equivalent of ELEN 110.* (4 units)

ELEN 217. Chaos Theory, Metamathematics and the Limits of Knowledge: A Scientific Perspective on Religion

Limitations of science are examined in the framework of nonlinear system theory and metamathematics. Strange attractors, bifurcations and chaos are studied in some detail. Additional topics include an introduction to formal systems and an overview of Godel's theorems. The mathematical background developed in the course is used as a basis for exploring the relationship between science, aesthetics, and religion. Particular emphasis is placed on the rationality of faith. *Also listed as ELEN 160. Prerequisites: AMTH 106 or an equivalent course in differential equation*s, and a basic familiarity with MATLAB. (4 units)

ELEN 219. Fundamentals of Computer-Aided Circuit Simulation

Introduction to the algorithms and principles used in circuit simulation packages (such as SPICE). Formation of equations for linear and nonlinear circuits. Detailed study of three different types of circuit analysis (AC, DC, and transient). Discussion of computational aspects, including sparse matrices, Newton's method, numerical integration, and parallel computing. Applications to electronic circuits, active filter, and CMOS digital circuits. Course includes a number of design projects in which simulation software is written in Matlab and verified using SPICE. Credit not allowed for both 118 and 219. *Prerequisites: ELEN 21, ELEN 100, and ELEN 115.* (4 units)

ELEN 223. Digital Signal Processing System Development

Hands-on experience with hardware and software development for real-time DSP applications. Students design, program, and build a DSP application from start to finish. Such applications include image processing, speech/audio/video compression, multimedia, etc. The development environment includes Texas Instruments TMS320C6X development systems. *Prerequisites: ELEN 234 or ELEN 233E and knowledge of "C" programming language.* (4 units)

ELEN 226. DSP Design in FPGA

Introduction to current state-of-the-art design and implementation of FPGA signal processing systems with emphasis on digital communications applications. Overview of current generation FPGAs; FPGA architecture and data path design for digital filters, multirate filters, canonic signed digit arithmetic, and spectrum channelization using digital down converters (DOCs). Implementation of FPGA DSP design using VHDL and visual dataflow methodologies. *Prerequisites: ELEN 133, ELEN 233E or ELEN 234, and ELEN 127 or the equivalent.* (2 units)

ELEN 229. Topics in Network Theory

(2 units)

ELEN 230. Introduction to Control Systems

Applications of control systems in engineering. Principle of feedback. Performance specifications: transient and steady-state response. Stability. Design of control systems by frequency and root-locus methods. Computer-controller systems. State-variable feedback design. Problem sessions. Credit not allowed for both ELEN 130 and ELEN 230. *Prerequisite: ELEN 210 or its undergraduate equivalent of ELEN 110.* (4 units)

ELEN 232. Introduction to Nonlinear Systems

Basic nonlinear phenomena in dynamic systems. State space and phase plane concepts. Equilibria. Linearization. Stability. Liapunov's method. *Prerequisite: ELEN 230E or 236.* (2 units)

ELEN 233. Digital Signal Processing I

Description of discrete signals and systems. Z-transform. Convolution and transfer functions. System response and stability. Fourier transform and discrete Fourier transform. Sampling theorem. Digital filtering. *Also listed as COEN 201. Prerequisite: ELEN 210 or its undergraduate equivalent of ELEN 110.* (2 units)

ELEN 233E. Digital Signal Processing I and II

Same description as ELEN 233 and ELEN 234. Credit not allowed for both ELEN 133 and 233E. (4 units)

ELEN 234. Digital Signal Processing II

Continuation of ELEN 233. Digital FIR and IIR filter design and realization techniques. Multirate signal processing. Fast Fourier transform. Quantization effects. *Also listed as COEN 202. Prerequisite: ELEN 233.* (2 units)

ELEN 235. Estimation I

Introduction to Classical estimation. Minimum Variance Unbiased Estimator (MVUE) from Cramer-Rao theorem, sufficient statistics, and linear estimator constraint. Maximum Likelihood Estimation (MLE) method. Least Square (LS) methods. *Prerequisites: AMTH 211 or AMTH 212, AMTH 246 or AMTH 247, familiarity with MATLAB.* (2 units)

ELEN 236. Linear Control Systems

Concept of state-space descriptions of dynamic systems. Relations to frequency domain descriptions. State-space realizations and canonical forms. Stability. Controllability and observability. Discrete time systems. *Prerequisite: ELEN 210 or its undergraduate equivalent of ELEN 110.* (2 units)

ELEN 237. Optimal Control

Linear regulator problem. Hamilton-Jacobi equation. Riccati equation. Stability. Estimators. *Prerequisite: ELEN 236.* (2 units)

ELEN 238. Model Predictive Control

Review of state-space model in discrete time, stability, optimal control, prediction, Kalman filter. Measurable and un-measurable disturbance, finite and receding horizon control, MPC formulation and design. *Also listed as MECH 420. Prerequisite: ELEN 237 or MECH 324 or equivalent.* (2 units)

ELEN 239. Topics in Systems Theory

(2 units)

ELEN 241. Introduction to Communication

Power spectral density and correlation; bandwidth; random processes; carrier frequency, modulation and baseband versus passband modulation. *Prerequisite: ELEN 210 or its undergraduate equivalent of ELEN 110.* (2 units)

ELEN 243. Digital Communication Systems

Digital modulation techniques including: QAM, PSK, FSK; matched-filter receivers; maximum-likelihood and maximum a priori detection. Signal-to-Noise ratio evaluation and its impact on error rate. *Prerequisite: ELEN 241 or equivalent.* (2 units)

ELEN 244. Information Theory

Introduction to the fundamental concepts of information theory. Source models. Source coding. Discrete channel without memory. Continuous channel. Alternate years. *Also listed as COEN 341. Prerequisite: AMTH 211.* (2 units)

ELEN 247. Communication Systems Modeling Using Simulink I

The objective of this course is for students to acquire and consolidate their practical skills of digital communication systems design through building simulation of some carefully selected prototype systems using MATLAB® and Simulink.® The components and the principle of operation of each system will be presented in a lecture, together with key simulation techniques required. Topics include digital modulation and synchronization. *Prerequisites: ELEN 233 and 243.* (2 units)

ELEN 248. Communication Systems Modeling Using Simulink II

Students learn how to build digital communication systems by using simulation of some carefully selected prototype systems using MATLAB and Simulink. Topics include equalization, single carrier systems, OFDM systems, Viterbi decoding and forward error correction. *Prerequisite: ELEN 247.* (2 units)

ELEN 249. Topics in Communication

(2 units)

ELEN 250. Electronic Circuits

Introductory presentation of semiconductor circuit theory. The p-n junction, bipolar junction transistors (BJT), field-effect transistors and circuit models for these devices. DC biasing required of small-signal amplifier circuits. Analysis and design of small-signal amplifiers. The ideal operational amplifier and circuit applications. May not be taken for credit by a student with an undergraduate degree in electrical engineering. Not for graduate credit. *Prerequisite: ELEN 50 or equivalent.* (2 units)

ELEN 251. Transistor Models for IC Design

Semiconductor device modeling methods based upon device physics, process technology, and parameter extraction. Model derivation for bipolar junction transistors and metal-oxide-semiconductor field-effect transistors for use in circuit simulators. Model parameter extraction methodology utilizing linear regression, data fitting, and optimization techniques. *Prerequisite: ELEN 265 or ELEN 266.* (2 units)

ELEN 252. Analog Integrated Circuits I

Design and analysis of multi-stage BJT and CMOS analog amplifiers. Study of differential amplifiers, current mirrors, and gain stages. Frequency response of cascaded amplifiers and gain-bandwidth considerations. Concepts of feedback, stability, and frequency compensation. *Prerequisite: ELEN 115 or equivalent.* (2 units)

ELEN 253. Analog Integrated Circuits II

Design of operational amplifiers and wideband amplifiers. Design of output stages and power amplifiers. Reference and biasing circuits. Study of noise and distortion in analog ICs and concepts of low noise design. Selected applications of analog circuits such as comparators. *Prerequisite: ELEN 252.* (2 units)

ELEN 254. Advanced Analog Integrated Circuit

Design architecture and design of sample and hold amplifiers, analog to digital, and digital to analog converters. Design of continuous time and switched capacitor filters. *Prerequisite: ELEN 253.* (4 units)

ELEN 259. Topics in Circuit Design

(2 units)

ELEN 261. Fundamentals of Semiconductor Physics

Wave mechanics. Crystal structure and energy band structure of semiconductors. Carrier statistics and transport. Electrical and optical properties. (2 units)

ELEN 264. Semiconductor Device Theory I

Physics of semiconductor materials, junctions, and contacts as a basis for understanding all types of semiconductor devices. *Prerequisite: ELEN 261 or ELEN 151 or equivalent.* (2 units)

ELEN 265. Semiconductor Device Theory II

Continuation of ELEN 264. Bipolar transistors, MOS, and junction field-effect transistors, and semiconductor surface phenomena. *Prerequisite: ELEN 264.* (2 units)

ELEN 266. Semiconductor Device Theory I and II

Same description as ELEN 264 and 265. *Prerequisite: ELEN 261 or ELEN 151 or equivalent.* (4 units)

ELEN 267. Device Electronics for IC Design

Same topics covered in ELEN 261, 264 and 265, for students planning to take analog circuit design courses. (4 units)

ELEN 270. Introduction to IC Materials

Materials issues in IC, classification of IC materials, Historical perspective. IC materials electrical conductivity, high-k, low-k materials. IC processing materials; solid liquid, gaseous dopants, chemicals and gases for etching and cleaning; IC lithography materials; photo-, e-beam-, x-ray resists, resist developers; IC packaging materials; IC thin film materials; adhesion, thermal conductivity and stress, electrical conductivity and sheet resistance. (2 units)

ELEN 271. Microsensors: Components and Systems

Microfabrication technologies, bulk and surface micromachining, sensor fundamentals, electronic, chemical, and mechanical components as sensors, system level issues, technology integration; application and examples of sensors. (2 units)

ELEN 274. Integrated Circuit Fabrication Processes I

Fundamental principles of silicon-integrated circuit fabrication processes. Practical and theoretical aspects of microelectronic fabrication. Basic materials properties, including crystal structure and crystallographic defects; physical and chemical models of crystal growth; and doping, thermal oxidation, diffusion, and ion implantation. *Prerequisite: ELEN 270.* (2 units)

ELEN 275. Integrated Circuit Fabrication Processes II

Physical and chemical models of etching and cleaning, epitaxy, deposited films, photolithography, and metallization. Process simulation and integration. Principles and practical aspects of fabrication of devices for MOS and bipolar integrated circuits. *Prerequisite: ELEN 270.* (2 units)

ELEN 276. Semiconductor Devices and Technology*

Continuation of MOS field-effect transistors, bipolar junction transistors, heterjunctions. Principles of silicon IC fabrication processes. Bulk and expitaxial crystal growth, thermal oxidation, diffusion, ion implantation. Process simulation for basic devices. *Also listed as ELEN 152. Prerequisite: ELEN 151 or ELEN 270.* (4 units)

ELEN 276L. Semiconductor Devices and Technology Lab

Laboratory for ELEN 276. *Also listed as ELEN 152L.* (1 unit)

ELEN 277. IC Assembly and Packaging Technology

IC assembly techniques, assembly flow, die bond pad design rules, eutectic bonding and other assembly techniques, package types and materials, package thermal and electrical design and fabrication, special package considerations, future trends, and package reliability. *Prerequisite: ELEN 201.* (2 units)

ELEN 278A. Electrical Modeling and Design of High Speed IC Packages

Basic definitions and electrical models of package structures. Basic electromagnetic theory, DC and AC resistance including skin effect, loop and partial inductance, Maxwell and SPICE capacitance, impedance. Transmission line theory and coplanar striplines. Packaging structures electrical characteristics. Noise in packages. Electrical design methodology of a high-speed multilayer package; students will be required to design and present an evaluation of the design of a high speed multilayer package using commercial design tools. *Prerequisite: ELEN 201.* (2 units)

ELEN 278B. 3D Packaging

VLSI chip designers need to prepare to engineer the next generation of chips using though silicon vias (TSVs) in order to build 3D silicon chip stacks. This package configuration offers improvements in performance, power reduction and form factor that are crucial to meet the future demands for the growing mobile market. 3D IC electrical design and packaging principles will be presented to make you a valuable 3D IC chip designer. (2 units)

ELEN 279. Topics in Semiconductor Devices and Processing

(2 units)

ELEN 280. Introduction to Alternative Energy Systems

An introduction to such alternative energy systems with an emphasis on those utilizing solar technologies. Learn how the technologies work to provide electrical power today and the capabilities foreseen for the future. The material is designed to be suitable for both undergraduate and graduate students in engineering and related applied sciences. *Also listed as MECH 287.* (2 units)

ELEN 281A. Power Systems: Generation

Electricity is the most versatile and widely used form of energy and as such it is the backbone of today's and tomorrow's global society. The course deals with the power system structure and components, electric power generation, transmission and distribution. It also examines how these components interact and are controlled to meet the requirement of: capacity, energy demand; reliability, availability, and quality of power delivery; efficiency, minimization of power loss; sustainability, and integration of low carbon energy sources. *Prerequisite: ELEN 280/MECH 287.* (3 units)

ELEN 281B. Power Systems: Transmission and Distribution

The objective of this course is to cover the fundamental as well as wider aspects of Electric Power Transmission and Distribution networks including monitoring and control application tools typically provided by Energy Management Systems that enable Electric Utility Companies manage these assets to achieve their goals. *Prerequisite: ELEN 281A.* (2 units)

ELEN 282. Photovoltaic Devices and Systems

This course begins with a discussion of the sun as a source of energy, emphasizing the characteristics of insolation. This leads to a study of solar cells, their performance, their models, and the effects on their performance of factors such as atmospheric attenuation, incidence angle, shading, and others. Cells are connected together to become modules, which in turn are connected in arrays. This leads to a discussion of power electronic devices used to control and condition the DC solar voltage, including charge controllers, inverters, and other devices. Energy storage is studied. These components are then collected together in a solar PV system. The course concludes with a discussion of system sizing. (2 units)

ELEN 283. Characterization of Photovoltaic Devices

This course consists of five pre-lab lectures and five experiments exploring different aspects of photovoltaic cells and modules, including: cell characterization under controlled conditions using a solar simulator; determining the spectral response and quantum efficiency of cells; measurement of solar irradiance and insolation; characterization of photovoltaic modules under real sun conditions; study of solar-related power electronics. *Prerequisite: ELEN 282 or equivalent.* (2 units)

ELEN 284. Solar Cell Technologies & Simulation Tools

Review of concepts needed to understand function, design, and manufacturing of PV cells and modules. PV cell physics leading to derivation of the I-V curve and equivalent circuit, along with contact and optical design, and use of computer-aided design tools. Manufacturing processes for silicon and thin film cells and modules. Cell measurements, including simulators, quantum efficiency, and parameter extraction. Cell types include silicon, thin film, organics, and concentrators. Markets, drivers, and LCOE (levelized cost of electricity) are surveyed. (2 units)

ELEN 284L. Laboratory for ELEN 284

Co-requisite: ELEN 284. (1 unit)

ELEN 285. Introduction to the Smart Grid

The smart grid initiative calls for the construction of a 21st-century electric system that connects everyone to abundant, affordable, clean, efficient, and reliable electric power anytime, anywhere. It is envisioned that it will seamlessly integrate many types of generation and storage systems with a simplified interconnection process analogous to "plug and play." This course describes the components of the grid and the tools needed to realize its main goals: communication systems, intelligent meters, and appropriate computer systems to manage the grid. (2 units)

ELEN 286. Introduction to Wind Energy Engineering

Introduction to renewable energy, history of wind energy, types and applications of various wind turbines, wind characteristics and resources, introduction to different parts of a wind turbine including the aerodynamics of propellers, mechanical systems, electrical and electronic systems, wind energy system economics, environmental aspects and impacts of wind turbines, and the future of wind energy. *Also listed as MECH 286.* (2 units)

ELEN 287. Energy Storage Systems

Energy storage systems play an essential role in the utilization of renewable energy. They are used to provide reserve power under different circumstances and needs such as peak shaving, load leveling, and ancillary services. Power electronics equipment converts the battery power into usable grid power. The course will survey batteries, pumped storage, flywheels, ultracapacitors, etc., with an analysis of the advantages and disadvantages, and uses of each. *Also listed as ENGR 339.* (2 units)

ELEN 288. Energy Management Systems

Energy Management Systems (EMS) is a class of control systems that Electric Utility Companies utilize for three main purposes: Monitoring, Engagement and Reporting. Monitoring tolls allow Electric Utility companies to manage their assets to maintain the sustainability and reliability of power generation and delivery. Engagement tools help in reducing energy production costs, transmission and distribution losses by optimizing utilization of resources and/or power network elements. The Reporting tolls help tracking operational costs and energy obligations. *Also listed as COEN 282.* (2 units)

ELEN 289. Topics in Energy Systems

(2 units)

ELEN 297. Master's Thesis Research

By arrangement. Limited to candidates for MSEE. (1–9 units)

ELEN 298. Ph.D. Thesis Research

By arrangement. A nominal number of 36 units is expected toward the Ph.D. degree. Limited to electrical engineering Ph.D. candidates. (1–15 units)

ELEN 299. Directed Research

Special problems and/or research. Limited to department majors only. By arrangement. (1–6 units)

ELEN 329. Introduction to Intelligent Control

Intelligent control, AI, and system science. Adaptive control and learning systems. Artificial neural networks and Hopfield model. Supervised and unsupervised learning in neural networks. Fuzzy sets and fuzzy control. *Also listed as MECH 329. Prerequisite: ELEN 236.* (2 units)

ELEN 330. Introduction to Stochastic Control for Supply and Demand Network

Managing inventories play an important role in supply and demand network optimization. This course covers basic inventory models. The foundations needed to characterize optimal policies using deterministic and stochastic control strategies. Markov chain. Optimal control. Stochastic control. P*rerequisites: Statistics, Probability, ELEN 130 or 230 or ELEN 236 or equivalent.* (2 units)

ELEN 333. Digital Control Systems

Difference equations. Sampling. Quantization. Z-transform. Transfer functions. Hidden oscillations. State-Space models. Controllability and observability. Stability. Pole-placement by feedback. Liapunov method. Nonlinearity. Output feedback: Root-locus. Frequency response methods. *Prerequisites: ELEN 230 or 230E and 236.* (2 units)

ELEN 334. Introduction to Statistical Signal Processing

Introduction to statistical signal processing concepts. Random variables, random vectors, and random processes. Second-moment analysis, estimation of first and second moments of a random process. Linear transformations; the matched filter. Spectral factorization, innovation representations of random processes. The orthogonality principle. Linear predictive filtering; linear prediction and AR models. Levinson algorithm. Burg algorithm. *Prerequisites: AMTH 211 and ELEN 233 or ELEN 233E.* (2 units)

ELEN 335. Estimation II

Introduction to Bayesian estimation. Minimum mean square error estimator (MMSE), Maximum a posteriori estimator (MAP). Wiener filter and Kalman filter. *Prerequisite: ELEN 235.* (2 units)

ELEN 336. Detection

Hypothesis testing. Neyman-Pearson lemma. Generalized matched filter. Detection of deterministic and random signals in Gaussian and non-Gaussian noise environments. *Prerequisite: AMTH 362, ELEN 243, or ELEN 335.* (2 units)

ELEN 337. Robotics I

Overview of robotics: control, AI, and computer vision. Components and structure of robots. Homogeneous transformation. Forward kinematics of robot arms. Denavit-Hartenberg representation. Inverse kinematics. Velocity kinematics. Manipulator Jacobian. Singular configurations. EulerLagrange equations. Dynamic equations of motion of manipulators. Task planning, path planning, and trajectory planning in the motion control problem of robots. *Also listed as MECH 337. Prerequisite: AMTH 245.* (2 units)

ELEN 338. Robotics II

Joint-based control. Linear control of manipulators. PID control and set-point tracking. Method of computer-torque in trajectory following control. *Also listed as MECH 338. Prerequisites: ELEN 236 and 337.* (2 units)

ELEN 339. Robotics III

Intelligent control of robots. Neural networks and fuzzy logic in robotic control. Selected topics of current research in robotics. *Also listed as MECH 339. Prerequisite: ELEN 338.* (2 units)

ELEN 345. Phase-Locked Loops

Basic loop. Components. Describing equations. Stability. Transients. Modulation and demodulation. *Prerequisite: ELEN 130.* (2 units)

ELEN 347. Advanced Digital Communication Systems

Receiver design, equalizers and maximum likelihood sequence detection. Modulation and receiver design for wireline and wireless communications. Particular emphasis on intersymbol interference and equalizers. Offered every other year. *Prerequisite: ELEN 243.* (2 units)

ELEN 348. FPGA for Communications Applications

This course is a project-based course to introduce students to architectures and implementations of Field-Programmable Gate Arrays (FPGAs) for DSP for communications applications. Examples of a final project include implementing a significant application in communications such as Software-Defined Radio (SDR) or, Wi-Fi. *Prerequisites: ELEN 226 and 247.* (2 units)

ELEN 351. RF Integrated Circuit Design

Introduction to RF terminology, technology tradeoffs in RFIC design. Architecture and design of radio receivers and transmitters. Low noise amplifiers, power amplifiers, mixers, oscillators, and frequency synthesizers. *Prerequisites: ELEN 252 and 387.* (2 units)

ELEN 352. Mixed Signal IC Design for Data Communications

Design and analysis of mixed signal circuits for data communications. Introduction to data communications terminology and signaling conventions. Data transmission media, noise sources. Data transceiver design: Signal coding/decoding, transmit signal waveshaping, receive equalization. Timing Circuits: Clock generation and recovery techniques. *Prerequisites: ELEN 252 and 387.* (2 units)

ELEN 353. DC to DC Power Conversion

Basic buck, boost, and buck-boost DC to DC converter topologies in both continuous and discontinuous conduction modes (CCM and DCM). Analog and digital controlled pulse width modulation techniques. Efficiency and control loop stability analysis. Critical MOSFET parameters and non-ideal circuit behavior will be studied using time and frequency domain computer modeling. *Prerequisites: ELEN 236, or 130 and ELEN 252 or 116.* (2 units)

ELEN 354. Advanced RFIC Design

Design and analysis of passive circuits (filters, splitters, and couplers), Gilbert cell mixers, low phase noise VCOs, frequency translators, and amplifiers. Advanced simulation methods, such as envelope and time domain simulations. Class project designed to meet specifications, design rules, and device models of RFIC foundry. *Prerequisite: ELEN 351.* (2 units)

ELEN 359. Advanced Topics in Circuit Design

(2 units)

ELEN 360. Nanomaterials

Physics, chemistry, and materials science of materials in the nanoscale. Thin films, inorganic nanowires, carbon nanotubes, and quantum dots are examples covered in detail as well as state-of-the-art synthesis processes and characterization techniques for these materials as used in various stages of technology development. *Also listed as ENGR 262. Prerequisites: ENGR 260 and ELEN 261 or ELEN 151.* (2 units)

ELEN 361. Nanoelectronics

Silicon-based technology in the sub-90nm regime. General scaling trend and ITRS Roadmap. Novel device architectures, logic and memory nanodevices, critical enabling device design and process technologies, interconnects, molecular electronics, and their potential usage in future technology nodes. *Prerequisite: ELEN 265 or ELEN 266.* (2 units)

ELEN 375. Semiconductor Surfaces and Interfaces

Structural and electronic properties of semiconductor surfaces, semiconductor/oxide interfaces, and metal/semiconductor interfaces. Relationship between interface morphology/composition and electrical properties. Modern techniques for characterizing surfaces and interfaces. Derivation of interface properties from electrical characterization of devices. *Prerequisite: ELEN 265.* (2 units)

ELEN 379. Topics in Micro/Nanoelectronics

(2 units)

ELEN 387. VLSI Design I

Introduction to VLSI design and methodology. Analysis of CMOS integrated circuits. Circuit modeling and performance evaluation supported by simulation (SPICE). Ratioed, switch, and dynamic logic families. Design of sequential elements. Full-custom layout using CAD tools. *Also listed as COEN 203. Prerequisite: COEN/ELEN 127 or equivalent.* (2 units)

ELEN 388. VLSI Design II

Continuation of VLSI design and methodology. Design of arithmetic circuits and memory. Comparison of semi-custom versus fully custom design. General concept of floor planning, placement, and routing. Introduction of signal integrity through the interconnect wires. *Also listed as COEN 204. Prerequisite: COEN 203/ELEN 387 or equivalent, or ELEN 153.* (2 units)

ELEN 389. VLSI Physical Design

Physical design is the phase that follows logic design, and it includes the following steps that precede the fabrication of the IC logic partitioning: cell layout, floor planning, placement, routing. These steps are examined in the context of very deep submicron technology. Effect of parasitic devices and packaging are also considered. Power distribution and thermal effects are essential issues in this design phase. *Also listed as COEN 305. Prerequisite: COEN 204/ELEN 388 or equivalent.* (2 units)

ELEN 390. Semiconductor Device Technology Reliability

Reliability challenges in device design, fabrication technology, and test methodology. Device design issues such as design tolerances for latch-up, hot carrier injection, and electromigration. Fabrication technology challenges for sub-micron processes. Test methodology in terms of design feasibility and high-level test/fault coverage. IC yield models and yield enhancement techniques. (2 units)

ELEN 391. Process and Device Simulation with Technology Computer Aided Design (TCAD)

Review of semiconductor technology fundamentals. TCAD tools and methods as a design aid for visualizing physical device quantities at different stages of design and influencing device process parameters and circuit performance. Introduction to numerical simulation and TCAD, 2D process and device simulation, CMOS process flow and device design, device characterization and parameter extraction, circuit simulation. Introduction to virtual IC factory concept, integration of process, device and circuit simulation tools. The concept of process variation, statistical analysis and modeling methods, such as Monte Carlo sampling, correlation analysis, response surface modeling. *Prerequisite: ELEN 274.* (2 units)

ELEN 398. Advanced Ph.D. Research

By arrangement. *Prerequisite: Completion of 72 units of graduate credit beyond the master's degree. Co-requisite: ELEN 298.* (1–7 units)

ELEN 421. Speech Coding I

Review of sampling and quantization. Introduction to Digital Speech Processing. Elementary principals and applications of speech analysis, synthesis, and coding. Speech signal analysis and modeling. The LPC Model. LPC Parameter quantization using Line Spectrum Pairs (LSPs). Digital coding techniques: Quantization, Waveform coding. Predictive coding, Transform coding, Hybrid coding, and Sub-band coding. Applications of speech coding in various systems. Standards for speech and audio coding. *Also listed as COEN 348. Prerequisite: ELEN 334 or equivalent.* (2 units)

ELEN 422. Speech Coding II

Advanced aspects of speech analysis and coding. Analysis-by-Synthesis (AbS) coding of speech, Analysis-as-Synthesis (AaS) coding of speech. Code-Excited Linear Speech Coding. Error-control in speech transmission. Application of coders in various systems (such as wireless phones). International Standards for Speech (and Audio) Coding. Real-Time DSP implementation of speech coders. Research project on speech coding. Introduction to speech recognition. *Also listed as COEN 349. Prerequisite: ELEN 421.* (2 units)

ELEN 423. Introduction to Voice-over-IP

Overview of voice encoding standards relevant to VoIP: G.711, G.726, G.723.1, G.729, G.729AB. VoIP packetization and signaling protocols: RTP/RTCP, H.323, MGCP/MEGACO, SIP. VoIP impairments and signal processing algorithms to improve QoS. Echo cancellation, packet loss concealment, adaptive jitter buffer, Decoder clock synchronization. Network convergence: Soft-switch architecture, VoIP/PSTN, interworking (Media and Signaling Gateways), signaling translation (SS7, DTMF/MF etc.), fax over IP. *Prerequisite: ELEN 233 or knowledge of basic digital signal processing concepts.* (2 units)

ELEN 431. Adaptive Signal Processing I

Theory of adaptive filters, Wiener filters, the performance surface, gradient estimation. The least-mean-square (LMS) algorithm, other gradient algorithms, transform-domain LMS adaptive filtering, block LMS algorithm. IIR adaptive filters. The method of least squares. Recursive least squares (RLS) adaptive transversal filters; application of adaptive filters in communications, control, radar, etc. Projects. *Prerequisites: ELEN 233 and ELEN 334 or AMTH 362 or knowledge of random processes.* (2 units)

ELEN 431E. Adaptive Signal Processing I and II

Same description as ELEN 431 and ELEN 432. *Prerequisites: ELEN 334 or AMTH 362 or knowledge of random processes.* (4 units)

ELEN 432. Adaptive Signal Processing II

Linear prediction. Recursive least squares lattice filters. Applications of Kalman filter theory to adaptive transversal filters. Performance analysis of different algorithms. Fast algorithms for recursive least squares adaptive transversal filters. Applications of adaptive filters in communications, control, radar, etc. Projects. Alternate years. *Prerequisite: ELEN 431.* (2 units)

ELEN 433. Array Signal Processing

Statistical analysis of array signal processing of a spectral analysis and direction-finding. Classical spectral analysis, maximum entropy, minimum variance, maximum likelihood, and super-resolution techniques. Alternate years. *Prerequisites: ELEN 234 and either ELEN 235 or AMTH 362.* (2 units)

ELEN 439. Topics in Adaptive Signal Processing

(2 units)

ELEN 441. Communications Satellite Systems Engineering

Satellite systems engineering considerations. Spacecraft. Satellite link design. Communication systems techniques for satellite links. Propagation on satellite-earth paths. Earth station technology. *Prerequisite: ELEN 243 or equivalent.* (2 units)

ELEN 444. Error-Correcting Codes

Theory and implementation of error-correcting codes. Linear block codes, cyclic codes. Encoding and decoding techniques and implementations analysis of code properties and error probabilities. Offered in alternate years. *Prerequisite: Knowledge of probability.* (2 units)

ELEN 446. Introduction to Wireless Communication Systems

Overview of digital communications. Topics include bit rate and error performance. Long-term and short-term propagation effects. Link budgets. Diversity techniques. *Prerequisites: Knowledge of random processes, AMTH 210, ELEN 241 or its equivalent.* (2 units)

ELEN 447. Wireless Network Architecture

Issues in wireless management. Topics include: Multiple access techniques, cellular and local area network standards, scheduling of users, handoff and channel assignment. *Prerequisite: ELEN 446 or equivalent.* (2 units)

ELEN 460. Advanced Mechatronics I

Theory of operation, analysis, and implementation of fundamental physical and electrical device components: basic circuit elements, transistors, op-amps, sensors, electro-mechanical actuators. Application to the development of simple devices. *Also listed as MECH 207. Prerequisite: MECH 141 or ELEN 100.* (3 units)

ELEN 461. Advanced Mechatronics II

Theory of operation, analysis, and implementation of fundamental controller implementations: analog computers, digital state machines, microcontrollers. Application to the development of closed-loop control systems. *Also listed as MECH 208. Prerequisites: ELEN 460 or MECH 207, and MECH 217.* (3 units)

ELEN 462. Advanced Mechatronics III

Electro-mechanical modeling and system development. Introduction to mechatronic support subsystems: power, communications. Fabrication techniques. Functional implementation of hybrid systems involving dynamic control and command logic. *Also listed as MECH 209. Prerequisite: MECH 208 or ELEN 461.* (2 units)

ELEN 500. Logic Analysis and Synthesis

Analysis and synthesis of combinational and sequential digital circuits with attention to static, dynamic, and essential hazards. Algorithmic techniques for logic minimization, state reductions, and state assignments. Decomposition of state machine, algorithmic state machine. Design for test concepts. *Also listed as COEN 200. Prerequisite: ELEN 127C or equivalent.* (2 units)

ELEN 510. Computer Architecture

Overview of major subsystems of small- to medium-scale digital computers. Machine instruction set characteristics. Typical arithmetic and logic unit functions, register dataflow organization, busing schemes, and their implementations. Computer memory systems; addressing techniques. Methods of system timing and control; hardware sequencers, microprogramming. Register transfer language and micro-operation. I/O subsystem structure; interrupts; direct memory access and I/O bus interfacing techniques. Detailed computer design project. Credit not allowed for both ELEN 510 and COEN 210. *Prerequisites: ELEN 33 or equivalent, ELEN 127C and COEN 44.* (2 units)

ELEN 601. Low Power Designs of VLSI Circuits and Systems

Design of digital circuits for reduced power consumption. Sources of power consumption in ICs and analysis algorithms for their estimation at different stages of design. Various power reduction techniques and their trade-offs with performance, manufacturability, and cost are analyzed. Project to design a digital circuit with power reduction as the primary objective. *Prerequisite: ELEN 387.* (2 units)

ELEN 602. Modern Time Analysis

Analysis in logic design review of background materials and introduction of concepts of false path, combinational delay, and minimum cycle time of finite state machines. Study of efficient computational algorithms. Examination of retiming for sequential circuits, speed/area trade-off. *Prerequisite: ELEN 500.* (2 units)

ELEN 603. Logic Design Using HDL

Algorithmic approach to design of digital systems. Use of hardware description languages for design specification. Structural, register transfer, and behavioral views of HDL. Simulation and synthesis of systems descriptions. *Also listed as COEN 303. Prerequisite: ELEN 127 or equivalent.* (2 units)

ELEN 604. Semicustom Design with Programmable Devices

Digital circuit design methodologies. Semicustom implementations. Programmable logic devices classification, technology, and utilization. Software tools synthesis, placement, and routing. Design verification and testing. *Also listed as COEN 304. Prerequisite: ELEN 500 or equivalent.* (2 units)

ELEN 605. High-Level Synthesis

Synthesis strategy. Hardware description language and its applications in synthesis. Cost elimination. Multilevel logic synthesis and optimization. Synthesis methods and systems. Module generation. Timing considerations. Area vs. speed trade-offs. Design simulation and verification. Heuristic techniques. CAD tools. *Also listed as COEN 301. Prerequisites: ELEN 500 and ELEN 603.* (2 units)

ELEN 608. Design for Testability

Principles and techniques of designing circuits for testability. Concept of fault models. The need for test development. Testability measures. Ad hoc rules to facilitate testing. Easily testable structures, PLAs. Scan-path techniques, full and partial scan. Built-in self-testing (BIST) techniques. Self-checking circuits. Use of computer-aided design (CAD) tools. *Also listed as COEN 308. Prerequisite: ELEN 500 or equivalent.* (2 units)

ELEN 609. Mixed-Signal DA and Test

Mixed-Signal test techniques using PLL and behavioral testing as major examples. Overview of the IEEE 1149.4 Mixed-Signal standard. Mixed-Signal DFT and BIST techniques with emphasis on test economics. Most recent industrial mixed-signal design and test EDA tools and examples of leading state-of-the-art SoCs. *Prerequisites: ELEN 500 or COEN 200 and ELEN 387 or COEN 203.* (2 units)

ELEN 613. SoC (System-on-Chip) Verification

This course presents various state-of-the-art verification techniques used to ensure the corrections of the SoC (System-on-Chip) design before committing it to manufacturing. Both Logical and Physical verification techniques will be covered, including Functional Verification, Static Timing, Power, and Layout Verification. Also, the use of Emulation, Assertion-based Verification, and Hardware/Software Co-Verification techniques will be presented. *Also listed as COEN 207. Prerequisites: ELEN 500 or COEN 200 and ELEN 603 or equivalent.* (2 units)

ELEN 614. SoC (System-on-Chip) Formal Verification Techniques

With continuous increase of size and complexity of SoC, informal simulation techniques are increasing design cost prohibitively and causing major delays in TTM (Time-To-Market). This course focuses on formal algorithmic techniques used for SoC Verification and the tools that are widely used in the industry to perform these types of verifications. These include programming languages such as System Verilog, Vera, and e-language. The course also covers the various formal verification techniques such as propositional logic; basics of temporal logic. Theorem proving, and equivalent checking. Industrial-level tools from leading EDA vendors will be used to demonstrate the capabilities of such techniques. *Also listed as COEN 208. Prerequisites: ELEN 500 or COEN 200 and ELEN 603 or equivalent.* (2 units)

ELEN 617. Storage Systems – Technology and Architecture

The course will address the developments in storage systems. Increase in data storage has led to an increase in storage needs. This arises from the increase of mobile devices as well as increase in Internet data storage. This course will provide the students good knowledge of different storage systems as well as challenges in data integrity. A discussion of the next generation of storage devices and architectures will also be done. (2 units)

ELEN 620. Design of System-on-Chip

A project-oriented course that draws on the student's knowledge of logic design, circuit design, synthesis, and digital testing. Implementation of designs in FPGAs. Advanced topics including design verification, floor planning, power and delay budgeting, backannotation, selection of the appropriate DFT constructs, etc. *Prerequisite: ELEN 388, 500, 603, or 608.* (2 units)

ELEN 624. Signal Integrity in IC and PCB Systems

Analysis, modeling and characterization of interconnects in electronic circuits; Transmission line theory; losses and frequency dependent parameters. Issues in signal integrity of high-speed/high-frequency circuits; means of identifying signal integrity problems. Reflection and crosstalk; analysis of coupled-line systems. Power distribution networks in VLSI and PCB environments and power integrity. Signal/Power integrity CAD. *Prerequisite: ELEN 201.* (2 units)

ELEN 639. Audio and Speech Compression

Audio and speech compression. Digital audio signal processing fundamentals. Non-perceptual coding. Perceptual coding. Psychoacoustic model. High-quality audio coding. Parametric and structured audio coding. Audio coding standards. Scalable audio coding. Speech coding. Speech coding standards. *Also listed as COEN 339. Prerequisites: AMTH 245, and COEN 279 or equivalent.* (2 units)

ELEN 640. Digital Image Processing I

Digital image representation and acquisition; Fourier, cosine, and wavelet transforms; linear and nonlinear filtering; image enhancement; morphological filtering. *Also listed as COEN 340. Prerequisite: ELEN 234.* (2 units)

ELEN 641. Image and Video Compression

Image and video compression. Entropy coding. Prediction. Quantization. Transform coding and 2-D discrete cosine transform. Color compression. Motion estimation and compensation. Digital video. Image coding standards such as JPEG. Video coding standards such as the MPEG series and the H.26x series. H.264/MPEG-4 AVC coding. JCT-VD HEVC coding. Rate-distortion theory and optimization. Visual quality and coding efficiency. Brief introduction to 3D video coding and JCT-3V 3D-HEVC. Applications. *Also listed as COEN 338. Prerequisites: AMTH 108, AMTH 245, basic knowledge of algorithms.* (4 units)

ELEN 642. Medical Imaging

Image formation from noninvasive measurements in computerized tomography, magnetic resonance imaging, and other modalities used clinically and in research. Analysis of accuracy and resolution of image formation based on measurement geometry and statistics. Offered in alternate years. *Also listed as BIOE 642. Prerequisites: AMTH 211 and either ELEN 234 or AMTH 358.* (2 units)

ELEN 643. Digital Image Processing II

Image restoration using least squares methods in image and spatial frequency domains; matrix representations; blind deconvolution; super-resolution methods; reconstructions from incomplete data; image segmentation methods, three-dimensional models from multiple views. *Also listed as COEN 343. Prerequisite: ELEN 640.* (2 units)

ELEN 644. Computer Vision I

Introduction to image understanding, psychology of vision, sensor models, feature extraction, shape from shading, stereo vision, motion detection and optical flow. *Also listed as COEN 344. Prerequisite: ELEN 233 or 640.* (2 units)

ELEN 645. Computer Vision II

Texture, segmentation, region growing. 2-D geometrical structures and 3-D inference. Syntatic models, object matching, and decision trees. *Also listed as COEN 345. Prerequisites: ELEN 644 and AMTH 211.* (2 units)

ELEN 649. Topics in Image Processing and Analysis

(2 units)

ELEN 701. RF and Microwave Systems

The purpose of this class is to introduce students to the general hardware components, system parameters, and architectures of RF and microwave wireless systems. Practical examples of components and system configurations are emphasized. Communication systems are used to illustrate the applications. Other systems, such as, radar, the global positioning system (GPS), RF identification (RFID), and direct broadcast systems (DBS) are introduced. (2 units)

ELEN 705. Computer-Aided Design for Microwaves

A survey of approaches to CAD and to existing CAD software packages. Extensive applications in microwaves. Modeling, synthesis, algorithms, optimization. *Prerequisite: ELEN 201.* (2 units)

ELEN 706. Microwave Circuit Analysis and Design

Microwave circuit theory and techniques. Emphasis on passive microwave circuits. Planar transmission lines. Field problems formulated into network problems for TEM and other structures, scattering and transmission parameters, Smith charts, impedance matching, and transformation techniques. Design of power dividers, couplers, hybrids and microwave filters. Microwave CAD. *Prerequisite: ELEN 201.* (2 units)

ELEN 711. Active Microwave Devices I

Scattering and noise parameters of microwave transistors, physics of silicon bipolar and gallium arsenide MOSFET transistors, device physics, models, and high-frequency limitations. Applications to microwave amplifier and oscillator designs. *Prerequisite: ELEN 251.* (2 units)

ELEN 712. Active Microwave Devices II

Continuation of ELEN 711. Emphasis on linear active circuits and computer-aided design techniques. *Prerequisite: ELEN 711.* (2 units)

ELEN 714. Nonlinear Microwave Device Modeling

Continuation of ELEN 712. Nonlinear models of diodes, bipolar transistors, and FETs applied to the design of frequency converters, amplifiers, and oscillators. Techniques. Offered in alternate years. *Prerequisite: ELEN 711.* (2 units)

ELEN 715. Antennas I

Fundamentals of radiation, antenna pattern, directivity and gain. Dipole and wire antennas. Microstrip Patch Antennas. Broadband antennas. Antennas as components of communications and radar systems. Antenna measurement. Antenna CAD. *Prerequisite: ELEN 201.* (2 units)

ELEN 716. Antennas II

Continuation of ELEN 715. Aperture antennas. Traveling-wave antennas. Antenna Arrays. Linear arrays with uniform and non-uniform excitations. Beam scanning and phased arrays; Planar arrays; Array Synthesis. *Prerequisite: ELEN 715.* (2 units)

ELEN 717. Antennas III

Continuation of ELEN 716. Reflector, and lens antennas. Large antenna design. High-frequency techniques. Geometrical optics. Physical optics. Diffraction. Antenna synthesis. Offered in alternate years. *Prerequisite: ELEN 716.* (2 units)

ELEN 725. Optics Fundamentals

Fundamental concepts of optics: geometrical and wave optics. Optical components—free space, lenses, mirrors, prisms. Optical field and beams. Coherent (lasers) and incoherent (LED, thermal) light sources. Elements of laser engineering. Optical materials. Fiber optics. Polarization phenomena and devices. *Also listed as PHYS 113. Prerequisite: ELEN 201 or equivalent.* (4 units)

ELEN 726. Microwave Measurements, Theory, and Techniques

Theory comprises six classroom meetings covering signal flow graphs, error models and corrections, S-parameter measurements, scalar and vector analyzers, microwave resonator measurements, noise figure measurements, signal generation and characterization, spectrum analyzers, and phase noise measurements. Four laboratory meetings. Offered in alternate years. *Prerequisite: ELEN 711.* (3 units)

ELEN 729. Topics in Electromagnetics and Optics

Selected advanced topics in electromagnetic field theory. *Prerequisite: As specified in class schedule.* (2 units)

ELEN 921C. Introduction to Logic Design

Boolean functions and their minimization. Designing combinational circuits, adders, multipliers, multiplexers, decoders. Noise margin, propagation delay. Bussing. Memory elements: latches and flip-flops; timing; registers; counters. Introduction to FPGAs and the need for the use of HDL. Taught in the graduate time format. Not for graduate credit. *Also listed as COEN 921C.* (2 units)

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Department of Engineering

In addition to the courses offered by the individual departments, the School of Engineering also offers courses which are interdisciplinary in nature as follows:

COURSE DESCRIPTIONS

ENGR 207. Medical Device Invention - From Ideas to Business Plan

This course will introduce students to various tools and processes that will improve their ability to identify and prioritize clinical needs, select the best medical device concepts that address those needs, and create a plan to implement inventions. *Also listed as BIOE 207.* (2 units)

ENGR 249. Topics in Bioengineering**

An introduction to the central topics of bioengineering including physiological modeling and cellular biomechanics (e.g., modeling of the human voice production and speech biomechanics), biophotonics, biomedical imaging, visualizaion technology and applications (e.g., virtual endoscopy), biosignals and analysis methods, microfluidic devices and bio-nanotechnology. *Also listed as BIOE 249.* (2 units)

ENGR 250. Introduction to Bioinformatics and Sequence Analysis**

Overview of bioinformatics. Brief introduction to molecular biology including DNA, RNA, and protein. Pairwise sequence alignment. Multiple sequence alignment. Hidden Markov models and protein sequence motifs. Phylogenetic analysis. Fragment assembly. Microarray data analysis. Protein structure analysis. Genome rearrangement. DNA computing. *Prerequisites: AMTH 377 or MATH 163 or equivalent and programming experience.* (4 units)

ENGR 251. Molecular Biology for Engineers**

Comprehensive introduction to molecular biology for the non-biologist. Study of macromolecules that are critical to understanding and manipulating living systems. Proteins. Nucleic acids, DNA, and RNA. Genes and genetic code. Transcriptions, translations, and protein synthesis. Information storage and replication in DNA. Mechanics and regulation of gene expression. Splicing. Chromosomes. The human genome project. Scientific, social, and ethical issues. *Also listed as BIOE 251.* (2 units)

ENGR 253. Molecular Biology for Engineers II**

The science underlying biotechnology: how DNA, genes, and cells work, and how they can be studied and manipulated in fields as diverse as biomedical research, bioengineering, pharmaceutical and vaccine development, forensics, and agriculture. Laboratory experiments will focus on isolating, studying, and using DNA in a variety of contexts. The course includes a laboratory component. *Prerequisite or co-requisite: ENGR 251 or equivalent.* (2 units)

*ENGR 256. Introduction to NanoBioengineering***

This course is designed to present a broad overview of diverse topics in nanobioengineering, with emphasis on areas that directly impact applications in biotechnology and medicine. Specific examples that highlight interactions between nanomaterials and various biomolecules will be discussed, as well as the current status and future possibilities in the development of functional nanohybrids that can sense, assemble, clean, and heal. *Also listed as BIOE 256.* (2 units)

*ENGR 257. Introduction to Biofuels Engineering***

This course will cover the basic principles used to classify and evaluate biofuels in terms of thermodynamic and economic efficiencies as well environmental impact for resource recovery. Special emphases will be placed on emerging applications namely Microbial Fuel Cell Technology and Photo-bioreactors. *Also listed as BIOE 157/257.* (2 units)

ENGR 258. Introduction to 3D Bioprinting

This is an introductory course to 3D bioprinting, covering basic concepts that drive this technology and fundamental concepts in the biomaterial requirements and 3D cell culture technology. Different techniques in bioprinting highlighting key aspects of each technology will be illustrated. In addition, the requirements and challenges in developing biocompatible scaffolds and 3D cell culture techniques will be discussed. Direct applications of 3D bioprinting in biomedicine and other areas today will be discussed in this course. (2 units)

*ENGR 260. Nanoscale Science and Technology***

Overview of key elements of physics, chemistry, biology, and engineering underlying this interdisciplinary field. Bulk vs. surface properties of materials. Surface phenomena and quantum phenomena. Self-assembly and soft lithography. Nanoscale materials characterization. Carbon nanotubes, inorganic nanowires, organic molecules for electronics, biological and bio-inspired materials. Emerging applications of nanoscale materials. *Prerequisite: Graduate standing.* (2 units)

ENGR 261. Nanotechnology and Society

Addresses the fundamental scientific and technological underpinnings of the important new field of nanotechnology. Examines how our understanding and our technological capabilities have evolved over the past century, and how nanotechnology proposes new applications that can address social and economic goals. An appreciation of the interaction between these goals and the evolution of the technology is central to the course. Students will develop critical thinking about the prospects for nanotechnology in order to be able to assess the relevant ethical and social issues, and also the possibility and/or likelihood of the development of specific applications. (4 units)

*ENGR 262. Nanomaterials***

Physics, chemistry, and materials science of materials in the nanoscale. Thin films, inorganic nanowires, carbon nanotubes, and quantum dots are examples covered in detail as well as state-of-the-art synthesis processes and characterization techniques for these materials as used in various stages of technology development. *Also listed as ELEN 360. Prerequisites: ENGR 260 and ELEN 261.* (2 units)

ENGR 271. Energy Conservation

It is by no means clear that the shortage of carbon-free energy can be resolved by identifying alternative resources. As a result, conservation must play a key role in the development of new energy policies, both locally and globally. This course explores how conservation and sustainability relate to each other, with special emphasis on the value of cost-effective, innovative water recycling, and strategies for reducing the use of electrical energy. (2 units)

ENGR 272. Energy Public Policy

The class will survey the types of energy used historically from traditional biomass, to coal, to natural gas, to nuclear and renewables, as well as the increasingly diverse possibilities for future use discussed in current policy debates. Coverage will also include a historical review of regulation and policy in the energy industry. The geographic scope will be international. The field of energy analysis and policy is inherently interdisciplinary. *Prerequisite: ELEN 280/MECH 287.* (2 units)

ENGR 273. Sustainable Energy and Ethics

This course explores the ethical implications of energy production, distribution and consumption, with the aim of understanding those normative considerations that motivate public, institutional and private bodies to develop sustainable energy policies and practices. Through examination of texts and case studies, students will learn to critically analyze, develop and defend ethical judgments and practices with respect to energy. Topics include considerations of environmental justice; tension between global and local spheres of ethical concern; the rights and interests of potential stakeholders, both human and non-human; our duties with respect to prevention or mitigation of harms and management of risk; our ethical obligations to future generations; and the role of personal, civic and professional virtues in guiding sustainable energy practices. (2 units)

ENGR 288. Co-op Education

The primary purpose of Co-op education is to give students an opportunity to gain practical knowledge in their field of study. This course is designed to prepare them for such an experience. It consists of a series of lectures on topics that will familiarize them with the Silicon Valley working environment, and will enable them to relate their experience in the industry to their academic program. This course is required for all international students who wish to do Curricular Practical Training (CPT). Engr 288 is not offered in the summer quarter. Attendance is mandatory. P/NP grading. (1 unit)

ENGR 289. Extended Co-Op Education

Students who extend their co-op experience beyond one quarter must be enrolled in this class. The course may be taken for credit up to four times, and students are required to submit a final report in each quarter in which they are enrolled. The final report should focus on skills, experiences and insights that they acquired in the current term. In order to get a passing grade, students must also submit a new supervisor report, which evaluates their performance during the most recent 10 week period. P/NP grading. *Prerequisite: ENGR 288.* (1 unit)

Note: ENGR 288 can be taken during the first quarter of CPT, or before the training begins. ***ENGR 288 is not offered in the summer quarter.*** *The units associated with ENGR 288 and ENGR 289 are additional to the 45 units that are required by the department.*

ENGR 293. Directed Research

Special research directed by a faculty member. By arrangement. *Prerequisite: Registration requires the faculty member's approval.* (1–6 units per quarter)

ENGR 302. Managing in the Multicultural Environment

Provides practical, theoretical, and experiential tools to manage a multicultural workforce. Cases from Silicon Valley engineering environments will be studied. Topics will include: (1) insights to various cultures' approaches to time, information, planning, decision making, relationships, power and change; (2) developing leadership, motivation, and participation in multicultural teams; (3) creating an environment that maximizes the benefits of diversity and retains workers from a variety of cultural backgrounds; (4) resolving conflict when there are different cultural approaches; and (5) the role of corporate culture for multicultural and global companies. (2 units)

ENGR 303. Gender and Engineering

This course, based on brain science, culture and communication, provides a foundation for managing the different worlds—the different cultural lenses, paradigms and different competencies—many women and men bring to an engineering workplace. Gender Competence, effective management of differences increases "fire prevention," customer focus, and innovation in research, development and marketing of products; and advancement of both women and men. (2 units)

ENGR 304. Building Global Teams

Challenges of working virtually and globally. Building global teams. Working across cultures and distance; achieving goals while managing differences. Diverse approaches to managing task, time, and hierarchy. Social interactions and decision-making. Culture's impact on teamwork. Global leader dimensions. Trust building. Empowering self and others. Business practices in China, India, Russia, and other countries. (2 units)

ENGR 306. Engineering and the Law

Exploration of legal issues affecting project engineers, contractors, and owners. Topics include structure of project teams, contracts, standard of care, insurance, and dispute resolution. Evolving legal issues with Integrated Project Delivery (IPD) and Building Information Modeling (BIM). (2 units)

ENGR 310. Engineering Ethics

This course is designed to help students develop a set of effective tools for handling everyday ethical dilemmas and for developing their own vision of what it means to be a morally good engineer. Fundamental concepts from classical ethics theory will be used as the framework for discussing a range of topics that are of interest to the engineering profession. The class will include case studies that are related to recent technological advances, as well as issues that practicing engineers commonly encounter in their work. (2 units)

ENGR 330. Law, Technology, and Intellectual Property

Study of available legal provisions for establishing, receiving, preserving, and enforcing intellectual property rights in research, development, engineering, and marketing of products. Includes a study of patents, trade secrets, copyrights, mask works, trademarks, and employer-employee contracts regarding intellectual property. (2 units)

ENGR 331. Patent Law for Engineers

Study of invention, invention disclosure, patent application drafting, patent application assignment, patent application filing, patent prosecution, and foreign filing. Includes a discussion of patent case law, patent statutory law, patent rules, and the Manual of Patent Examining Procedure (MPEP). (2 units)

ENGR 334. Energy, Climate Change, and Social Justice

The field of climate ethics has emerged recently to negotiate the serious and complex ethical choices facing human society as we balance energy, environmental, and economic development needs. Social science and ethical lenses are used to examine energy use and climate disruption in light of the moral principle of social justice. This course gives graduate engineering students the background and skills to communicate these issues in several different modes. It consists of three main thematic parts: energy choices; social vulnerabilities; and difficult policy dilemmas. (2 units)

ENGR 336. Engineering for the Developing World

How does one innovate products and services for developing countries? How can complex problems be tackled with simple technologies and low-cost business models? This course presents a framework of engineering design and management techniques that are appropriate for developing markets. Topics such as "ruggedization," cost control, and local resource use will be explored through a variety of examples and case studies, which range from alternate energy and low-cost diagnostics to mobile applications and micro entrepreneurship. This course examines the potential social benefits that design, manufacturing, and business innovation can provide to address various challenges in the developing world. (2 units)

ENGR 337. Sustainability and Green Information Technology

The course is designed to give a thorough understanding of how IT infrastructure can be managed and optimized for maximum energy efficiency and minimum environmental impact. It also describes in some detail how IT leaders, data center operators, and other related sustainability advocates can benefit (and profit) from implementing energy efficient corporate IT infrastructure both inside and outside the data centers. Topics that will be covered include technologies and strategies for implementing green data centers, re-configuring existing infrastructure to ensure reduced energy consumption, managing air flow, and implementing sustainable IT asset disposal policies. (2 units)

ENGR 338. Mobile Applications for Emerging Markets

The mobile revolution is changing the lives of people across the globe, from Wall Street to Main Street to rural villages. This course will provide an overview of the technological innovation, including applications and instrumentation, which the mobile revolution is spawning, particularly in underserved communities globally. It will feature guest speakers from technology companies involved in Mobile R&D, look at market and beneficiary needs, and discuss how to innovate products and services for these customers and how to tackle complex 'life' problems with simple technologies, applications, and business models, using real-life case studies. (2 units)

*ENGR 339. Energy Storage Systems***

Energy storage systems play an essential role in the utilization of renewable energy. They are used to provide reserve power under different circumstances and needs such as peak shaving, load leveling, and ancillary services. Power electronics equipment converts the battery power into usable grid power. The course will survey batteries, pumped storage, flywheels, ultracapacitors, etc., with an analysis of the advantages and disadvantages, and uses of each. *Also listed as ELEN 287.* (2 units)

ENGR 340. Distributed & Renewable Energy

This course surveys energy engineering and entrepreneurship in emerging market countries, with an emphasis on strategies for coping with the absence of a grid. It analyzes strategies for energy generation, transmission and storage at household, community and regional scales drawing from sector and case studies in the developing world. (2 units)

ENGR 341. Innovation, Design and Spirituality

This course integrates the social, human, ethical, and creative dimensions of frugal innovation for graduate engineering students. Frugal innovation is a creative engineering design process, whose primary purpose is to address the basic human needs of people in underserved communities worldwide. This course presents the what and the how of frugal innovation, but emphasizes the why and the who. Why should engineers and technology creation address the needs of economically marginalized communities? And, who are the kinds of engineers that are able to create frugal innovation strategies? By framing innovation and design in terms of moral purpose and spiritual meaning, students will deepen their self-knowledge and enhance their leadership skills. (2 units)

ENGR 342. 3D Print Technology and Society

This class is designed to introduce students to 3D print technology, which offers a range of exciting possibilities for product design, delivery and democratization of entrepreneurship. Along with hands-on experience of the technology, students will be exposed to the eco-system engaged by the technology. Implications for life sciences, career opportunities, entrepreneurship and restructuring of global markets and society will be examined. (2 units)

ENGR 343. Science, Religion and the Limits of Knowledge**

The limits of scientific knowledge are examined in the framework of nonlinear system theory, metamathematics and modern physics. The technical background developed in the course is used as a basis for exploring the relationship between science, aesthetics, and religion. Particular emphasis is placed on the rationality of faith, and on controversial questions where the views of scientists and theologians appear to conflict. *Prerequisite: Basic familiarity with differential equations.* (2 units)

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Department of Engineering Management and Leadership

Dean's Executive Professor: Frank Barone *(Chair)*

OVERVIEW

The engineering management and leadership degree focuses on how we work—the management of technical activities through which the manager integrates physical and human resources. Technical managers ensure that personal and organizational objectives are realized by coupling task and process in the achievement of objectives primarily in the areas of research, development, design, operations, testing, marketing, and field service. Engineering management and leadership coursework encompasses these activities and the ways in which they interface with other activities within organizations.

DEGREE PROGRAM

Surveys of technical professionals around the world reveal that there are two major motivators in play: personal career growth and expanded responsibility in the firm. Santa Clara's Engineering Management and Leadership Program addresses both concerns.

The goal of this program is to support the development of technical managers. To this end, the program requires that approximately half of the degree units be devoted to a technical stem, drawn from one or more of the other engineering departments. The remaining units are in management-leadership related studies.

Master of Science in Engineering Management and Leadership

Admission to the Engineering Management and Leadership Program **is open only to those students who hold an undergraduate degree or graduate degree in engineering or computer science.** The undergraduate degree must be from a four-year engineering program substantially equivalent to Santa Clara's. Students holding undergraduate degrees in disciplines other than civil engineering, computer engineering, electrical engineering or mechanical engineering must be prepared to select technical stem courses from these disciplines as listed in the current Graduate Engineering Bulletin. In addition, the GRE is required for all students who do not have at least two years of working experience in the United States.

Requirements

Students are required to complete a minimum of 45 quarter units to complete the master's degree, following these guidelines:

- Engineering Management 20 units
- The Technical Stem 19 units
- The Graduate Core 6 units

Courses for the technical stem are selected from the Graduate Engineering Bulletin. All of the requirements for the engineering management and leadership degree must be completed within a six-year timeframe.

A completed program of studies for Engineering Management and Leadership degree candidates must be submitted to the chair of the Department of Engineering Management and Leadership during the first term of enrollment to ensure that all courses undertaken are applicable to the degree. Students who take courses that have not been approved for their program of studies by both the department chair and the Graduate Services Office do so at their own risk, as they may not be counted toward completion of the degree.

A maximum of nine quarter units (six semester units) of graduate-level coursework may be transferred from other accredited institutions at the discretion of the student's advisor provided they have not been applied to a previous degree. However, in no case will the minimum units taken in the Department of Engineering Management and Leadership be fewer than 16. Extension classes, continuing education classes, professional development courses, or classes from international universities are not accepted for transfer credits.

Technical Stem Courses

Courses for the technical stem of Engineering Management and Leadership are selected from the graduate course listings in the Graduate Bulletin. However, not all graduate classes listed in the bulletin are considered technical in terms of fulfilling the technical stem requirements. This is especially the case of ENGR courses. In addition, there are other limitations some of which are listed below. Therefore, it is important that students complete a program of studies in their first term, as recommended above, to make sure all of the courses they select will fulfill the degree requirements.

- All courses applied to the Engineering Management and Leadership degree must be graded courses—no P/NP courses are allowed.
- Undergraduate courses cross-listed with graduate course numbers do not apply unless the student registers with the graduate course number.
- Graduate seminars in other departments such as ELEN 200, COEN 400, MECH 261, MECH 297 are not applicable.
- COEN 485 Software Engineering Capstone is not applicable to the technical stem unless students complete three one-quarter consecutive sessions beginning in the fall quarter.
- ENGR 207, 258, 261, 271, 272, 273, 275, 288, 289, 293, 302, 303, 304, 306, 310, 330, and 331-338 and 340, 341, 342 do not count toward the technical stem.
- In order to accommodate the 19 unit technical stem requirement, students are allowed to enroll in one unit of Independent Study or Directed Research under the direction of a full time faculty member in the respective engineering department. Any additional units will not be counted toward graduation.
- New courses are often developed and offered during the academic year that are not listed in this bulletin. It is important that students check with their advisor prior to enrolling in those courses to make sure they will count toward their degree.

In addition to the overall 3.0 GPA graduation requirement, engineering management and leadership degree candidates must earn a 3.0 GPA in those courses applied to their technical stem and a 3.0 GPA in their engineering management course stem. All courses in which a student is enrolled at Santa Clara are included in these calculations.

Please Note: International students or students not fluent in the English language should enroll in the following course prior to enrolling in advanced course in engineering management:

- *EMGT 270 Effective Oral Technical Presentations or*
- *EMGT 271 Effective Written Technical Communications I or*
- *EMGT 318 Strategies For Career and Academic Success (for foreign-born technical professionals)*

ENGINEERING MANAGEMENT FIVE-YEAR PROGRAM

The School of Engineering offers qualified Santa Clara University undergraduates the opportunity to earn both a Bachelor of Science degree in their technical discipline and a Master of Science degree in Engineering Management in five years. This is an excellent path to continue your technical education while learning the essential skills required to manage hi-tech projects and people. It is an excellent way to save time and open up more career possibilities early on. The degree program is open to students in bioengineering, civil engineering, computer science and engineering, electrical engineering, mechanical engineering, and software engineering.

The application fee and GRE General Test requirement are waived for students completing their undergraduate B.S. degree in the technical disciplines listed above and have a minimum GPA of 3.0 in their technical major. Students are required to apply no later than the end of their junior year. Upon notification of acceptance into the Engineering Management Five-Year Program, students may begin taking graduate-level courses in the fall quarter of their senior year. The maximum number of graduate units allowed as an undergraduate in this program is 20.

Students in this program will receive a B.S. degree after satisfying the standard undergraduate degree requirements. Students will then be matriculated to the Engineering Management and Leadership M.S. program and must then fulfill all requirements for the M.S. degree.

Notes:

1. B.S. degrees (for those who are graduating seniors) must be posted by September 1 to allow the student progression in their graduate career.
2. Undergraduate students must submit "Permission to Take Graduate Course" form to be correctly registered for graduate courses.
3. All coursework applied to the M.S. degree must be at the 200 level or above and not applied to any other degree.
4. Course numbers below 200 indicate undergraduate courses, numbers of 200 and above indicate graduate courses. Students may take courses assigned both undergraduate and graduate numbers (same title used for both numbers) only once as an undergraduate or graduate student.
5. Students must register with the graduate course number in cross-listed courses to apply the course to an M.S. degree.
6. Students who are entering this program should meet with their Engineering Management advisor at the end of their junior year to develop a program of studies to ensure that all graduate courses they plan to take are applicable to the Engineering Management and Leadership M.S. degree.

COURSE DESCRIPTIONS

EMGT 251. Production and Operations Management

Planning and controlling operations, operations strategy, inventory and capacity planning, forecasting, purchasing, scheduling. Facilities, layout, quality assurance. (2 units)

EMGT 253. Operations and Production Systems

Provides the knowledge and techniques required to properly manage operations and production systems. Topics include operations strategies, decision making, technology management, computer-integrated manufacturing. TQM, statistical process control, Just-in-Time, capacity and resource planning, simulation, and project management. (2 units)

EMGT 255. Managerial Accounting for Operating Managers

This course provides an introductory survey to the underlying principles and applications of managerial accounting and financial analysis. Taken from the perspective of the recipient of accounting data, rather than the generator of reports, this course will equip operating managers with the skills to interpret the story behind the numbers to gain a more accurate understanding of the status of their business and to make more informed decisions. (2 units)

EMGT 256. Finance and Budgeting for Engineering Managers

Profit planning, return on investment, accounting conventions, evaluation of economic alternatives, break-even analysis, tax environment, capital budgeting, cash flow, inventory policy, capital structure, security markets, financial controls, finance in general management. *Prerequisite: EMGT 255 or accounting knowledge.* (2 units)

EMGT 257. The Business Environment

The economy; the price system; business cycles, money and banking, securities markets, business organizations, the corporation, business functions; marketing technology, finance, and operations. (2 units)

EMGT 258. Global Marketing of Technical Systems

The problems of meeting different needs in different countries without overwhelming costs. (2 units)

EMGT 261. Technical Products and Profits

Organizing a technical firm. Creating a business plan. Integrating marketing, finance, design, manufacturing, and service systems. (2 units)

EMGT 264. Managing Research and Development

Role of R&D in corporate growth; unique characteristics of R&D management; financing applied research; measuring return on investment; planning for diversification; structure of R&D organizations; choice of an R&D portfolio; idea generation process; selecting projects and establishing objectives; developing technical personnel; motivation of personnel; technical assistance to R&D staff; planning, scheduling, and control; project budgets and controls; performance appraisal; leadership in research organizations. (2 units)

EMGT 269. Human Resource Development and the Engineering Manager

Concepts of human resource management, the meaning of work, the individual and the organization, growth and learning, the manager's role in career/life management, human resource strategies. (2 units)

EMGT 270. Effective Oral Technical Presentations

Role of communications, persuasive communications, speaking as a meeting leader, substitutes for reading speeches, purposes and effects, selling ideas to one or more persons, how to make meetings work. (2 units)

EMGT 271. Effective Written Technical Communication I

Cluster writing; pyramid technique; audience analysis; opening, body, and end of text; technical correspondence; abstracts and summaries; presentation patterns for reports and proposals; proposal presentation. (2 units)

EMGT 272. Effective Written Technical Communication II

Intensive writing practicum, overview of writing, mechanics of style, editing techniques, strategies for editing the work of others. (2 units)

EMGT 280. Integral Systems/Micro/Nano Product Development

The management of a process: architecture, design process, development, technology strategy, manufacturing, marketing, education, finance, and probability. (2 units)

EMGT 283. Engineering Venture Management

All facets of developing and starting an engineering project venture. Class works as a team to develop one new engineering business venture considering behavioral, marketing, financial, manufacturing engineering, and administrative aspects. (2 units)

EMGT 285. Relationship Management

The management of relationships in a supply chain. Integrating product requirements from concept through service and support. Skills taught for characterizing, developing, and leveraging, various key relationships in one's organization. Articulating and developing interaction models, dependency analyses, and team structures. Developing tools to manage outsourcing models, partnerships, co-development strategies and organizational synergy in line with overall business objectives. (2 units)

EMGT 286. Fundamentals of Quality Management

A broad view of quality management through systems thinking, people and organization, measurement and processes, and continuous learning and improvement. Each of the four areas represents a critical aspect of quality management. (2 units)

EMGT 289. Managing, Controlling, and Improving Quality

Management structure and statistical and analytical tools for quality success: total quality management, six-sigma and beyond, statistical inference (made simple), control charts (SPC), sampling procedures, designed experiments (DOE), and reliability. (2 units)

EMGT 292. Managing Equipment Utilization

Improving equipment utilization, availability, reliability, and sustainability. Computerized equipment management systems. Preventive maintenance, reliability-centered maintenance, and platform ownership. (2 units)

EMGT 295. Project Planning Under Conditions of Uncertainty

Managerial decision making in project management under conditions of varying knowledge about the future. Decisions relying on certainty and decisions based on probabilities and made under risk. Situations in which there is no basis for probabilities; decisions made under conditions of uncertainty. Use of applications of decision theory to help develop strategies for project selection and evaluation. (2 units)

EMGT 296. Project Risk Management

There are three fundamental steps: risk analysis, risk evaluation, and risk migration and management. The acceptable risk threshold is defined by the customer and management, and identifies the level above which risk reduction strategies will be implemented. (2units)

EMGT 299. Directed Research

By arrangement. Limited to a single enrollment. (1 unit)

EMGT 300. Coaction: Learning Leadership

Reg Revan developed Action Learning as a manager development tool. If groups of managers discuss their daily problems, it is a learning opportunity. It is also an opportunity for Tacit Knowledge exchange. *Prerequisite: Two years of industrial experience.* (2 units)

EMGT 301. Coaction Circles I

Team problem solving. (2 units)

EMGT 302. Coaction Circles II

Team problem solving. Additional leadership experience. (2 units)

EMGT 304. Sustaining High Achievement Careers

Discusses problems and issues involved with a lifetime career in a single firm. Adaptability and morale issues. (2 units)

EMGT 305. Technology Policy Issues

The issues that impact technology leadership roles. The environment to which Adaptive Systems must adjust. Current issues include sustainability, renewable energies, and global outsourcing. (2 units)

EMGT 307. Medical Device Product Development

The purpose of this course is to provide background information and knowledge to start or enhance a career in medical device product development. Discusses medical device examples, product development processes, regulation, industry information, and intellectual property. (2 units)

EMGT 318. Strategies For Career and Academic Success (for Foreign-born Technical Professionals)

Designed to help foreign-born engineers and technical professionals develop the knowledge and skills needed to be more effective in the American academic and corporate environments and to achieve career success. Focuses on key skills in career development, effective communication, interpersonal effectiveness, and building relationships with co-workers. Uses participatory, experiential training methods including role plays, simulations, and small group exercises. (2 units)

EMGT 319. Human Interaction I

Individuals interacting in groups to solve problems. Discusses mix of electronic and personal elements to achieve goals. (2 units)

EMGT 320. Human Interaction II

A close look at communications. Personal limits. Electronic interfacing. The role of communication skills, attitudes, knowledge level, and culture in the communication process. (2 units)

EMGT 322. Engineering Management Skills

This course will cover the skills required in transitioning from a technical contributor to a technical manager or team leader. This transition requires a new set of skills and knowledge in which engineers and scientists are typically not trained. These new skills will include "soft skills" from the areas of psychology, ethics, and interpersonal relationships as well as the management processes essential to becoming an effective manager. Students will think introspectively about their new managerial roles and responsibilities through lectures and discussions with classroom participation exercises and topical essay homework. (2 units)

EMGT 327. New Product Definition

The use of quality function deployment as a design system to effectively link a company with its customers. How to interview customers and generate design concepts that meet their needs. (2 units)

EMGT 329. Parallel Thinking

This workshop-style program will provide the tools and coaching engineering leaders need to be effective in harnessing the brainpower of groups. Draws heavily on the application of the research done at Stanford University on precision questioning, the work of Edward DeBono, and group processing work on high-performance systems. (2 units)

EMGT 330. Project Management Basics

Designed to provide the basic knowledge and techniques required to properly manage projects. Covers the fundamental concepts and approaches in project management such as the triple constraints, project life cycle and processes, project organizations, project scheduling, budgeting, resource loading, project monitoring and controls, and project information systems. (2 units)

EMGT 331. Strategic Technology Management

Translating strategic plans into action plans and ensuring their implementation. Integration of a process that crosses all organizational boundaries. Performance objectives and priorities, change and discontinuities, managed growth, accelerated technology transfer. Analyzing competitive technical position, collecting and utilizing user/customer information, and change leadership. (2 units)

EMGT 333. Computer-Aided Project Management Scheduling and Control

This course is designed to teach students real world project management using modern project management software. We consider customers, competition, technology, and financial realities in order to develop project requirements. We then go on to project planning, resource allocation, and strategies for dealing with multiple projects. Finally, we focus on project tracking, including earned value analysis and taking corrective action. (2 units)

EMGT 335. Advanced Project Management and Leadership

Covers the approaches and practices in project management over the lifespan of the project cycle. Highly interactive advanced course with in-class practice and analysis of real-world project examples. While providing the knowledge in project planning and control techniques, it focuses on the development of project leadership, teamwork, and problem solving skills. *Prerequisite: EMGT 330.* (2 units)

EMGT 336. Global Software Management (Introduction)

Discuss and understand the software development techniques and issues in view of offshore outsourcing. Discuss best practices, do's and don'ts in project management, and other techniques due to off-shoring and outsourcing. Case studies. (2 units)

EMGT 337. Global Software Management (Advanced)

Analyze the impact and changes in software development and management techniques because of offshore outsourcing. Discuss the people and technology issues. Analyze the business models and ROI. Understand the impact of culture on project dynamics. Special attention to outsourcing to India, China, and Europe. (2 units)

EMGT 338. Technical Product Management and Marketing

Introduction to product management, market/business planning and analysis, competitor and customer analysis and value propositions, product planning and strategy. Pricing, channel, promotion, and financial considerations. (2 units)

EMGT 340. Time-Effective Software Management

The management of software projects recognizing that this is a continuous change activity. Continuous enhancement of a product is necessary to remain competitive. Focuses on the differences between products and projects. (2 units)

EMGT 341. Software Project Metrics

Application of measurement techniques to software development management. The GQM paradigm. Product, project, and process metrics. The role of statistical quality control. Reading in the current literature. (2 units)

EMGT 345. Program Management

Fundamentals of program and portfolio management and how they are applied to improve business results on programs of varying size, within all types of businesses, from small companies to large enterprises. *Prerequisite: EMGT 330 (Project Management Basics) or equivalent experience.* (2 units)

EMGT 346. Engineering Economics

Valuating and selecting engineering projects based on their characteristics of risk, available information, time horizon, and goals. Utilization of classical capital budgeting techniques, qualitative criteria, and financial option theory. Exploration of the value of individual projects on the company's total portfolio of projects. Introduction to decision theory as it applies to project evaluation. *Prerequisite: Finance or familiarity with time value of money concepts such as net present value.* (2 units)

EMGT 347. Engineering Economics Advanced Concepts

A continuation of the concepts from EMGT 346. Rate of return analysis, uncertainty in future events, depreciation, replacement analysis, income taxes, inflation, selection of MARR, real options. *Prerequisite: EMGT 346.* (2 units)

EMGT 349. Advanced Leadership

Designed to create a holistic understanding of leadership. Through readings, discussions, and case studies, students will learn to integrate key leadership concepts from psychology, ethics, political science, philosophy, and sociology. Students will be able to characterize their individual approaches to leadership and learn to adapt it to changes resulting from globalization and advancing technology. (2 units)

EMGT 350. Success in Global Emerging Markets

Strategies and tactics for moving new products and technologies into global emerging markets, comprehending cultural impact, and creating new markets. Understanding your company's objective, determining what is possible, and developing practical go-to-market strategies. Topics include new ventures, sustainability, social responsibility, risk assessment and mitigation. (2 units)

EMGT 351. Strategic Marketing and New Product Development

New products in the strategic planning process. Developing new product criteria to meet enterprise goals. Market segmentation. Leveraging investments in new technology. (2 units)

EMGT 352. Marketing of High-Tech Products and Innovations

This course is designed to give engineers and managers an appreciation of the role that marketing plays in setting strategy for a successful high-technology product or venture. The course is not designed to provide training for a marketing role, but rather to provide an understanding of the importance of a marketing orientation, particularly for engineers and innovators who tend to pay less attention to market factors then to product development or technology. For those interested in marketing, the course provides insights into the particular challenges of marketing high-tech products and devices. (2 units)

EMGT 353. Introduction to Total Quality Management

The basic tenets of TQM: customer focus, continuous improvement, and total participation. Particular emphasis on using TQM to enhance new product development. (2 units)

EMGT 354. Innovation, Creativity, and Engineering Design

Research, development, the process of discovery, recognizing a need, encouraging change, assuming risks, technological feasibility, marketability, and the environment for innovation. (2 units)

EMGT 355. Accelerated Time to Market

The competitive edge, as well as market share, goes to the firm that is first to market with new products, placing pressure on the product development cycle. Addresses the steps taken to compress the product development cycle and to achieve first-to-market status. (2 units)

EMGT 356. Advanced Management of Technology

A continuation of EMGT 331. Enactment of a technology strategy including developing the firm's innovative capabilities, and creating and implementing a development strategy. *Prerequisite: EMGT 331 or instructor approval.* (2 units)

EMGT 357. Root Cause Analysis (RCA) Effective Problem Solving

Solving problems is one of the main functions of engineering and one of the main concerns of engineering managers. This course will focus on a step by step problem solving approach, used by the best engineering practitioners in the world, designed to improve the efficiency and effectiveness of the problem-solving process. Topics will include proper methods of problem description, identification, correction, and containment. (2 units)

EMGT 358. Global Technology Development

Global markets present growth opportunities for both business and professionals. Approaches the development of global technology from the perspective of the engineering manager engaged as either part of a large corporate team or as an entrepreneur in small business. Topics ranging from formal methodologies to practical lessons learned from industry. (2 units)

EMGT 360. Current Papers in Engineering Management and Leadership

Individual topics to be selected in concurrence with the instructor. (2 units)

EMGT 362. Topics in Engineering Management

Topics of current interest in engineering management and leadership. May be taken more than once as the topics change. (2 units)

EMGT 363. Seminar: Coaction Leadership

(2 units)

EMGT 364. Seminar: Leading for Collaborative Action

(2 units)

EMGT 365. Seminar: Self-Leadership

(2 units)

EMGT 367. Seminar: Leading Technical Professionals

(2 units)

EMGT 369. E-Commerce Technology and Strategy

Introduces e-commerce technology strategy fundamentals and then methodically classifies and examines several e-commerce models that incorporate value created for the customer, mechanisms for generating revenue and profits, economics and cost factors, growth and diversification strategies, risk factors and key strategic decisions, and tracking and sustainment. Course concepts are applied to specific case studies. (2 units)

EMGT 370. International (Global) Technology Operations

Examines methods and important issues in managing operations when customers, facilities, and suppliers are located across the globe. Topics include the global technology environment, international operations strategy and process formulation, and issues on the location and coordination of overseas facilities. These and other course topics are examined through a combination of lectures, text material, and integrated case studies. (2 units)

EMGT 373. Technology Entrepreneurship

Designed for students who are interested in starting their own venture as well as those working for a start-up company. Students will discover the process of moving from an idea to making a profit. Topics will include idea development, intellectual property, forming a team, obtaining funding, start-up logistics, executing your plan, and finding customers. Understanding the steps, risks, and pitfalls to avoid in starting a high-tech business can help in being better prepared for launching a successful technology venture. (2 units)

EMGT 376. Systems Thinking

Peter Senge's best seller The Fifth Discipline describes "A Learning Organization." He suggests that an organization's ability to learn faster than the competition is the only way to sustain a competitive advantage. Systems Thinking is among the capabilities to be developed. What kind of leadership is required to make this a reality? (2 units)

EMGT 378. New Product Planning and Development

This course blends the perspectives of marketing, design, and manufacture into a single approach to product development. Students are provided with an appreciation for the realities of industrial practice and for the complex and essential roles played by members of the product development teams. For industrial practitioners, in particular, the product development methods described can be put into immediate practice on development projects. (2 units)

EMGT 380. Introduction to Systems Engineering Management

Introduces the fundamental principles and methods of systems engineering and their application to complex systems. For the engineer and project manager it provides a basic framework for planning and assessing system development. For the non-engineer it provides an overview of how a system is developed. (2 units)

EMGT 381. Managing System Conceptual Design

A continuation of EMGT 380 addressing in detail the system engineer's responsibilities and activities in the concept development stage of the system lifecycle. Topics include needs and requirements analysis, system concept exploration and definition, and risk assessment. It concludes with a discussion of advanced development and the system engineer's role in planning and preparing for full scale engineering development. *Prerequisite: EMGT 380.* (2 units)

EMGT 382. Managing System Design, Integration, Test and Evaluation

A continuation of EMGT 381 with a focus on the system engineer's responsibilities and activities in the engineering development and post development stages of the system lifecycle. Topics include engineering design, system integration and evaluation, and the systems engineer's role in preparing for full scale manufacturing and subsequent deployment and support. *Prerequisite: EMGT 380.* (2 units)

EMGT 388. System Supportability and Logistics

The supportability of a system can be defined as the ability of a system to be supported in a cost effective and timely manner, with a minimum of logistics support resources. The required resources might include test and support equipment, trained maintenance personnel, spare and repair parts, technical documentation, and special facilities. For large complex systems, supportability considerations may be significant and often have a major impact upon life-cycle cost. It is therefore particularly important that these considerations be included early during the system design trade studies and design decision-making. (2 units)

EMGT 389. Design for Reliability, Maintainability, and Supportability

Provides the tools and techniques that can be used early in the design phase to effectively influence a design from the perspective of system reliability, maintainability, and supportability. Students will be introduced to various requirements definition and analysis tools and techniques to include Quality Function Deployment, Input-Output Matrices, and Parameter Taxonomy. (2 units)

EMGT 390. System Architecture and Design

Fundamentals of system architecting and the architecting process, along with practical heuristics. The course has a strong "how-to" orientation, and numerous case studies are used to convey and discuss good architectural concepts as well as lessons learned. Adaptation of the architectural process to ensure effective application of COTS will be discussed. (2 units)

EMGT 395. Intrapreneurship – Innovation from Within

This course speaks directly to the needs of an organization seeking to create an innovative business opportunity within the existing structure of the organization. The methods from this class are widely used by the most successful innovators in start-ups as well as established companies. This class will present the differences between entrepreneurship and intrapreneurship. Innovation and creativity are key components of intrapreneurship. (2 units)

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Department of Mechanical Engineering

Professors Emeriti: Mark D. Ardema, R. Ian Murray, Michel A. Saad
Professors: M. Godfrey Mungal, Terry E. Shoup
Associate Professors: Mohammad Ayoubi, Drazen Fabris *(Chair)*, Timothy K. Hight, Christopher Kitts, Hohyun Lee
Assistant Professors: On Shun Pak, Panthea Sepehrband, Michael Taylor

OVERVIEW

The Department of Mechanical Engineering is dedicated to delivering up-to-date, high-quality courses across a broad range of the discipline to meet the needs of both part- and full-time graduate students. These courses are concentrated in five technical areas: (1) design and analysis of thermofluid systems; (2) analysis and control of dynamic systems; (3) robotics and mechatronic systems; (4) mechanical design; and (5) materials engineering. In addition students interested in space systems are referred to the Lockheed Martin-Santa Clara University program in Chapter 17. Educational efforts are channeled to expand the skills of prospective and practicing engineers not only in understanding fundamentals, but also in developing competence in analyzing engineering systems. The department offers graduate degrees at the master, engineer, and doctorate levels, as well as certificates.

MASTER OF SCIENCE PROGRAMS

An M.S. degree requires 45 units of study with an overall GPA of 3.0 or higher. The student must select one of the five concentration areas, and develop a program of studies with an advisor. Courses taken to satisfy any particular requirement may be used to simultaneously satisfy additional requirements for which they are appropriate. Master of Science degrees must include the following:

- Engineering Core requirement as described in Chapter 4 (6 units)
- Math requirement (8 units): MECH 200 and 201, or MECH 202 and an approved two-course sequence or equivalent four unit course in applied math
- Topic Requirement: 12 or more units depending on concentration area
- Concentration Electives depending on the area (0–10 units)
- Culminating experience: 4–9 units towards a thesis, capstone project, or project course sequence

Culminating experience options depend on the concentration area. A thesis requires a faculty advisor and must be approved by an additional reader and the department chair. Thesis topics are to be determined by the student and faculty advisor, who need not be the concentration advisor. The additional reader need not be a Mechanical faculty member, but must be a full-time faculty member in the School of Engineering.

The student may take any additional graduate courses offered by the School of Engineering to meet the 45-unit requirement but no more than six units of Engineering Management courses may be taken.

Dynamics and Controls

Advisors: Dr. Mohammad Ayoubi, Dr. Christopher Kitts

Math requirement (8 units): MECH 200 and 201, or MECH 202 and approved two-course sequence or equivalent four unit course in Applied Math. Optimization techniques, numerical methods, probability, or linear algebra are recommended.

Required Courses

- MECH 214, 215 Advanced Dynamics I, II (4 units)
- MECH 305, 306 Advanced Vibrations I, II (4 units)
- MECH 323, 324 Modern Control Systems I, II (4 units)

Elective Courses (8 units required)

- MECH 205, 206 Aircraft Flight Dynamics I, II (4 units)
- MECH 221, 222 Orbital Mechanics I, II (4 units)
- MECH 232, 233 Multibody Dynamics I, II (4 units)
- MECH 329 Introduction to Intelligent Control (2 units)
- MECH 337, 338 Robotics I, II (4 units)
- MECH 355, 356 Adaptive Control I, II (4 units)
- MECH 423 and 424 Nonlinear Systems and Control I, II (4 units)
- MECH 429 and 430 Optimal Control I and II (4 units)
- MECH 431 and 432 Spacecraft Dynamics I, II (4 units)

Culminating experience: Thesis optional, counts towards concentration electives (4–9 units).

Materials Engineering

Advisor: Dr. Panthea Sepehrband

Math requirement (8 units): MECH 200 and 201, or MECH 202 and approved two-course sequence or equivalent four unit course in Applied Math.

Required Courses

- MECH 256 Introduction to Biomaterials (2 units)
- MECH 281 Fracture Mechanics and Fatigue (2 units)
- MECH 330 Atomic Arrangement, Defects, and Mechanical Behavior (2 units)
- MECH 331 Phase Equilibria and Transformations (2 units)
- MECH 332 Electronic Structure and Properties (2 units)
- MECH 333 Experiments in Materials Science (2 units)
- MECH 334 Elasticity (2 units)
- MECH 345 Modern Instrumentation and Experimentation (2 units)

Recommended Courses

- AMTH 210 Introduction to Probability I and AMTH 211 Continuous Probability (2 units)
- AMTH 217 Design of Scientific Experiments (2 units) and AMTH 219 Analysis of Scientific Experiments (2 units)
- AMTH 218 Process Troubleshooting and Control (2 units)
- CENG 205, 206, and 207 Finite Element Methods I, II, and III (2 units each)
- CENG 211 Advanced Strength of Materials (4 units)
- ELEN 271 Microsensors: Components and Systems (2 units)
- ELEN 274 and 275 Integrated Circuit Fabrication Processes I and II (2 units each)
- ELEN 276 Integrated Circuits Devices and Technology (2 units)
- ELEN 277 IC Assembly and Packaging Technology (2 units)
- ELEN 390 Semiconductor Device Technology Reliability (2 units)
- MECH 273 Designing with Plastic Materials (2 units)
- MECH 274 Processing Plastic Materials (2 units)
- MECH 277 Injection Mold Tool Design (2 units)
- MECH 350 and 351 Composite Materials I and II (2 units each)

Culminating experience: Thesis (4–9 units), or MECH 333B, or MECH 346.

Mechanical Design

Advisors: Dr. Tim Hight, Dr. Terry Shoup

Math requirement (8 units): MECH 200 and 201, or MECH 202 and approved two-course sequence or equivalent four unit course in Applied Math.

Required Courses

- CENG 205, 206, and 207 Finite Element Methods I, II, and III (2 units each)
- MECH 275 Design for Competitiveness (2 units)
- MECH 285 Computer-Aided Design of Mechanisms (2 units)
- MECH 325 Computational Geometry for Computer-Aided Design and Manufacture (2 units)
- MECH 334 Elasticity (2 units)
- MECH 415 Optimization in Mechanical Design (2 units)

Recommended Courses

- MECH 207, 208, and 209 Advanced Mechatronics I, II, and III (3 units each)
- MECH 273 and 274 Designing with Plastic Materials and Processing Plastic Materials (2 units each)
- MECH 281 Fracture Mechanics and Fatigue I (2 units)
- MECH 330 Atomic Arrangement, Defects, and Mechanical Behavior (2 units)
- MECH 331 Phase Equilibria and Transformations (2 units)

- MECH 332 Electronic Structure and Properties (2 units)
- MECH 371 and 372 Space Systems Design and Engineering I and II (4 units each)

Culminating experience: Thesis (4–9 units) or MECH 275B.

Robotics and Mechatronic Systems

Advisor: Dr. Chris Kitts

Math requirement (8 units): MECH 200 and 201, or MECH 202 and approved two-course sequence or equivalent four unit course in Applied Math.

Required Courses

- MECH 207 and 208 Advanced Mechatronics I, II (6 units)
- MECH 299 Thesis (1–9 units) or 290 Capstone Project (4–6 units)
- MECH 337 and 338 Robotics I, II (2 units each)

The student must also choose one of the following two-course sequences:

- MECH 218 and 219 Guidance and Control I, II (2 units each)
- MECH 323 and 324 Modern Control System I, II (2 units each)

Elective Courses (8 units required)

- MECH 209 Advanced Mechatronics III (2 units)
- MECH 218 Guidance and Control I (2 units)
- MECH 219 Guidance and Control II (2 units)
- MECH 275 Design for Competitiveness (2 units)
- MECH 311 Modeling and Control of Telerobotic Systems (4 units)
- MECH 315 Advanced Digital Control Systems I (2 units)
- MECH 316 Advanced Digital Control Systems II (2 units)
- MECH 323 Modern Control System Design I (2 units)
- MECH 324 Modern Control System Design II (2 units)
- MECH 329 Introduction to Intelligent Control (2 units)
- MECH 339 Robotics III (2 units)
- MECH 345 Modern Instrumentation and Experimentation (2 units)

Culminating experience: Thesis (4–9 units) or Capstone (4–6 units).

Thermofluids

Advisors: Dr. Drazen Fabris, Dr. Hohyun Lee, Dr. On Shun Pak

Math requirement (8 units): MECH 200 and 201, or MECH 202 and approved two-course sequence or equivalent four unit course in Applied Math.

Required Courses

- MECH 228 Equilibrium Thermodynamics (2 units)
- MECH 236 Conduction Heat Transfer (2 units)
- MECH 238 Convective Heat and Mass Transfer I (2 units)
- MECH 240 Radiation Heat Transfer I (2 units)
- MECH 266 Fundamentals of Fluid Mechanics (2 units)
- MECH 270 Viscous Flow I (2 units)

Elective Courses (8 units required)

- MECH 225 Gas Dynamics I (2 units)
- MECH 226 Gas Dynamics II (2 units)
- MECH 230 Statistical Thermodynamics (2 units)
- MECH 239 Convective Heat and Mass Transfer II (2 units)
- MECH 241 Radiation Heat Transfer II (2 units)
- MECH 242 Nanoscale Heat Transfer (2 units)
- MECH 268 Computational Fluid Dynamics I (2 units)
- MECH 269 Computational Fluid Dynamics II (2 units)
- MECH 271 Viscous Flow II (2 units)
- MECH 288 Energy Conversion I (2 units)
- MECH 345 Modern Instrumentation and Control (2 units)

Culminating experience: Thesis (4–9 units), or MECH 345 and MECH 346.

DOCTOR OF PHILOSOPHY PROGRAM

The doctor of philosophy degree is conferred by the School of Engineering in recognition of competence in the subject field and the ability to investigate engineering problems independently, resulting in a new contribution to knowledge in the field.

See the section on Academic Regulations for details on admission and general degree requirements. The following departmental information augments the general School requirements.

Academic Advisor

A temporary academic advisor will be provided to the student upon admission. The student and advisor must meet prior to registration for the second quarter to complete a preliminary program of studies, which will be determined largely by the coursework needed for the preliminary exam.

Preliminary Exam

A preliminary written exam is offered at least once per year by the School of Engineering as needed. The purpose is to ascertain the depth and breadth of the student's preparation and suitability for Ph.D. work. Each student in mechanical engineering must take and pass an exam in mathematics, as well as in four areas from the following list Fluid Mechanics, Heat Transfer, Strength of Materials, Dynamics, Design, Controls, Vibrations, Finite Element Analysis, Material Science, and Thermodynamics. The advisor must approve the student's petition to take the exam.

Doctoral Committee

After passing the Ph.D. preliminary exam, a student requests his or her thesis advisor to form a doctoral committee. The committee consists of at least five members, each of which must have earned a doctoral degree in a field of engineering or a related discipline. This includes the student's thesis advisor, at least two other current faculty members of the student's major department at Santa Clara University, and at least one current faculty member from another appropriate academic department at Santa Clara University. The committee reviews the student's program of study, conducts an oral comprehensive exam, conducts the dissertation defense, and reviews the thesis. Successful completion of the doctoral program requires that the student's program of study, performance on the oral comprehensive examination, dissertation defense, and thesis itself meet with the approval of all committee members.

ENGINEER'S DEGREE PROGRAM

The Department of Mechanical Engineering offers an engineer's degree program. Details on admissions and requirements are shown in the Academic Regulations section. Students interested in this program should seek individual advice from the department chair prior to applying.

CERTIFICATE PROGRAMS

Controls

Objective

The Controls Certificate is intended for working engineers in mechanical and closely related fields of engineering. The certificate will provide a foundation in contemporary control theory and methods. The Controls Certificate covers classical and modern control systems and analysis. Specialization in digital control, mechatronics, robotics, or aerospace applications is possible with a suitable choice of electives. Completion of the certificate will allow the student to design and analyze modern control systems.

Admission

Applicants must have completed an accredited bachelor's degree program in mechanical or a closely related field of engineering. They are expected to have prior coursework in undergraduate mathematics. No prior control courses are required.

Program Requirements

Students must complete a total of 16 units as described below, with a minimum GPA of 3.0 and a grade of C or better in each course.

Required Courses (8 units)

- MECH 217 Introduction to Control (2 units)
- MECH 218 Guidance and Control I (2 units)
- MECH 323 Modern Control Systems I (2 units)
- MECH 324 Modern Control Systems II (2 units)

Elective Courses (8 units)

- AMTH 245 Linear Algebra I (2 units)
- AMTH 246 Linear Algebra II (2 units)
- CENG 211 Advanced Strength of Materials (4 units)
- MECH 207 Advanced Mechatronics I (2 units)
- MECH 208 Advanced Mechatronics II (2 units)
- MECH 209 Advanced Mechatronics III (2 units)
- MECH 219 Guidance and Control II (2 units)
- MECH 329 Introduction to Intelligent Control (2 units)
- MECH 429, 430 Optimal Control I, II (2 units each)
- MECH 355, 356 Adaptive Control I, II (2 units each)

Dynamics

Objective

The Dynamics Certificate is intended for working engineers in mechanical and related fields of engineering. The certificate will provide a fundamental and broad background in engineering dynamics. The Dynamics Certificate includes a strong foundational base in dynamics and applications in optimization, robotics, mechatronics, or dynamics of aircraft or spacecraft (depending on the chosen elective courses). Completion of the certificate will allow the student to formulate and solve the complex dynamics problems that arise in such fields as robotics and space flight.

Admission

Applicants must have completed an accredited bachelor's degree program in mechanical or a closely related field of engineering. They are expected to have prior coursework in undergraduate dynamics and mathematics.

Program Requirements

Students must complete a total of 16 units as described below, with a minimum GPA of 3.0 and a grade of C or better in each course.

Required Courses (16 units)

- MECH 214, 215 Advanced Dynamics I, II (2 units each)
- MECH 305, 306 Advanced Vibrations I, II (2 units each)

Elective Courses

- MECH 205, 206 Aircraft Flight Dynamics I, II (2 units each)
- MECH 431, 432 Spacecraft Dynamics I, II (2 units each)

Materials Engineering

Objective

The Materials Engineering Certificate is intended for working engineers in mechanical, materials, or manufacturing engineering. The certificate will provide either an upgrade in materials understanding, or advanced study in a particular aspect of the subject. Completion of the certificate will allow the student to develop a deeper understanding of materials and their applications in design and manufacturing.

Admission

Applicants must have completed an accredited bachelor's degree program in mechanical or a related engineering discipline. They are expected to have prior coursework in basic materials science and strength of materials.

Program Requirements

Students must complete a total of 16 units as described below, with a minimum GPA of 3.0 and a grade of C or better in each course.

Required Courses (12 units)

- MECH 281 Fracture Mechanics and Fatigue (2 units)
- MECH 330 Atomic Arrangements, Defects, and Mechanical Behavior (2 units)
- MECH 331 Phase Equilibria and Transformations (2 units)
- MECH 332 Electronic Structure and Properties (2 units)
- MECH 333 Experiments in Materials Science (2 units)
- MECH 345 Modern Instrumentation and Control (2 units)

Elective Courses (4 units)

- AMTH 210 Introduction to Probability I and AMTH 211 Continuous probability (2 units each)
- AMTH 217 Design of Scientific Experiments and AMTH 219 Analysis of Scientific Experiments (2 units each)
- CENG 211 Advanced Strength of Materials (4 units)
- ENGR 260 Nanoscale Science and Technology (2 units)
- ENGR 262 Nanomaterials (2 units)
- MECH 273 Designing with Plastic Materials (2 units)
- MECH 274 Processing Plastic Materials (2 units)
- MECH 277 Injection Mold Tool Design (2 units)
- MECH 334 Elasticity (2 units)
- MECH 350 and 351 Composite Materials I and II (2 units each)

Mechanical Design Analysis

Objective

The Mechanical Design Analysis Certificate is intended for working engineers in mechanical or structural engineering. The certificate will provide a succinct upgrade in knowledge and skills that will allow the student to gain a deeper understanding of CAD and FEA principles and practices. Completion of the certificate will allow the student to pursue more advanced design and analysis tasks.

Admission

Applicants must have completed an accredited bachelor's degree program in mechanical, civil, aerospace, or related field. They are expected to have prior coursework in strength of materials, thermodynamics, fluid mechanics, and mathematics through differential equations.

Program Requirements

Students must complete a total of 16 units as described below, with a minimum GPA of 3.0 and a grade of C or better in each course.

Required Courses (12 units)

- CENG 205 Finite Element Methods I (2 units)
- CENG 206 Finite Element Methods II (2 units)
- CENG 207 Finite Element Methods III (2 units)
- MECH 325 Computational Geometry for Computer-Aided Design and Manufacture (2 units)
- MECH 334 Elasticity (2 units)
- MECH 415 Optimization in Mechanical Design (2 units)

Elective Courses (4 units)

- AMTH 220 Numerical Analysis I (2 units)
- AMTH 221 Numerical Analysis II (2 units)
- AMTH 308 Mathematical Modeling I (2 units)
- AMTH 309 Mathematical Modeling II (2 units)
- AMTH 370 Optimization Techniques I (2 units)
- AMTH 371 Optimization Techniques II (2 units)
- CENG 211 Advanced Strength of Materials (4 units)
- CENG 214 Theory of Elasticity (4 units)
- CENG 222 Advanced Structural Analysis (4 units)
- MECH 268 Computational Fluid Mechanics I (2 units)
- MECH 269 Computational Fluid Mechanics II (2 units)

Mechatronics Systems Engineering

Objective

The Mechatronics Systems Engineering Certificate is intended for working engineers in mechanical engineering and related fields. The certificate program introduces students to the primary technologies, analysis techniques, and implementation methodologies relevant to the detailed design of electro-mechanical devices. Completion of the certificate will allow the student to develop systems that involve the sensing, actuation and control of the physical world. Knowledge such as this is vital to engineers in the modern aerospace, robotics and motion control industries.

Admission

Applicants must have completed an accredited bachelor's degree program in mechanical, aerospace, electrical, engineering physics, or a related field. They are expected to have prior coursework in mathematics through differential equations, introductory linear control theory, and introductory electronics and programming.

Program Requirements

Students must complete a total of 16 units as described below, with a minimum GPA of 3.0 and a grade of C or better in each course.

Required Courses (8 units)

- MECH 207 Advanced Mechatronics I (3 units)
- MECH 208 Advanced Mechatronics II (3 units)
- MECH 209 Advanced Mechatronics III (3 units)
- MECH 217 Introduction to Control (2 units)

Elective Courses (8 units)

- MECH 218 Guidance and Control I (2 units)
- MECH 219 Guidance and Control II (2 units)
- MECH 275 Design for Competitiveness (2 units)
- MECH 310 Advanced Mechatronics IV (2 units)
- MECH 311 Modeling and Control of Telerobotic Systems (4 units)
- MECH 315 Digital Control Systems I (2 units)
- MECH 316 Digital Control Systems II (2 units)
- MECH 323 Modern Control Systems I (2 units)
- MECH 324 Modern Control Systems II (2 units)
- MECH 329 Intelligent Control (2 units)
- MECH 337 Robotics I (2 units)
- MECH 338 Robotics II (2 units)
- MECH 339 Robotics III (2 units)
- MECH 345 Modern Instrumentation (2 units)

An independent study or Capstone project would be suitable as one of the electives. In addition, other courses may serve as electives at the discretion of the program advisor.

Thermofluids

Objective

The Thermofluids Certificate is intended for working engineers in mechanical, chemical, or a closely related field of engineering. The certificate will provide fundamental theoretical and analytic background, as well as exposure to modern topics and applications. Specialization in fluid mechanics, thermodynamics, or heat transfer is possible with suitable choice of electives. Completion of the certificate will allow the student to design heat transfer and fluid solutions for a range of modern applications.

Admission

Applicants must have completed an accredited bachelor's degree program in mechanical or a closely related field of engineering. They are expected to have prior undergraduate coursework in fluid mechanics, thermodynamics, and heat transfer.

Program Requirements

Students must complete a total of 16 units as described below, with a minimum GPA of 3.0 and a grade of C or better in each course.

Required Courses (12 units)

- MECH 228 Equilibrium Thermodynamics (2 units)
- MECH 236 Conduction Heat Transfer (2 units)
- MECH 238 Convective Heat Transfer I (2 units)
- MECH 240 Radiation Heat Transfer I (2 units)
- MECH 266 Fundamentals of Fluid Mechanics (2 units)
- MECH 270 Viscous Flow I (2 units)

Elective Courses (4 units)

- MECH 202 Mathematical Methods in Mechanical Engineering (4 units)
- MECH 225 Gas Dynamics I (2 units)
- MECH 226 Gas Dynamics II (2 units)
- MECH 230 Statistical Thermodynamics (2 units)
- MECH 239 Convective Heat Transfer II (2 units)
- MECH 241 Radiation Heat Transfer II (2 units)
- MECH 242 Nanoscale Heat Transfer (2 units)
- MECH 268 Computational Fluid Mechanics I (2 units)
- MECH 269 Computational Fluid Mechanics II (2 units)
- MECH 271 Viscous Flow II (2 units)
- MECH 288 Energy Conversion I (2 units)
- MECH 289 Energy Conversion II (2 units)

MECHANICAL ENGINEERING LABORATORIES

The mechanical engineering laboratories contain facilities for instruction and research in the fields of manufacturing, materials science, fluid mechanics, thermodynamics, heat and mass transfer, combustion, instrumentation, vibration and control systems, and robotic systems.

The ***Robotic Systems Laboratory*** is an interdisciplinary laboratory specializing in the design, control, and teleoperation of highly capable robotic systems for scientific discovery, technology validation, and engineering education. Laboratory students develop and operate systems that include spacecraft, underwater robots, aircraft, and land rovers. These projects serve as ideal testbeds for learning and conducting research in mechatronic system design, guidance and navigation, command and control systems, and human-machine interfaces.

The ***2009 Solar Decathlon House*** is highly instrumented testbed for study of photovoltaic and solar thermal systems, as well as general home control systems. Projects include development of a carbon meter, investigation of the impact of micro-invertors on performance, and control of a solar thermal driven vapor absorption chiller.

The ***Micro Scale Heat Transfer Laboratory (MSHTL)*** develops state-of-the-art experimentation in processes such as micro-boiling, spray cooling, and laser induced fluorescence thermometry. Today, trends indicate that these processes are finding interesting applications on drop-on-demand delivery systems, ink-jet technology, and fast transient systems (such as combustion or microseconds scale boiling).

The ***CAM and Prototyping Laboratory*** consists of two machine shops and a prototyping area. One machine shop is dedicated to student use for University-directed design and research projects. The second is a teaching lab used for undergraduate and graduate instruction. Both are equipped with modern machine tools, such as lathes and milling machines. The milling machines all have two-axis computer numerically controlled (CNC) capability. The teaching lab also houses both a three-axis CNC vertical milling center (VMC) and a CNC lathe. Commercial CAM software is available to aid programming of the computer controlled equipment. The prototyping area is equipped with a rapid prototyping system that utilizes fused deposition modeling (FDM) to create plastic prototypes from CAD-generated models. Also featured in this area is a Laser CAMM CNC laser cutting system for nonmetallic materials.

The ***Engine Laboratory*** contains a variety of internal combustion engines installed on dynamometer stands that can be used for studies of diesel and spark-ignition engines. The facilities include a chassis dynamometer and instrumentation for evaluating engine performance, measuring exhaust gas emissions, and measuring noise. Studies can be conducted using a variety of fuels.

The ***Fluid Dynamics/Thermal Science Laboratory*** contains equipment to illustrate the principles of fluid flow and heat transfer and to familiarize students with hydraulic machines, refrigeration cycles, and their instrumentation. The lab also contains a subsonic wind tunnel equipped with an axial flow fan with adjustable pitch blades to study aerodynamics. Research tools include modern nonintrusive flow measurement systems.

The ***Heat Transfer Laboratory*** contains equipment to describe three modes of heat transfer. The temperature measurement of the extended surface system allows students to learn steady state conduction, and the pyrometer enables measurement of emitted power by radiation. The training systems for heat exchanger and refrigeration system are also placed in the lab.

The ***Instrumentation Laboratory*** contains seven computer stations equipped with state-of-the-art, PC-based data acquisition hardware and software systems. A variety of transducers and test experiments for making mechanical, thermal, and fluid measurements are part of this lab.

The ***Materials Laboratory*** contains equipment for metallography and optical examination of the microstructure of materials as well as instruments for mechanical properties characterization including tension, compression, hardness, and impact testing. The Materials Laboratory also has a tube furnace for heat treating and a specialized bell-jar furnace for pour casting and suction casting of metallic glasses and novel alloy compositions.

The ***Vibrations and Control Systems Laboratory*** is equipped with two flexible test systems. One is capable of single or multi degree of freedom modes, free or forced motion, and adjustable damping. The other is an inverted pendulum. Both systems can be controlled by a wide variety of control algorithms and are fully computer connected for data acquisition and control.

COURSE DESCRIPTIONS

Lower-Division Undergraduate Courses

MECH 10. Graphical Communication in Design

Introduction to the design process and graphical communications tools used by engineers. Documentation of design through freehand sketching and engineering drawings. Basic descriptive geometry. Computer-aided design as a design tool. Conceptual design projects presented in poster format. *Co-requisite: MECH 10L.* (4 units)

MECH 10L. Laboratory for MECH 10

Co-requisite: MECH 10. (1 unit)

MECH 11. Materials and Manufacturing Processes

Manufacturing processes and their use in the production of mechanical components from metals and plastics. *Prerequisites: MECH 10 and 15.* (4 units)

MECH 15. Introduction to Materials Science

Physical basis of the electrical, mechanical, optical, and thermal behavior of solids. Relations between atomic structure and physical properties. *Prerequisite: CHEM 11. Co-requisite: MECH 15L.* (4 units)

MECH 15L. Laboratory for MECH 15

The laboratory reinforces the lecture component through hands-on experience with materials testing and analysis. Potential experiments involve hardness testing, metallography, galvanic corrosion, and stress-strain measurements. *Co-requisite: MECH 15.* (1 unit)

MECH 80. Solar Home Analysis and Design

Students will research technologies and design approaches relevant to solar powered homes. Topics may include capture and use of solar thermal energy, conversion of solar energy to electricity, and passive solar home design. Available and emerging technologies will be investigated, and analysis tools will be used to compare options. Other aspects of house design, such as windows, lighting, and appliance choice will also be examined, as well as architecture and system level design. Successive offerings will build on the developed knowledge and expertise. Careful documentation will be stressed as well as optimizing the design within constraints. Course may be taken several times. (4 units)

Upper-Division Undergraduate Courses

MECH 101L. Laboratory for MECH 101

Practical experience with machine tools such as mills, lathes, band saws, etc. Basic training in safe and proper use of the equipment associated with simple mechanical projects. Laboratory. P/NP grading. *Prerequisite: Senior standing. Co-requisite: MECH 194.* (1 unit)

MECH 102. Introduction to Mathematical Methods in Mechanical Engineering

The application of mathematical methods to the solution of practical engineering problems. A review of fundamental mathematical methods and calculus of a single variable, multivariable calculus, ordinary differential equations, numerical methods, and basics of linear algebra. (4 units)

MECH 114. Machine Design I

Analysis and design of mechanical systems for safe operation. Stress and deflection analysis. Failure theories for static loading and fatigue failure criteria. Team design projects begun. Formal conceptual design reports required. *Prerequisites: MECH 15, CENG 41, and CENG 43.* (4 units)

MECH 115. Machine Design II

Continuation of MECH 114. Treatment of basic machine elements (e.g., bolts, springs, gears, bearings). Design and analysis of machine elements for static and fatigue loading. Team design projects completed. Design prototypes and formal final report required. *Prerequisite: MECH 114.* (4 units)

MECH 120. Engineering Mathematics

Review of ordinary differential equations (ODEs) and Laplace transform, vector calculus, linear algebra, orthogonal functions and Fourier series, partial differentia equations (PDEs), and introduction to numerical solution of ODEs. (4 units)

MECH 121. Thermodynamics

Definitions of work, heat, and energy. First and second laws of thermodynamics. Properties of pure substances. Application to fixed mass systems and control volumes. Irreversibility and availability. *Prerequisite: PHYS 32.* (4 units)

MECH 122. Fluid Mechanics

Fluid properties and definitions. Fluid statics, forces on submerged surfaces, manometry. Streamlines and the description of flow fields. Euler's and Bernoulli's equations. Mass, momentum, and energy analysis with a control volume. Laminar and turbulent flows. Losses in pipes and ducts. Dimensional analysis and similitude. *Prerequisite: CENG 42 or MECH 140 (can be taken concurrently). Co-requisite: MECH 122L.* (4 units)

MECH 122L. Laboratory for MECH 122

Experiments designed to the principles of fluid flow, industrial measurement techniques, and aerodynamics. Use of modern data acquisition and writing of formal lab reports. *Co-requisite: MECH 122.* (1 unit)

MECH 123. Heat Transfer

Introduction to the concepts of conduction, convection, and radiation heat transfer. Application of these concepts to engineering problems. *Prerequisites: MECH 121 and 122, AMTH 118 or MATH 166. Co-requisite: MECH 123L.* (4 units)

MECH 123L. Laboratory for MECH 123

Laboratory work to understand concept of heat transfer. Practical experience with temperature and heat flux measurement. *Co-requisite: MECH 123.* (1 unit)

MECH 125. Thermal Systems Design

Analysis, design, and simulation of fluids and thermal engineering systems. Application of optimization techniques, life cycle and sustainability concepts in these systems. *Prerequisite: MECH 123.* (4 units)

MECH 132. Aerodynamics

Introduction to gas dynamics. Concepts of lift and drag. Mechanics of laminar and turbulent flow. Introduction to boundary-layer theory. Application to selected topics in lubrication theory, aerodynamics, turbo- machinery, and pipe networks. Offered every other year. *Prerequisites: MECH 121 and 122.* (4 units)

MECH 140. Dynamics

Kinematics of particles in rectlinear and curvelinear motion. Kinetics of particles, Newton's second law, energy and momentum methods. Systems of particles. Kinematics and plane motion of rigid bodies, forces and accelerations, energy and momentum methods. Introduction to three-dimensional dynamics of rigid bodies. *Prerequisites: PHYS 31, CENG 41, AMTH 106, and MECH 10.* (4 units)

MECH 141. Mechanical Vibrations

Fundamentals of vibration, free and force vibration of (undamped/damped) single degree of freedom systems. Vibration under general forcing conditions. Free and force vibration of (undamped/damped) two degree of freedom systems. Free and force vibration of (undamped/damped) multidegree of freedom systems. Determination of natural frequencies and mode shapes. *Prerequisites: MECH 140 and AMTH 106. Co-requisite: MECH 141L.* (4 units)

MECH 141L. Laboratory for MECH 141

Dynamics and vibration experiments. The dynamics experiments include measuring moment-of-inertia of different planar shapes and gyroscopic effect. The vibration experiments include measuring spring constant, damping coefficient, and study of the behavior of overdamped, critical damped, and underdamped systems. *Co-requisite: MECH 141.* (1 unit)

MECH 142. Control Systems, Analysis, and Design

Introduction to system theory, transfer functions, and state space modeling of physical systems. Course topics include stability, analysis and design of PID, lead/lag, other forms of controllers in time and frequency domains, root locus Bode diagrams, gain and phase margins. *Prerequisite: MECH 141. Co-requisite: MECH 142L.* (4 units)

MECH 142L. Laboratory for MECH 142

Employs the use of simulation and experimental exercises that allow the student to explore the design and performance of feedback control systems. Exercises include the modeling and analysis of physical systems, the design of feedback controllers, and the quantitative characterization of the performance of the resulting closed-loop systems. *Co-requisite: MECH 142.* (1 unit)

MECH 143. Mechatronics

Introduction to behavior, design, and integration of electromechanical components and systems. Review of appropriate electronic components/circuitry, mechanism configurations, and programming constructs. Use and integration of transducers, microcontrollers, and actuators. *Also listed as ELEN 123. Prerequisite: ELEN 50. Co-requisite: MECH 143L.* (4 units)

MECH 143L. Laboratory for MECH 143

Co-requisite MECH 143. (1 unit)

MECH 144. Smart Product Design

Design of innovative smart electro-mechanical devices and products. Topics include a review of the basics of mechanical, electrical, and software design and prototyping, and will emphasize the synthesis of functional systems that solve a customer need, that are developed in a team-based environment, and that are informed by the use of methodologies from the fields of systems engineering, concurrent design, and project/business management. Designs will be developed in the context of a cost-constrained business environment, and principles of accounting, marketing, and supply chain are addressed. Societal impacts of technical products and services are reviewed. Enrollment is controlled in order to have a class with students from diverse majors. Offered every other year. *Prerequisites: Core Foundation-level natural science and mathematics, or equivalent and instructor approval.* (4 units)

MECH 144L. Laboratory for MECH 144

Co-requisite: MECH 144. (1 unit)

MECH 145. Introduction to Aerospace Engineering

Basic design and analysis of atmospheric flight vehicles. Principles of aerodynamics, propulsion, structures and materials, flight dynamics, stability and control, mission analysis, and performance estimation. Introduction to orbital dynamics. Offered every other year. *Prerequisites: MECH 122 and 140. Co-requisite: MECH 121.* (4 units)

MECH 146. Mechanism Design

Kinematic analysis and synthesis of planar mechanisms. Graphical synthesis of linkages and cams. Graphical and analytical techniques for the displacement, velocity, and acceleration analysis of mechanisms. Computer-aided design of mechanisms. Three or four individual mechanism design projects. Offered every other year. *Prerequisite: MECH 114.* (4 units)

MECH 151. Finite Element Theory and Applications

Basic introduction to finite elements; direct and variational basis for the governing equations; elements and interpolating functions. Applications to general field problems—elasticity, fluid mechanics, and heat transfer. Extensive use of software packages. Offered every other year. *Prerequisites: COEN 44 or 45 and AMTH 106.* (4 units)

MECH 152. Composite Materials

Analysis of composite materials and structures. Calculation of properties and failure of composite laminates. Manufacturing considerations and design of simple composite structures. Knowledge of MATLAB or equivalent programming environment is required. *Prerequisites: MECH 15, CENG 43, and COEN 44 or COEN 45.* (4 units)

MECH 153. Aerospace Structures

This introductory course presents the application of fundamental theories of elasticity and stress analysis to aerospace structures. Course topics include fundamentals of elasticity, virtual work and matrix methods, bending and buckling of thin plates, component load analysis, and airframe loads, torsion, shear, and bending of thin-walled sections. *Prerequisites: CENG 43 and 43L-Mechanics III.* (4 units)

MECH 155. Astrodynamics

This course provides the foundations of basic gravitation and orbital theory. Topics include gravitation and the two-body problem, position and time, orbit determination, Laplace and Gibbs methods, basic orbital maneuvers, lunar trajectories, and rocket dynamics. *Prerequisite: MECH 140.* (4 units)

MECH 156. Introduction to Nanotechnology

Introduction to the field of nanoscience and nanotechnology. Properties of nanomaterials and devices. Nanoelectronics: from silicon and beyond. Measurements of nanosystems. Applications and implications. Laboratory experience is an integral part of the course. This course is part of the Mechanical Engineering Program and should be suitable for juniors and seniors in engineering and first-year graduate students. *Also listed as ELEN 156. Prerequisites: PHYS 33 and either PHYS 34 or MECH 15. Co-requisite: MECH 156L.* (4 units)

MECH 156L. Laboratory for MECH 156

Co-requisite: MECH 156. (1 unit)

MECH 158. Aerospace Propulsion Systems

Fundamentals of air breathing and rocket jet propulsion. Gas dynamics fundamentals, review of thermodynamic relation. Basic theory ofaircraft gas turbine engines, propulsive efficiency, and application of Brayton cycle to gas turbine engine analysis. Rocket engine nozzle configuration and design. Thrust Equation. Chemical rocket engine fundamentals. Solid vs. liquid propellant rockets. *Prerequisites: MECH 121, and 122.* (4 units)

MECH 160. Modern Instrumentation for Engineers

Introduction to engineering instrumentation, computer data acquisition hardware and software, sampling theory, statistics, and error analysis. Laboratory work spans the disciplines of mechanical engineering: dynamics, fluids, heat transfer, controls, with an emphasis on report writing and experimental design. *Prerequisites: MECH 123 and 141. Co-requisite: MECH 160L.* (4 units)

MECH 160L. Laboratory for MECH 160

Laboratory work spans the disciplines of mechanical engineering: dynamics, controls, fluids, heat transfer, and thermodynamics, with emphasis on report writing. Students will design their own experiment and learn how to set up instrumentation using computer data acquisition hardware and software. *Co-requisite: MECH 160.* (1 unit)

MECH 179. Satellite Operations Laboratory

This laboratory course reviews the physical principles and control techniques appropriate to communicating with, commanding and monitoring spacecraft. Students learn to operate real satellite tracking, commanding and telemetry systems and to perform spacecraft-specific operations using approved procedures. Given the operational status of the system, students may conduct these operations on orbiting NASA spacecraft and interact with NASA scientists and engineers as part of operations process. *Prerequisite: Instructor approval.* (1 unit)

MECH 188. Co-op Education

Practical experience in a planned program designed to give students work experience related to their academic field of study and career objectives. Satisfactory completion of the assignment includes preparation of a summary report on co-op activities. P/NP grading. May be taken for graduate credit. (2 units)

MECH 189. Co-op Technical Report

Credit given for a technical report on a specific activity such as a design or research project, etc., after completing the co-op assignment. Approval of department co-op advisor required. Letter grades based on content and presentation quality of report. May be taken twice. May be taken for graduate credit. (2 units)

MECH 191. Senior Design Manufacturing

Laboratory course that provides supervised evening access to the machine shop and/or light fabrication area for qualified mechanical engineering students to work on their University-directed projects. Students wishing to utilize the machine shop or light fabrication during the evening lab/shop hours are required to enroll. Enrollment in any section allows students to attend any/all evening shop hours on a drop-in basis. Staff or faculty will be present during each scheduled meeting to supervise as well as be available for consultation and manufacturing advising. P/NP Grading. *Prerequisites: Students must be qualified for machine shop use through successful completion of MECH 101L and passing grade on the Mechanical Engineering Lab Safety Test. Qualifications for light fabrication area use: successful completion of the Light Fabrication Training Seminar and a passing grade on the Mechanical Engineering Lab Safety Test.* (1 unit)

MECH 194. Advanced Design I: Tools

Design tools basic to all aspects of mechanical engineering, including design methodology, computer-design tools, CAD, finite element method, simulation, engineering economics, and decision making. Senior design projects begun. *Prerequisite: MECH 115.* (3 units)

MECH 195. Advanced Design II: Implementation

Implementation of design strategy. Detail design and fabrication of senior design projects. Quality control, testing and evaluation, standards and specifications, and human factors. *Prerequisite: MECH 194.* (4 units)

MECH 196. Advanced Design III: Completion and Evaluation

Design projects completed, assembled, tested, evaluated, and judged with opportunities for detailed re-evaluation by the designers. Formal public presentation of results. Final written report required. *Prerequisite: MECH 195.* (3 units)

MECH 198. Individual Study

By arrangement with faculty. (1–5 units)

MECH 199. Directed Research/ Reading

Investigation of an engineering problem and writing an acceptable thesis. Conferences as required. *Prerequisite: Senior standing.* (2–4 units)

Graduate Courses

MECH 200. Advanced Engineering Mathematics I

Method of solution of the first, second, and higher order differential equations (ODEs). Integral transforms including Laplace transforms, Fourier series and Fourier transforms. *Cross-listed with AMTH 200. Prerequisite: AMTH 106 or equivalent.* (2 units)

MECH 201. Advanced Engineering Mathematics II

Method of solution of partial differential equations (PDEs) including separation of variables, Fourier series and Laplace transforms. Introduction to calculus of variations. Selected topics from vector analysis and linear algebra. *Cross-listed with AMTH 201. Prerequisite: AMTH/MECH 200.* (2 units)

MECH 202. Advanced Engineering Mathematics I and II

Method of solution of the first, second, and higher order ordinary differential equations, Laplace transforms, Fourier series and Fourier transforms, method of solution of partial differential equations including separation of variables, Fourier series, and Laplace transforms. Selected topics from vector analysis, linear algebra, and calculus of variations. *Also listed as AMTH 202.* (4 units)

MECH 205. Aircraft Flight Dynamics I

Review of basic aerodynamics and propulsion. Aircraft performance, including equations of flight in vertical plane, gliding, level, and climbing flight, range and endurance, turning flight, takeoff and landing. *Prerequisite: MECH 140.* (2 units)

MECH 206. Aircraft Flight Dynamics II

Developing a nonlinear six-degrees-of-freedom aircraft model, longitudinal and lateral static stability and trim, linearized longitudinal dynamics including short period and phugoid modes. Linearized lateral-directional dynamics including roll, spiral, and Dutch roll modes. Aircraft handling qualities and introduction to flight control systems. *Prerequisite: MECH 140 or MECH 205.* (2 units)

MECH 207. Advanced Mechatronics I

Theory of operation, analysis, and implementation of fundamental physical and electrical device components: basic circuit elements, transistors, op-amps, sensors, electro-mechanical actuators. Application to the development of simple devices. *Also listed as ELEN 460. Prerequisite: MECH 141 or ELEN 100.* (3 units)

MECH 208. Advanced Mechatronics II

Theory of operation, analysis, and implementation of fundamental controller implementations: analog computers, digital state machines, microcontrollers. Application to the development of closed-loop control systems. *Also listed as ELEN 461. Prerequisites: MECH 207 and 217.* (3 units)

MECH 209. Advanced Mechatronics III

Electro-mechanical modeling and system development. Introduction to mechatronic support subsystems: power, communications. Fabrication techniques. Functional implementation of hybrid systems involving dynamic control and command logic. *Also listed as ELEN 462. Prerequisite: MECH 208.* (2 units)

MECH 214. Advanced Dynamics I

Partial differentiation of vector functions in a reference frame. Configuration constraints. Generalized speeds. Motion constraints. Partial angular velocities and partial linear velocities. Inertia scalars, vectors, matrices, and dyadics; principal moments of inertia. *Prerequisites: MECH 140 and AMTH 106.* (2 units)

MECH 215. Advanced Dynamics II

Generalized active forces. Contributing and noncontributing interaction forces. Generalized inertia forces. Relationship between generalized active forces and potential energy; generalized inertia forces and kinetic energy. *Prerequisite: MECH 214.* (2 units)

MECH 217. Introduction to Control

Laplace transforms, block diagrams, modeling of control system components and kinematics and dynamics of control systems, and compensation. Frequency domain techniques, such as root-locus, gain-phase, Nyquist and Nichols diagrams used to analyze control systems applications. *Prerequisite: AMTH 106.* (2 units)

MECH 218. Guidance and Control I

Modern and classical concepts for synthesis and analysis of guidance and control systems. Frequency and time domain methods for both continuous-time and sampled data systems. Compensation techniques for continuous-time and discrete-time control systems. *Prerequisite: MECH 217, 142, or instructor approval.* (2 units)

MECH 219. Guidance and Control II

Continuation of MECH 218. Design and synthesis of digital and continuous-time control systems. Nonlinear control system design using phase plane and describing functions. Relay and modulator controllers. *Prerequisite: MECH 218.* (2 units)

MECH 220. Orbital Mechanics I

This course provides the foundations of basic gravitation and orbital theory. Topics include the two-body problem, three-body problem, Lagrangian points, orbital position as a function of time, orbits in space and classical orbital elements, launch window, and calculating launch velocity. *Prerequisites: MECH 140 or equivalent and AMTH 118 or equivalent.* (2 units)

MECH 221. Orbital Mechanics II

Continuation of MECH 220. Rocket dynamics and performance, orbital maneuvers, preliminary orbit determination including Gibbs and Gauss methods, Lambert's problem, relative motion and Clohessy-Wiltshire equations, and interplanetary flight *Prerequisite: MECH 220.* (2 units)

MECH 225. Gas Dynamics I

Flow of compressible fluids. One-dimensional isentropic flow, normal shock waves, frictional flow. *Prerequisites: MECH 121 and 132.* (2 units)

MECH 226. Gas Dynamics II

Continuation of MECH 225. Flow with heat interaction and generalized one-dimensional flow. Oblique shock waves and unsteady wave motion. *Prerequisite: MECH 225.* (2 units)

MECH 228. Equilibrium Thermodynamics

Principles of thermodynamic equilibrium. Equations of state, thermodynamic potentials, phase transitions, and thermodynamic stability. *Prerequisite: MECH 131 or equivalent.* (2 units)

MECH 230. Statistical Thermodynamics

Kinetic theory of gases. Maxwell-Boltzmann distributions, thermodynamic properties in terms of partition functions, quantum statistics, and applications. *Prerequisites: AMTH 106 and MECH 121.* (2 units)

MECH 232. Multibody Dynamics I

Kinematics (angular velocity, differentiation in two reference frames, velocity and acceleration of two points fixed on a rigid body and one point moving on a rigid body, generalized coordinates and generalized speeds, basis transformation matrices in terms of Euler angles and quaternions), Newton-Euler equations, kinetic energy, partial angular velocities and partial velocities, Lagrange's equation, generalized active and inertia forces, Kane's equation and its operational superiority in formulating equations of motion for a system of particles and hinge-connected rigid bodies in a topological tree. *Prerequisite: MECH 140 or equivalent.* (2 units)

MECH 233. Multibody Dynamics II

Linearization of dynamical equations, application to Kane's formulation of the equations of motion of beams and plates undergoing large rotation with small deformation, dynamics of an arbitrary elastic body in large overall motion with small deformation and motion-induced stiffness, computationally efficient, recursive formulation of the equations of motion of a system of hinge-connected flexible bodies, component elastic mode selection, recursive formulation for a system of flexible bodies with structural loops, variable mass flexible rocket dynamics, modeling large elastic deformation with large reference frame motion. *Prerequisite: MECH 232.* (2 units)

MECH 234. Combustion Technology

Theory of combustion processes. Reaction kinetics, flame propagation theories. Emphasis on factors influencing pollution. *Prerequisites: AMTH 106 and MECH 131.* (2 units)

MECH 236. Conduction Heat Transfer

Flow of heat through solid and porous media for steady and transient conditions. Consideration of stationary and moving heat sources. *Prerequisites: AMTH 106 and MECH 123.* (2 units)

MECH 238. Convective Heat and Mass Transfer I

Solutions of basic problems in convective heat and mass transfer, including boundary layers and flow in pipes. *Prerequisites: MECH 123 and 266.* (2 units)

MECH 239. Convective Heat and Mass Transfer II

Application of transfer theory to reacting boundary layers, ablating and reacting surfaces, multicomponent diffusion. Introduction of modern turbulence theory to predict fluctuations and other flow properties. *Prerequisite: MECH 238.* (2 units)

MECH 240. Radiation Heat Transfer I

Introduction to concepts of quantum mechanics, black body behavior, and radiant heat exchange between bodies. *Prerequisite: MECH 123.* (2 units)

MECH 241. Radiation Heat Transfer II

Treatment of gaseous radiation in enclosures. Solutions of transfer equation in various limits and for different molecular radiation models. Gray and nongray applications. Mathematical techniques of solutions. *Prerequisite: MECH 240.* (2 units)

MECH 242. Nanoscale Heat Transfer

Understand fundamental heat transfer mechanisms at nanoscale. Students will learn how thermal transport properties are defined at atomic level, and how properties can be engineered with nanotechnology. Both classical size effect and quantum size effect will be discussed. Topics include introduction to statistical thermodynamics, solid state physics, scattering of charge/energy carriers, Boltzamann Transport Equation with Relaxation Time Approximation, heat conduction in thin film structure. *Prerequisites: MECH123 or Undergraduate Heat Transfer.* (2 units)

MECH 254. Introduction to Biomechanics

Overview of basic human anatomy, physiology, and anthropometry. Applications of mechanical engineering to the analysis of human motion, function, and injury. Review of issues related to designing devices for use in, or around, the human body including safety, biocompatibility, ethics, and FDA regulations. Offered every other year. (4 units)

MECH 256. Clinical Biomaterials

The objective of this course is to convey the state-of-the-art of biomaterials currently used in medical devices. The course is taught as a series of semi-independent modules on each class of biomaterials, each with examples of medical applications. Students will explore the research, commercial and regulatory literature. In teams of 2 to 4, students will prepare and orally present a design study for a solution to a medical problem requiring one or more biomaterials, covering alternatives and selection criteria, manufacture and use of the proposed medical device, and economic, regulatory, legal and ethical aspects. Students should be familiar with or prepared to learn medical, anatomical and physiological terminology. Written assignments are an annotated bibliography on the topic of the design study and an individual-written section of the team's report. Material from lectures and student presentations will be covered on a mid-term quiz and a final examination. *Also listed as BIOE 178/BIOE 278.* (2 units)

MECH 266. Fundamentals of Fluid Mechanics

Mathematical formulation of the conservation laws and theorems applied to flow fields. Analytical solutions. The viscous boundary layer. *Prerequisite: MECH 122.* (2 units)

MECH 268. Computational Fluid Mechanics I

Introduction to numerical solution of fluid flow. Application to general and simplified forms of the fluid dynamics equations. Discretization methods, numerical grid generation, and numerical algorithms based on finite difference techniques. *Prerequisite: MECH 266.* (2 units)

MECH 269. Computational Fluid Mechanics II

Continuation of MECH 268. Generalized coordinate systems. Multidimensional compressible flow problems, turbulence modeling. *Prerequisite: MECH 268.* (2 units)

MECH 270. Viscous Flow I

Derivation of the Navier-Stokes equations. The boundary layer approximations for high Reynolds number flow. Exact and approximate solutions of laminar flows. *Prerequisite: MECH 266.* (2 units)

MECH 271. Viscous Flow II

Continuation of MECH 270. Similarity solutions of laminar flows. Separated flows. Fundamentals of turbulence. Introduction to numerical methods in fluid mechanics. *Prerequisite: MECH 270.* (2 units)

MECH 275A. Design for Competitiveness

Overview of current design techniques aimed at improving global competitiveness. Design strategies and specific techniques. Group design projects in order to put these design ideas into simulated practice. (2 units)

MECH 275B. Project Design Development

This course is a follow-up to MECH 275A and is focused on further developing product ideas from MECH 275A into physical prototypes, performing market analysis, honing business plans, and presenting these ideas to a panel of venture capitalists. *Prerequisite: MECH 275A.* (2 units)

MECH 276. Design for Manufacturability

Design for manufacturability and its applications within the product design process. Survey of design for manufacturability as it relates to design process, quality, robust design, material and process selection, functionality and usability. Students will participate in group and individual projects that explore design for manufacturability considerations in consumer products. (2 units)

MECH 279. Introduction to CNC I

Introduction to Computer Numeric Control (CNC) machining. Principles of conventional and CNC machining. Process identification and practical application using conventional machine tools. Job planning logic and program development for CNC.

Set-up and basic operation of CNC machine through "hands-on" exercises. Introduction to Computer Aided Manufacturing (CAM) software, conversational programming, verification software, and file transfers. The class is lab intensive; the topics will be presented primarily by demonstration or student use of the equipment. (3 units)

MECH 280. Introduction to CNC II

Builds on foundation provided by MECH 279. Emphasis on CNC programming. Overview of controllers, features of CNC machines, manual and computer-aided programming, G-code basics, advanced cycles and codes. Lab projects will consist of "hands-on" operation of CNC milling machines, programming tools, and verification software. Lab component. *Prerequisite: MECH 279 or instructor approval.* (3 units)

MECH 281. Fracture Mechanics and Fatigue

Fracture mechanics evaluation of structures containing defects. Theoretical development of stress intensity factors. Fracture toughness testing. Relationships among stress, flaw size, and material toughness. Emphasis on design applications with examples from aerospace, nuclear, and structural components. *Prerequisite: Instructor approval.* (2 units)

MECH 282. Failure Analysis

This course will examine how and why engineering structures fail, and will provide the student with the tools to identify failure mechanisms and perform a failure analysis. Students will review several case studies, and will conduct independent failure analysis investigations of actual engineering systems and parts using state-of-the-art-tools. (2 units)

MECH 285. Computer-Aided Design of Mechanisms

Kinematic synthesis of mechanisms. Graphical and analytical mechanism synthesis techniques for motion generation, function generation, and path generation problems. Overview of various computer software packages available for mechanism design. (2 units)

MECH 286. Introduction to Wind Energy Engineering

Introduction to renewable energy, history of wind energy, types and applications of various wind turbines, wind characteristics and resources, introduction to different parts of a wind turbine including the aerodynamics of propellers, mechanical systems, electrical and electronic systems, wind energy system economics, environmental aspects and impacts of wind turbines, and the future of wind energy. *Also listed as ELEN 286.* (2 units)

MECH 287. Introduction to Alternative Energy Systems

Assessment of current and potential future energy systems; covering resources, extraction, conversion, and end-use. Emphasis on meeting regional and global energy needs in a sustainable manner. Different renewable and conventional energy technologies will be presented and their attributes described to evaluate and analyze energy technology systems. *Also listed as ELEN 280.* (2 units)

MECH 288. Energy Conversion I

Introduction to nonconventional methods of power generation using solar energy, thermoelectric effect, and fuel cells. Description of the physical phenomena involved, analysis of device performance, and assessment of potential for future use. *Prerequisite: MECH 121.* (2 units)

MECH 289. Energy Conversion II

Discussion of magnetohydrodynamic power generation, thermionic converters, and thermonuclear fusion. *Note: MECH 288 is NOT a prerequisite.* (2 units)

MECH 290. Capstone Project

(2–6 units)

MECH 292. Theory and Design of Turbomachinery

Theory, operation, and elements of the design of turbomachinery that performs by the dynamic interaction of fluid stream with a bladed rotor. Emphasis on the design and efficient energy transfer between fluid stream and mechanical elements of turbomachines, including compressors, pumps, and turbines. *Prerequisites: MECH 121 and 122.* (2 units)

MECH 293. Special Topics in Manufacturing and Materials

(2 units)

MECH 294. Special Topics in Mechanical Design

(2 units)

MECH 295. Special Topics in Thermofluid Sciences

(2 units)

MECH 296. Special Topics in Dynamics and Control

(2 units)

MECH 297. Seminar

Discrete lectures on current problems and progress in fields related to mechanical engineering. P/NP grading. (1 unit)

MECH 298. Individual Study

By arrangement. (1–6 units)

MECH 299. Master's Thesis Research

By arrangement. (1–9 units)

MECH 300. Directed Research

Research into topics of mechanical engineering; topics and credit to be determined by instructor, report required, cannot be converted into Master or PhD research. By arrangement. *Prerequisites: instructor and department chair approval.* (1–6 units)

MECH 304. Design and Mechanics Problems in the Computer Industry

Design and mechanics problems related to computer peripherals. Dynamics of disk interface, stresses, and vibrations in rotating disks and flexible disks. Actuator design, impact and nonimpact printing, materials and design for manufacturability, role of CAD/CAM in design. *Prerequisite: Instructor approval.* (2 units)

MECH 305. Advanced Vibrations I

Response of single and two-degrees-of- freedom systems to initial, periodic, nonperiodic excitations. Reviewing the elements of analytical dynamics, including the principle of virtual work, the Hamilton's principle and Lagrange's equations. Response of multi-degree-of-freedom systems. Modeling and dynamic response of discrete vibrating elastic bodies. Analytical techniques for solving dynamic and vibration problems. *Prerequisite: MECH 141.* (2 units)

MECH 306. Advanced Vibrations II

Vector-tensor-matrix formulation with practical applications to computer simulation. Dynamic response of continuous elastic systems. Strings, membranes, beams, and plates exposed to various dynamic loading. Applications to aero-elastic systems and mechanical systems. Modal analysis and finite element methods applied to vibrating systems. *Prerequisite: MECH 305.* (2 units)

MECH 308. Thermal Control of Electronic Equipment

Heat transfer methods to cool electronic equipment. Contact resistance, cooling fins, immersion cooling, boiling, and direct air cooling. Use of heat exchangers, cold plates, and heat pipes. Applications involving transistor cooling, printed circuit boards, and microelectronics. *Prerequisites: MECH 122 and 123.* (2 units)

MECH 310. Advanced Mechatronics IV

Application of mechatronics knowledge and skills to the development of an industry- or laboratory-sponsored mechatronics device/system. Systems engineering, concurrent design, and project management techniques. Performance assessment, verification, and validation. Advanced technical topics appropriate to the project may include robotic teleoperation, human-machine interfaces, multi-robot collaboration, and other advanced applications. *Prerequisite: MECH 209.* (2 units)

MECH 311. Modeling and Control of Telerobotic Systems

Case studies of telerobotic devices and mission control architectures. Analysis and control techniques relevant to the remote operation of devices, vehicles, and facilities. Development of a significant research project involving modeling, simulation, or experimentation, and leading to the publication of results. *Prerequisite: Instructor approval.* (4 units)

MECH 313. Aerospace Structures

Presents the fundamental theories of elasticity and stress analysis pertaining to aircraft and spacecraft structures. Course topics include aircraft/spacecraft structural elements, material selection, elasticity, torsion, shear, bending, thin-walled sections, failure criteria, buckling, fatigue, and an introduction to mechanics of composites. (4 units)

MECH 315. Digital Control Systems I

Introduction to digital control systems design. Mini- and microcomputer application in industrial control. Analog-to-digital and digital-to-analog converters. Discrete time systems, state-space representation, stability. Digital control algorithms, optimal tuning of controller gains. Finite-time settling control. Controllability and observability of discrete-time systems. *Prerequisite: MECH 142 or 217.* (2 units)

MECH 316. Digital Control Systems II

Continuation of MECH 315. Linear state vector feedback control, linear quadratic optimal control. State variable estimators, observers. System identification, model reference adaptive systems, pole-placement control. Minimum variance control, tracking, and regulation problems. Adaptive control. *Prerequisite: MECH 315.* (2 units)

MECH 323. Modern Control Systems I

State space fundamentals, observer and controller canonical forms, controllability, Observability, minimum realization, stability theory, stabilizability, and tracking problem of continuous systems. *Prerequisite: MECH 142 or 217.* (2 units)

MECH 324. Modern Control Systems II

Shaping the dynamic response, pole placement, reduced-order observers, LQG/LTR, introduction to random process and Kalman filters. *Prerequisite: MECH 323.* (2 units)

MECH 325. Computational Geometry for Computer-Aided Design and Manufacture

Analytic basis for description of points, curves, and surfaces in three-dimensional space. Generation of surfaces for numerically driven machine tools. Plane coordinate geometry, three-dimensional geometry and vector algebra, coordinate transformations, three-dimensional curve and surface geometry, and curve and surface design. (2 units)

MECH 329. Introduction to Intelligent Control

Intelligent control, AI, and system science. Adaptive control and learning systems. Artificial neural networks and Hopfield model. Supervised and unsupervised learning in neural networks. Fuzzy sets and fuzzy control. *Also listed as ELEN 329. Prerequisite: MECH 324.* (2 units)

MECH 330. Atomic Arrangements, Defects, and Mechanical Behavior

Structure of crystalline and non-crystalline materials and the relationship between structure, defects, and mechanical properties. For all engineering disciplines. (2 units)

MECH 331. Phase Equilibria and Transformations

Thermodynamics of multi-component systems and phase diagrams. Diffusion and phase transformations. For all engineering disciplines. (2 units)

MECH 332. Electronic Structure and Properties

Band structure and electrical conductivity of metals, semiconductors, and insulators with applications to electronic devices such as the p-n junction and materials characterization techniques utilizing electron-solid interactions. For all engineering disciplines. (2 units)

MECH 333A. Experiments in Materials Science

This course will focus on experimental techniques and data analysis for three experiments involving the characterization of metallic and polymeric systems in bulk and thin film form. Potential topics include tension testing of composite materials, nanoindentation, and scanning electron microscopy. Written laboratory reports will be assigned. (2 units)

MECH 333B. Experimental Analysis in Materials Science

Experimental design and analysis for evaluating materials properties. In this course, students work in teams to design and implement experiments, record and interpret results and prepare a final report. *Prerequisite: MECH 333A or equivalent.* (2 units)

MECH 334. Elasticity

Fundamentals of the theory of ineary elasticity, formulation of boundary value problems, applications to torsion, plane strain, flexture, and bending of plates. Introduction to three-dimensional solutions. *Prerequisite: MECH 330 or CENG 205.* (2 units)

MECH 335. Adaptive Control I

Overview of adaptive control, Lyapunov stability theory, direct and indirect model-reference adaptive control, least-squares system identification technique, neural network approximation, and neural-network adaptive control. *Prerequisites: MECH 324, ELEN 237, and knowledge of Matlab/ Simulink.* (2 units)

MECH 336. Adaptive Control II

Stability and robustness of adaptive controller, robust modification, bounded linear stability analysis, metrics-driven adaptive control, constraint-based optimal adaptive control, and advanced topics in adaptive control. *Prerequisite: MECH 335 or instructor approval, ELEN 237.* (2 units)

MECH 337. Robotics I

Overview of robotic systems and applications. Components. Homogeneous transforms. Denavit-Hartenberg representation. Forward and inverse kinematics. Manipulator Jacobian. Singular configurations. *Also listed as ELEN 337. Prerequisites: AMTH 245 and MECH 217.* (2 units)

MECH 338. Robotics II

Newton-Euler Dynamics. Trajectory planning. Linear manipulator control. Nonlinear manipulator control. Joint space control. Cartesian space control. Hybrid force/position control. Obstacle avoidance. Robotic simulation. *Also listed as ELEN 338. Prerequisite: MECH 337.* (2 units)

MECH 339. Robotics III

Advanced topics: parallel manipulators, redundant manipulators, underactuated manipulators, coupled manipulator/platform dynamics and control, hardware experimentation and control, dextrous manipulation, multi-robot manipulation, current research in robotic manipulation. *Also listed as ELEN 339. Prerequisite: MECH 338.* (2 units)

MECH 340. Introduction to Direct Access Storage Devices

Introduction to direct access storage devices, including flexible and rigid disk drives. Overview of magnetic and optical recording technology emphasizing their similarity and differences and basic principles of operation. Device components technology, including head, disk, positioning actuator, drive mechanism, drive interface, and controller. *Prerequisite: Instructor approval.* (2 units)

MECH 345. Modern Instrumentation and Experimentation

Overview of sensors and experimental techniques. Fundamentals of computer-based data acquisition and control, principles of operation of components in a data acquisitions system. Design and analysis of engineering experiments with emphasis on practical applications. Characterization of experimental accuracy, error analysis, and statistical analysis. Experiments involving measurements and control of equipment. (2 units)

MECH 346. Design of Experiments in Mechanical Engineering

Design, planning, and implementation of an experiment. Students will work in a group to define a project, conduct background research, provide analysis, and record data. A formal report is required. *Prerequisite: MECH 345 or equivalent.* (2 units)

MECH 350. Composite Materials I

Design, analysis, and manufacturing of composite materials. Characterization of composites at the materials and substructural levels. Hyperselection. Manufacturing technology and its impact on design. *Prerequisite: Instructor approval.* (2 units)

MECH 351. Composite Materials II

Composite material design at the structural level. Fabrication methods. Design for damage tolerance, durability, and safety. Transfer of loads. *Prerequisite: MECH 350.* (2 units)

MECH 371. Space Systems Design and Engineering I

A review of the engineering principles, technical subsystems, and design processes that serve as the foundation of developing and operating spacecraft systems. This course focuses on subsystems and analyses relating to orbital mechanics, power, command and data handling, and attitude determination and control. *Also listed as ENGR 371. Note: MECH 371 and 372 may be taken in any order.* (4 units)

MECH 372. Space Systems Design and Engineering II

A review of the engineering principles, technical subsystems, and design processes that serve as the foundation of developing and operating spacecraft systems. This course focuses on subsystems and analyses relating to mechanical, thermal, software, and sensing elements. *Also listed as ENGR 372. Note: MECH 371 and 372 may be taken in any order.* (4 units)

MECH 379. Satellite Operations Laboratory

Introduces analysis and control topics relating to the operation of on-orbit spacecraft. Several teaching modules address conceptual topics to include mission and orbit planning, antenna tracking, command and telemetry operations, resource allocation, and anomaly management. Students will become certified to operate real spacecraft and will participate in the operation of both orbiting satellites and ground prototype systems. (1 unit)

MECH 399. Ph.D. Thesis Research

By arrangement. May be repeated up to 40 units. (1–9 units)

MECH 413. Vehicle Design I

Automotive vehicle design overview addressing the major subsystems that comprise a typical on-road vehicle application, including frame/cab, powertrain, suspension/ steering, and auxiliary automotive. The class will cover the vehicle development constraints, requirement and technology assessments, design drivers, benchmarking, and subsystem synergies within the overall vehicle system context. (2 units)

MECH 414. Vehicle Design II

Building on Vehicle Design I instruction and material, system level automotive vehicle design that addresses the off-road vehicle applications. Major subsystems reviewedinclude frame/cab, powertrain, suspension/ steering (including track laying), and supporting subsystems. Unique off-road duty cycle/load cases and supportability issues are addressed. *Prerequisite: MECH 413.* (2 units)

MECH 415. Optimization in Mechanical Design

Introduction to optimization: design and performance criteria. Application of optimization techniques in engineering design, including case studies. Functions of single and multiple variables. Optimization with constraints. *Prerequisites: AMTH 106 and 245.* (2 units)

MECH 416. System Design and Project Operation

An overview of the tools and processes of systems design as it applies to complex projects involving mechanical engineering and multidisciplinary engineering. Traditional lectures by the faculty coordinator, as well as special presentations by selected industry speakers. (2 units)

MECH 420. Model Predictive Control

Review of state-space model in discrete time, stability, optimal control, prediction, Kalman filter. Measurable and un-measurable disturbance, finite and receding horizon control, MPC formulation and design. *Also listed as ELEN 238. Prerequisite: MECH 323 or ELEN 236.* (2 units)

MECH 423. Nonlinear Control I

Introduction to nonlinear phenomena, planar or second-order systems: qualitative behavior of linear systems, linearization, Lyapunov stability theory, LaSalle's invariance principle, small gain theorem, and input-to-state stability. *Prerequisite: MECH 323 or equivalent.* (2 units)

MECH 424 Nonlinear Control II

Continuation of MECH 423. Stabilization via linearization, Integral control, integral control via linearization, feedback linearization including input-output, input-state, and full-state linearization, sliding mode control, back-stepping, controllability and observability of nonlinear systems, model reference and self-tuning adaptive control. (2 units)

MECH 429. Optimal Control I

Introduction to the principles and methods of the optimal control approach: performance measure criteria including the definition of minimum-time, terminal control, minimum-control effort, tracking, and regulator problems, calculus of variations applied to optimal control problems including Euler-Lagrange equation, transversality condition constraint, Pontryagin's minimum principle (PMP), linear quadratic regulator (LQR) and tracking control problems. *Prerequisite: MECH 323 or equivalent.* (2 units)

MECH 430. Optimal Control II

Continuation of MECH 429. Singular arcs, control with state constraints, minimum-time, minimum-fuel and control effort problems, Bellman's principle of optimality, dynamic programming, the Hamilton-Jacobi-Bellman (H-J-B) equation, and some advanced topics in optimal control. *Prerequisite: MECH 429.* (2 units)

MECH 431. Spacecraft Dynamics I

Kinematics and Attitude dynamics, gravity-gradient stabilization, single and dual-spin stabilization, control laws with momentum exchange devices, momentum wheels, *Prerequisites: MECH 140 and AMTH 106.* (2 units)

MECH 432. Spacecraft Dynamics II

Continuation of MECH 431. Time-optimal slew maneuvers, momentum-biased attitude stabilization, reaction thruster attitude control, introduction to dynamics of flexible spacecraft and liquid sloshing problem. *Prerequisite: MECH 431* (2 units)

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Sustainable Energy Program

Program Advisor: Dr. Samiha Mourad

Students interested in this major must satisfy the standard admissions criteria used by the School of Engineering, which include an undergraduate degree in a field of engineering (physics degrees will also be considered), appropriate GRE scores and (for international students) demonstrated proficiency in English. Both TOEFL and IELTS scores are acceptable for this purpose. All students are expected to maintain a minimum grade point average of 3.0 while enrolled in the program. They must also develop a Sustainable Energy Program of Studies with an academic advisor and file this document with the Graduate Services Office by the end of their first quarter at SCU.

Required Courses

Foundational classes:

- ELEN 280/MECH 287 Introduction to Alternative Energy Systems (2 units)
- ELEN 281A Power Systems: Generation (3 units)
- ELEN 285 Introduction to the Smart Grid (2 units)

Fundamental sustainablity courses:
(These courses also satisfy the Graduate Core requirements)

- CENG 208 Engineering Economics and Project Finance (3 units)
- ENGR 272 Energy Public Policy (2 units)
- ENGR 273 Sustainable Energy and Ethics (2 units)

Eight units in applied mathematics, which are to be selected in consultation with the student's academic advisor A set of specialized energy-related courses which are appropriate to the area of engineering in which the student is interested. These four areas are:

Mechanical Engineering

- ELEN 281B Power Systems: Transmission and Distribution (2 units)
- ELEN 287/ENGR 339 Energy Storage Systems (2 units)
- MECH 228 Equilibrium Thermodynamics (2 units)
- MECH 288 Energy Conversion I (2 units)

Electrical Engineering

- COEN 282/ELEN 288 Energy Management (2 units)
- ELEN 281B Power Systems: Transmission and Distribution (2 units)
- ELEN 287/ENGR 339 Energy Storage Systems (2 units)
- ELEN 353 DC to DC Power Conversion (2 units)

Computer Engineering

- COEN 250 Information Security Management (2 units)
- COEN 282/ELEN 288 Energy Management (2 units)
- COEN 389 Energy-Efficient Computing (2 units)
- ELEN 281B Power Systems: Transmission and Distribution (2 units)

Civil Engineering

- CENG 213 Sustainable Materials (4 units) and CENG 213L (1 unit)
- CENG 215 Sustainable Structural Engineering (4 units) and CENG 215L (1 unit)

Additional elective courses to complete the 45-unit requirement, which must be approved by the academic advisor. These elective courses may include a thesis, up to nine units.

Please Note: ELEN 379 Nanotechnology for Energy does not count toward the completion of this degree.

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The Lockheed Martin-Santa Clara University Program

OBJECTIVE

The purpose of this chapter is to describe a joint program between Lockheed Martin and Santa Clara University (SCU) for graduate education in space systems engineering. It contains background on the program and its description and structure. The program was formulated in consultation with the faculty and administrators of the School of Engineering at Santa Clara and the University of Denver as well as with management from Lockheed Martin. The program is approved by the SCU Provost Office.

BACKGROUND

Lockheed Martin has developed an Engineering Leadership Development Program (ELDP) to develop its most promising engineers who have demonstrated leadership potential and are team-oriented, excellent communicators, and problem solvers. The ELDP was first introduced at Lockheed Martin's site near Denver and the company established an agreement with the University of Denver (DU) by which the University provides graduate degrees for ELDP participants in two aspects of systems engineering: computer systems engineering and mechatronics systems engineering. The degree program in mechatronics systems engineering commenced in January 2005; the program in computer systems engineering 12 months later. The yearly average number chosen for the ELDP program at Denver is about 30.

Lockheed Martin has now launched the ELDP at its Sunnyvale, California, site, which employs more engineers than its Denver site. The company has established a program at Santa Clara University similar to the one at DU. This program serves two purposes: to provide a graduate degree in some aspect of space systems engineering for the Sunnyvale employees and to enable members of the ELDP group who are transferred from Denver to Sunnyvale and from Sunnyvale to Denver to continue their education in the other city at the other university. This chapter describes the Santa Clara program that meets the needs of Lockheed Martin and cooperates with the University of Denver so that ELDP members who move between Denver and Sunnyvale can take courses at both universities and receive their degree from the university that gives more than 50 percent unit credits.

Although this program was motivated by the interests of Lockheed Martin and establishes specific opportunities for its ELDP student, the Santa Clara University degree tracks and courses offered through this program are available for all qualifying Santa Clara University students.

THE SCU-LOCKHEED MARTIN-DU PROGRAMS

Curricula

Currently, two degree programs exist at DU tailored to the ELDP, both in "Systems Engineering": the M.S. in Computer Systems Engineering and the M.S. in Mechatronics Systems Engineering.

Santa Clara has created two new courses in space systems engineering (called Technical Development Curriculum or TDC courses by Lockheed Martin) and has defined four program tracks (shown below) within the current degree structure, in line with the "Systems Engineering" emphasis as requested by Lockheed Martin. There are other tracks available.

1. M.S. in Mechanical Engineering (specialization in Mechatronics) (see Plan A for curricular details) 45 units
2. M.S. in Electrical Engineering (specialization in Mechatronics) (see Plan B for curricular details) 46 units
3. M.S. in Software Engineering (see Plan C for curricular details) 46 units
4. M.S. in Computer Engineering (specialization in Software Engineering) (see Plan D for curricular details) 45 units

Common features of these programs:

1. The programs adhere to the current existing curriculum structures with the incorporation of the TDC courses, in order to maintain program quality and provide the right mixture of theory and practice.
2. The programs are in close alignment with existing DU-Lockheed Martin programs and their courses, and thus have many one-to-one correspondences on a course-by-course basis. This facilitates students transferring from one site to another.
3. There are two Technical Development Curriculum (TDC) courses—a total of eight units, specified under the "elective" portion of the SCU existing structure. The TDC courses are "Space Systems Design and Engineering I and II," developed by SCU.
4. There is a project management sequence—a total of four units, current recommended courses are EMGT 330 and 335.
5. There is a systems engineering sequence—a total of four units, current recommended courses are EMGT 380 and 381.

Admissions

Per SCU regulations, all ELDP students follow normal application procedures through the School of Engineering Graduate Services office. This includes submission of official copies of transcripts from all previous institutions. Admission to SCU is determined by the School of Engineering. Lockheed will inform SCU of applicants who are participants in ELDP.

The School of Engineering waives the GRE for ELDP applicants who have completed a B.S. degree in engineering, computer science, natural science, or mathematics with a GPA of 3.0 or better (on a scale of 4), except that all M.S. in Software Engineering applicants must have a prior degree in computing or must take the GRE Subject Test in Computer Science, which would then be considered in the admissions decision.

The School of Engineering waives the TOEFL requirement for ELDP students with degrees from foreign institutions who have demonstrated English proficiency in their positions at Lockheed Martin.

Except as noted in the previous two paragraphs, the final determination on admission to each degree program must be completed according to all existing criteria.

Advising

An SCU faculty advisor will be assigned to each student. Faculty advisors will need access to transcripts to make a determination about which courses must be taken and which may not be taken as part of a given student's degree program, and which foundation requirements have been satisfied. (Note: Students with insufficient background might be required to take additional foundation courses beyond the units required for the master's degree.)

The faculty advisor will work with the student to develop a program of study that includes the TDC, project management, and systems engineering courses and that meets the remaining degree requirements.

Where our current programs have different tracks, ELDP students may complete any track for which they satisfy the requirements.

Transfer Credits

The School of Engineering will accept up to 22 units of transfer credit toward a 45-unit or 46-unit master's degree (so that at least half the credits for an SCU degree will have been earned at Santa Clara) provided that no more than nine of the units may be transferred from institutions other than the University of Denver. (The 22-unit limit therefore applies to all students from DU, not just Lockheed students, but not to students from other institutions.) The DU department faculty and Graduate Council approved a similar policy with respect to SCU.

Departments may establish specific lists of DU courses that are pre-approved for transfer into SCU degree programs. Any department may ask its department faculty in charge of each specialization track to determine transfer equivalents from DU courses required by their track. Any request for transfer credit for courses other than those pre-approved as above must be approved by the student's faculty advisor.

All transfer units must meet the usual criteria:

- Transferred courses must be of appropriate graduate level and quality compared to courses at SCU.
- Transferred courses must have a grade of B or better.
- Transferred courses must not have been applied to another degree.
- Transferred courses must not repeat prior coursework.

Venue

In general, SCU courses will be taught on the Santa Clara campus. The exception to this are the TDC courses which are often taught at a campus laboratory located in the NASA Research Park in Moffett Field, CA.

Minimum Enrollment

In any quarter, a TDC course will be offered only if ten or more students are registered (or paid for).

Tuition Payment

There is no change to the current practice for collecting tuition.

Oversight

Santa Clara University will monitor the program for continuous improvement and will conduct a review after three years to make a decision about the future of the program, i.e., continue without modification, continue with modification, or discontinue.

PLAN A
M.S. DEGREE IN MECHANICAL ENGINEERING
(SPECIALIZATION IN MECHATRONICS)

Prerequisite

For students without a B.S. degree in Mechanical Engineering or equivalent, some foundation courses may be needed.

Overview

• TDC courses	8 units
• Systems Engineering and Project Management	8
• Mathematics	8
• Mechatronics	6
• Robotics and Control	8
• Thesis or Capstone Project	2
• Issues in Professional Practice	2
• Technical Electives	3
Total	**45 units**

TDC Courses

• Space Systems Design and Engineering I	ENGR/MECH 371	4 units
• Space Systems Design and Engineering II	ENGR/MECH 372	4

Systems Engineering and Project Management

• Project Management	EMGT 330 and 335	4 units
• Intro to Systems Engineering	EMGT 380	2
• System Conceptual Design	EMGT 381	2

Mathematics

• Advanced Engineering Mathematics I & II or the equivalent two-course sequence	AMTH/MECH 202 AMTH/MECH 200 and 201	4 units
• One additional math sequence approved by advisor	AMTH courses	4

Mechatronics

• Advanced Mechatronics I	MECH 207	3 units
• Advanced Mechatronics II	MECH 208	3

Robotics and Control

• Robotics I	MECH/ELEN 337	2 units
• Robotics II	MECH/ELEN 338	2
• Control systems sequence approved by advisor	MECH courses	4

Thesis or Capstone Project

• Thesis or Capstone Project	MECH 290 or 299	2 units
• Issues in Professional Practice course, from the Engineering & Society list of approved graduate core courses	ENGR or EMGT courses	2

Technical Electives

• Technical Electives	3 units

PLAN B
M.S. DEGREE IN ELECTRICAL ENGINEERING
(SPECIALIZATION IN MECHATRONICS)

Prerequisite

For students without a B.S. degree in Electrical Engineering or equivalent, some foundation courses may be needed.

Overview

• TDC courses	8 units
• Systems Engineering and Project Management	8
• Core: Mathematics and Electrical Engineering	14
• Mechatronics	8
• Issues in Professional Practice	2
• Technical Electives	6
Total	**46 units**

TDC Courses

• Space Systems Design and Engineering I	ENGR/MECH 371	4 units
• Space Systems Design and Engineering II	ENGR/MECH 372	4

Systems Engineering and Project Management

• Project Management	EMGT 330 and 335	4 units
• Intro to Systems Engineering	EMGT 380	2
• System Conceptual Design	EMGT 381	2

Core: Mathematics and Electrical Engineering: Select 14 units from:

• Design of Scientific Experiments	AMTH 217 and 219	4 units
• Linear Algebra II	AMTH 246	2
• Applied Graph Theory I	AMTH 256	2
• Design and Analysis of Algorithms	AMTH 377	4
• Advanced Logic Design	ELEN 127	2
• Electromagnetic Field Theory I	ELEN 201	2
• Signals, Circuits, and Systems	ELEN 210	2
• Modern Network Analysis I	ELEN 211	2

Mechatronics

• Intro to Control Systems	ELEN 230	2 units
• Advanced Mechatronics I	ELEN 460/MECH 207	2
• Advanced Mechatronics II	ELEN 461/MECH 208	2
• Advanced Mechatronics III	ELEN 462/MECH 209	2

Technical Electives: Select 6 units from:

• Design of Feedback Control Systems	ELEN 231	2 units
• Control Systems I, II	ELEN 236, 330	2, 2
• Microsensors	ELEN 271	2
• Robotics I, II, III	ELEN/MECH 337, 338, 339	2, 2, 2
• Special Topics: Vision Systems for Robotic Applications	MECH 296	2
• Advanced Mechatronics IV	MECH 310	2
• Modeling and Control of Telerobotic Systems	MECH 311	4

PLAN C
M.S. DEGREE IN SOFTWARE ENGINEERING

Prerequisite

This is for students who have a bachelor's degree in computer science, computer engineering, or equivalent.

Overview

• TDC courses	8 units
• Systems Engineering and Project Management	8
• Core: Software Engineering Core	20
• Capstone Project	6
• Computer Engineering Graduate Electives	4
Total	**46 units**

TDC Courses

• Space Systems Design and Engineering I	ENGR/MECH 371	4 units
• Space Systems Design and Engineering II	ENGR/MECH 372	4

Systems Engineering and Project Management

• Project Management	EMGT 330 and 335	4 units
• Intro to Systems Engineering	EMGT 380	2
• System Conceptual Design	EMGT 381	2

Core: Software Engineering Core

• Design and Analysis of Algorithms	AMTH 377/COEN 279	4 units
• Truth, Deduction, and Computation	COEN 260	4
• Software Engineering	COEN 285	4
• Software Quality Assurance & Testing	COEN 286	2
• Software Ethics	COEN 288	2
• Formal Methods in Software Engnrng	COEN 385	2
• Software Architecture	COEN 386	2

Capstone Project

• Software Engineering Capstone *(Prerequisites: COEN 286, 386)*	COEN 485	6 units

Computer Engineering Electives

• Computer Engineering Graduate Courses	COEN courses	4 units

PLAN D
M.S. DEGREE IN COMPUTER ENGINEERING
(EMPHASIS IN SOFTWARE ENGINEERING)

Prerequisite

This is for students who have completed (grade B or better) the undergraduate senior/graduate first-year level or equivalent of at least two of the following core courses prior to this M.S. degree:

Core Courses

• Design and Analysis of Algorithms	AMTH 377/COEN 279	4 units
• Computer Architecture	COEN 210	4
• Computer Networks	COEN 233	4
• Principles of Programming Languages	COEN 256	4
• Operating Systems	COEN 283	4

Overview

• TDC courses	8 units
• Systems Engineering and Project Management	8
• Computer Engineering Core and Graduate Electives	13
• Software Engineering Specialization Courses	16
Total	**45 units**

TDC Courses

• Space Systems Design and Engineering I	ENGR/MECH 371	4 units
• Space Systems Design and Engineering II	ENGR/MECH 372	4

Systems Engineering and Project Management

• Project Management	EMGT 330 and 335	4 units
• Intro to Systems Engineering	EMGT 380	2
• System Conceptual Design	EMGT 381	2

(A) Computer Engineering Core: Select 0–12 units from:

• Design and Analysis of Algorithms	AMTH 377/COEN 279	4 units
• Computer Architecture	COEN 210	4
• Computer Networks	COEN 233	4
• Principles of Programming Languages	COEN 256	4
• Operating Systems	COEN 283	4

The student must take these core course(s) or equivalent that is/are not completed prior to admission. Equivalent core courses completed prior to admission should not be repeated, but the units may be used for graduate engineering elective courses instead.

(B) Graduate Engineering Electives: Select 0–13 units to complete the 45-unit degree requirement:

- Graduate Engineering Electives 0–13 units

Software Engineering Specialization Courses

• Truth, Deduction, and Computation	COEN 260	4 units
• Software Engineering	COEN 285	4
• Software Quality Assurance & Testing	COEN 286	2
• Software Ethics	COEN 288	2
• Formal Methods in Software Engineering	COEN 385	2
• Software Architecture	COEN 386	2

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Campus Life

Santa Clara students are encouraged to participate in extracurricular activities as part of their total development. The primary educational objective in supporting student activities and organizations is to foster a community that is enriched by men and women of diverse backgrounds, wherein freedom of inquiry and expression enjoys high priority.

The following sections describe various aspects of student life and services.

CAMPUS MINISTRY

Fostering the University's mission to develop the whole person, Campus Ministry offers a variety of programs and opportunities where faith may be explored, discovered, and developed. The Campus Ministry team is committed to supporting the spiritual and personal growth of all students, regardless of faith tradition, if any, and a welcoming and inclusive environment for all.

The team consists of ten full-time members, eleven resident ministers residing in residence halls, and sixteen student interns. Campus Ministry offers the University community a variety of programs: liturgies, other sacramental celebrations, retreats, discussion groups, Christian Life Communities (CLCs), Bible study, ecumenical and interfaith gatherings, social justice events, counseling and spiritual direction. Campus Ministry also supports religiously-affiliated student clubs, including those for Muslim, Jewish, Hindu, and Orthodox students.

Please visit the website at: scu.edu/cm or stop by our office in Benson Center.

STUDENT MEDIA

KSCU: *KSCU* is a student-run, non-commercial radio station at 103.3 FM. The program format features primarily independent music, including indie rock, punk, ska, jazz, blues, and reggae. Students may get involved with the radio station as a staff member or as a volunteer disc jockey, office assistant, fundraiser, or sound technical staff. The staff of *KSCU* operates all aspects of an FM radio station in accordance with SCU's mission and goals, and Federal Communications Commission regulations.

The Redwood: SCU's yearbook strives to maintain proper journalistic guidelines while producing an accurate and quality book for the University community. Entirely student run, with the aid of a faculty advisor, *The Redwood* offers paid and volunteer positions in writing, design, and photography. Students at-large are encouraged to participate by contributing to the yearbook.

Santa Clara Review: A student-edited literary magazine that publishes poetry, fiction, nonfiction, and art, the Santa Clara Review is published biannually, drawing on submissions from SCU students, faculty, staff, and writers outside of SCU. *The Santa Clara Review* is committed to the development of student literary talent, in both editorial

knowledge and creative writing skills. Students may get involved with the magazine in several staff positions and with opportunities to volunteer in the areas of poetry, fiction, nonfiction, art, and management.

The Santa Clara: *The Santa Clara* is the University's undergraduate weekly newspaper, serving as an informative and entertaining student-run campus publication. Students may get involved in a staff position or as a volunteer writer, photographer, or member of the business staff.

STUDENT RESOURCES AND SERVICES

Listed below are some of the service centers established to meet the needs of students. Each center provides a variety of programs to encourage personal growth.

COWELL COUNSELING AND PSYCHOLOGICAL SERVICES (CAPS)

Counseling and Psychological Services offers mental health services to undergraduate and graduate students. The mission of the services is to support the developmental growth of students in ways that enable them to become more effective in their personal, academic, and social functioning. Counseling helps students address psychological issues that may affect their successful participation in the learning community. Among the psychosocial and developmental issues that students work on with their counselors are depression, anxiety, interpersonal problems, disturbed sleep or eating behaviors, acculturation, academic motivation, homesickness, family concerns, intimacy, and sexuality. The services are confidential and free and include individual counseling, couples counseling, group counseling, and psycho-educational programs.

COWELL STUDENT HEALTH SERVICES

Student Health Services provides quality, accessible, and convenient medical care to Santa Clara students. The Health Services provides primary medical care, physicals, diagnosis of illness and injuries, immunizations, gynecological examinations, limited in-house pharmacy, and referral to specialists when needed. The Health Services staff includes a physician, nurse practitioners, physician assistants, registered nurses, and medical assistants. In addition, a psychiatrist, registered dietician, and physical therapy assistant are each available on a part-time basis.

Graduate students who choose to use the Health Services must pay a health fee of $90 per quarter to be seen. The Health Services does not charge for visits, but does charge students for laboratory work, medications, medical equipment, and other specialized services. Students are seen on an appointment basis and usually can be seen the same day, if an appointment is requested in the morning. The center is open from 8:30 a.m. to 5 p.m. Monday through Friday when classes are in session. When the Health Services is closed, there is an advice nurse available by phone and volunteer student emergency medical technicians who can visit students on campus. The center is closed from mid-June to mid-August.

All international graduate students must carry health insurance, either their own personal plan or the University-sponsored plan. Graduate students who want to purchase the University health insurance must also pay the $90 per quarter health fee. Please call the insurance coordinator at 408-554-2379 for further information.

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Facilities

The University is located on a 106-acre campus in the city of Santa Clara near the southern end of the San Francisco Bay in one of the world's great cultural centers. More than 50 buildings on campus house 15 student residences, a main library, a law library, two student centers, the de Saisset Museum, extensive performing arts and athletic facilities, and a recreation and fitness center.

Santa Clara's campus has the advantage of being located in Silicon Valley—a region known for its extraordinary visionaries, who have designed and created some of the most significant scientific and technological advances of our age. More than a place, Silicon Valley is a mindset—home to more than 2 million residents and 6,600 science- and technology-related companies. And that does not include San Francisco, which is just an hour away.

Santa Clara's campus is well known for its beauty and mission-style architecture. Newly opened in 2013, the brick-paved Abby Sobrato Mall leads visitors from the University's main entrance to the heart of campus—the Mission Santa Clara de Asís. The roses and palm and olive trees of the Mission Gardens surround the historic Mission Church, which was restored in 1928. The adjacent Adobe Lodge is the oldest building on campus. In 1981, it was restored to its 1822 decor.

ACADEMIC FACILITIES

Amid all this beauty and history are modern, world-class academic facilities. Students study and thrive in places such as the Joanne E. Harrington Learning Commons, Sobrato Family Technology Center, and Orradre Library. Individuals and groups alike enjoy studying in its inviting, light-filled, and open environment. Notably, the library features an Automated Retrieval System, a high-density storage area where up to 900,000 books and other publications can be stored and retrieved using robotic-assisted technology.

Another example of Santa Clara's excellent academic facilities is Lucas Hall, home of the Leavey School of Business. This modern 85,000-square-foot building houses classrooms, meeting rooms, offices, study spaces, and a café. Classrooms are equipped with state-of-the-art videoconferencing equipment as well as a multiplatform system to record faculty lectures for later review by students. The Arts and Sciences Building adjacent to Lucas Hall is home to the Markkula Center for Applied Ethics as well as academic departments, classrooms, and a 2,200-square-foot digital television studio—among the best found on any campus nationwide.

Also nearby is the Patricia A. and Stephen C. Schott Admission and Enrollment Services Building, a welcome center for campus visitors and home to several University departments. Opened in 2012, the lobby of this green-certified structure includes technology-infused exhibits that illustrate Santa Clara's Jesuit mission. Among other green features on campus are two solar-powered homes built in 2007 and 2009 for the U.S. Department of Energy's Solar Decathlon. Both now serve as laboratories for solar and sustainability technologies.

ATHLETICS AND THE ARTS

Athletics are an important part of the University, and Bronco spirit is evident everywhere on campus. Among the newest additions to Santa Clara's athletics facilities is Stephen Schott Stadium, home field for the men's baseball team. The stadium features batting cages, a clubhouse, concessions stands, and seating for 1,500 fans. Across the street is Bellomy Field—eight acres of well-lit, grassy field space used for club and intramural sports like rugby and field hockey. Adjacent to Bellomy Field is the well-appointed women's softball field, which opened in 2013. Other athletic venues on campus include the 6,400-seat Stevens Stadium, home to the men's and women's soccer programs, and the Leavey Event Center, the University's premier basketball facility. Over the years, it has hosted nine West Coast Conference Basketball Championships.

The arts, an equally important part of life at Santa Clara University, are on vibrant display at the de Saisset Museum, the University's accredited museum of art and history. The de Saisset presents changing art exhibitions throughout the year and serves as the caretaker of the University's California History Collection, which includes artifacts from the Native American, Mission, and early Santa Clara College periods. The Edward M. Dowd Art and Art History building opened in 2016. The 45,000-square-foot facility includes modern studios for students and faculty, technology-rich classrooms, student workspaces, and meeting areas. The building features a rotunda on the third floor with an outdoor terrace area. Student, faculty, and visiting artists' work is displayed both indoors and outdoors.

SCU Presents represents the performing arts on campus, including the Louis B. Mayer Theatre, the Fess Parker Studio Theatre, and the Music Recital Hall. Mayer Theatre is Santa Clara University's premier theatrical venue, housing 500 intimate seats in either a flexible proscenium or thrust stage setting. The Fess Parker Studio Theatre has no fixed stage or seating. Its black-box design, complete with movable catwalks, provides superb flexibility in an experimental setting. The 250-seat Music Recital Hall provides a contemporary setting where students, faculty, and guest artists offer a variety of performances.

STUDENT LIFE

Santa Clara has 10 on-campus residence halls, most with traditional double rooms and large common bathrooms, others with suite arrangements conducive to more informal living. Juniors and seniors can apply for townhouse-style living in the 138-unit University Villas across from the main campus. Opened in 2012, Graham Hall is Santa Clara's newest residence hall. The environmentally friendly building boasts 96 mini-suites, lounges, full kitchens, and laundry facilities for every eight-room "neighborhood." In addition, the residence hall has two classrooms, a small theater, outdoor barbecue and picnic areas, and a large courtyard.

The Robert F. Benson Memorial Center serves as a hub for campus life. The Benson Center offers dining services and houses the campus bookstore, post office, and meeting rooms. The University's main dining hall there, Marketplace, resembles an upscale food court with numerous stations and options. For a more informal experience, The Bronco is the Benson Center's late-night venue, serving beverages and pub-style food.

Another hot-spot for student life, the Paul L. Locatelli, S.J., Student Activity Center includes a 6,000-square-foot gathering hall with a high ceiling that can accommodate dances and concerts as well as pre- and post-game activities. Designed with environmental sensitivity, the building is energy efficient and has daytime lighting controls and motion sensors to maximize use of natural light. For fitness-minded students, the Pat Malley Fitness and Recreation Center features a 9,500-square-foot weight training and cardiovascular exercise room, three basketball courts, a swimming pool, and other facilities to support the recreational and fitness needs of the campus community.

The campus features many locations for quiet reflection as well. One such place is the St. Clare Garden, which features plants and flowers arranged into five groups to portray the stages of the saint's life. For campus members who want a more hands-on relationship with nature, the Forge Garden, SCU's half-acre organic garden, serves as a campus space for course research, service learning, and sustainable food production.

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Student Conduct Code

STATEMENT OF RESPONSIBILITIES AND STANDARDS OF CONDUCT

For the most current information on the student conduct code and all policies and procedures regarding the student judicial system, please refer to the Office of Student Life website at www.scu.edu/studentlife/osl.

The goal of Santa Clara University is to provide students with a general education so that they will acquire knowledge, skill, and wisdom to deal with and contribute to contemporary society in constructive ways. As an institution of higher education rooted in the Jesuit tradition, the University is committed to creating and sustaining an environment that facilitates not only academic development but also the personal and spiritual development of its members. This commitment of the University encourages the greatest possible degree of freedom for individual choice and expression, with the expectation that individual members of the community will:

- Be honest.
- Demonstrate self-respect.
- Demonstrate respect for others.
- Demonstrate respect for the law and University policies, procedures, and standards; their administration; and the process for changing those laws, policies, procedures, and standards.

In keeping with this commitment, this Statement of Responsibilities and Standards of Conduct and related policies and procedures have been formulated to guarantee each student's freedom to learn and to protect the fundamental rights of others. There can be no rights and freedoms if all who claim them do not recognize and respect the same rights and freedoms for others. In addition to the laws of the nation, the state of California, and the local community, the University administration has established policies, procedures, and standards deemed necessary to achieve its objectives as a Catholic, Jesuit university.

All members of the Santa Clara community are expected to conduct themselves in a manner that is consistent with the goals of the institution and to demonstrate respect for self, others, and their property. Students living off campus are members of this community, and as such are representatives to the community at large. In this regard, students living off campus maintain an equal measure of accountability to the values and expectations of all members of this community as identified in the Student Conduct Code.

Whether living in or traversing through the neighborhood, or parking in the street, students are expected to adhere to the same high standards of conduct and behavior that are consistent with the students' developing role as responsible and accountable citizens, and that reflect well upon the Santa Clara University community.

All members of the University community have a strong responsibility to protect and maintain an academic climate in which the fundamental freedom to learn can be enjoyed by all and where the rights and well-being of all members of the community are protected. The University reserves the right to review student conduct that occurs on and off campus when such behavior is inconsistent with this expectation and the Student Conduct Code. The following acts subject students to disciplinary action:

1. Engaging in any form of academic dishonesty, such as plagiarism (representing the work or ideas of others as one's own without giving proper acknowledgment), cheating (e.g., copying the work of another person, falsifying laboratory data, sabotaging the work of others), and other acts generally understood to be dishonest by faculty or students in an academic context. (Law students, refer to School of Law code.)
2. Illegal use, possession, or distribution of drugs. The use or possession of equipment, products, or materials that are used or intended for use in manufacturing, growing, using, or distributing any drug or controlled substance. Possessing, concealing, storing, carrying, or using any drug paraphernalia as defined in California Health and Safety Code § 11364.5, including, but not limited to, objects intended for use or designed for use in ingesting, inhaling, or otherwise introducing marijuana, cocaine, hashish, or hashish oil into the human body. A reported violation of this section will result in the confiscation and immediate disposal of drugs and drug paraphernalia by University officials
3. Falsification or misuse, including non-authentic, altered, or fraudulent misuse, of University records, permits, documents, communication equipment, or identification cards and government-issued documents
4. Knowingly furnishing false or incomplete information to the University, a University official, or judicial hearing board in response to an authorized request
5. Disorderly, lewd, indecent, or obscene conduct; excessive or prolonged noise; behavior that interferes with the orderly functioning of the University, or interferes with an individual's pursuit of an education on University-owned or controlled property or during an authorized University class, field trip, seminar, competition or other meeting, or University-related activity
6. Detention, physical abuse, or conduct that threatens imminent bodily harm or endangers the physical well-being of any person, including harm to self
7. Nonconsensual physical contact of a sexual nature such as sexual misconduct, sexual assault, and rape
8. Destruction, damage, or misuse of University property or the property of any other person or group
9. Theft or conversion of University property or the property of any other person or group
10. Hazing, harassing, threatening, degrading language or actions, including stalking, or any practice by a group or individual that degrades a student or employee, endangers health, jeopardizes personal safety, or interferes with an employee's duties or with a student's class attendance or a person's educational pursuits
11. Intentional obstruction or disruption of teaching, research, administration, disciplinary procedures, or other University activities; or obstruction or disruption that interferes with the freedom of movement, both pedestrian and vehicular

12. Possessing, concealing, storing, carrying, or using any real or simulated weapons (including toy guns). The definition of weapons includes, but is not limited to, firearms (including BB/pellet, Airsoft, and paintball guns—regardless of whether they are disassembled), knives (switchblade, double-edged, hunting-style [fixed-blade] of any length, throwing, folding [pocket-style with a blade that locks into place], and knives with blades of 2.5 inches in length or greater), explosives (including, though not limited to, fireworks and firecrackers), ammunition, dangerous chemicals, or any other dangerous weapons or instruments, or chemicals as defined by, though not limited to, California State Law except if expressly authorized by University policy or procedure (see "Housing and Residence Life Policies" for information that pertains to Residence Life). A reported violation of this section will result in the immediate confiscation and disposal of real or simulated weapons by University officials
13. Unauthorized entry into or use or defacement of University facilities, including residence halls and other buildings and grounds, including unauthorized entry into or presence in or on a University building; unauthorized erection or use on University property of any structures including specifically but not limited to tents, huts, gazebos, shelters, platforms, and public address systems; or unauthorized use of University property for dances, concerts, assemblies, meetings, sleeping, cooking, or eating if said activity interferes with the operation of the University or surrounding community
14. Publication, posting, or distribution through the use of University resources (e.g., computer networks, telephone lines, e-mail services, Internet connections), or at authorized University activities of material that violates the law of libel, obscenity, postal regulations, the fair use of copyrighted materials, or any law or statute or University policy
15. Failure to comply with a reasonable request or order of a University executive or other authorized official(s); refusal or failure to leave such premises because of conduct prescribed by this code when such conduct constitutes violations of this code or a danger to personal safety, property, or educational or other appropriate University activities on such premises; or refusal or failure to identify oneself when requested by a University official provided the official is identified and indicates legitimate reason for the request
16. Possession, consumption, sale, or action under the influence of alcoholic beverages by persons under the age of 21; furnishing alcoholic beverages to persons under the age of 21; consumption of alcoholic beverages in a public place (all areas other than individual residences, private offices, and scheduled private functions); excessive and inappropriate use of alcoholic beverages (See also "Alcohol Policy Within the Residence Halls" on page 27)
17. Misconduct in which a student is detained, arrested, cited, or otherwise charged with violations of local, state, or federal laws that materially or adversely affect the individual's suitability as a member of the Santa Clara University community
18. Tampering with, removing, damaging, or destroying fire extinguishers, fire alarm boxes, smoke or heat detectors, emergency call boxes, and other safety equipment anywhere on University property; creating a fire, safety, or health hazard; or failure to respond to fire alarms, evacuate buildings during alarm activation, or respond to the directions of emergency personnel

19. Any behavior that disrupts or causes disruption of computer services; damages, alters, or destroys data or records; adversely affects computer software, programs, systems, or networks; or uses data, computer systems, or networks to devise or execute any scheme to defraud, deceive, extort, or wrongfully obtain money, property, or data

Students who are alleged to have violated the Student Conduct Code may be subject to disciplinary action and, if applicable, may also be subject to criminal prosecution.

Judicial Records Policy

The Office of Student Life maintains a hard copy file and a digital record of a student's judicial history. Judicial records are educational records, and are thereby subject to the Family Educational Rights and Privacy Act (FERPA) and the University's Student Records Policy.

The judicial record is confidential and is only shared internally with University officials in instances when the student grants permission to release the record, or there is what FERPA defines "an educational need to know" basis for the request. The judicial record is maintained throughout the student's enrollment and thereafter as indicated below. A student's judicial record will only be released from the hard copy file to a person or party external to the University if the student has granted permission, where the disclosure of the record is permissible under the provisions of FERPA, or where the University is required to do so by law. The digital copy of the judicial record will only be released to an external person or party where the University is required to do so by law.

Retention of Hard Copy of Judicial Records

1. The hard copy file of a student's entire judicial history is kept for a minimum of one (1) academic year beyond the academic year in which the date of the last violation of the Student Conduct Code occurred. When a student commits a violation of academic integrity, the hard copy file is retained for the remainder of a student's academic career.
2. The files of any student who has received one or more of the following sanctions will be maintained for three (3) academic years beyond the academic year in which the student's tenure in his/her current degree program at the University has ended:
   - Removal from University housing
   - Disciplinary probation
   - Deferred suspension
   - Suspension
3. The judicial files of a student who has been expelled will be maintained for seven (7) years beyond the academic year in which the student's tenure at the University has ended.

The University reserves the right to change this policy at any time at its sole discretion.

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University Policies

SPEAKERS POLICY

The purpose of this policy is to assure the right of free expression and exchange of ideas, to minimize conflict between the exercise of that right and the rights of others in the effective use of University facilities, and to minimize possible interference with the University's responsibilities as an educational institution.

The time, place, and manner of exercising speech on campus are subject to regulations adopted by the University administration. Orderly conduct, noninterference with University functions or activities, and identification of sponsoring groups or individuals are required. Outdoor sound amplification will be permitted only with explicit approval of the Vice Provost for Student Life or designee. (Refer to "Amplification of Sound.")

Members of the faculty, academic departments, staff, administrative offices, or student organizations registered by authorized student government bodies may invite non-University speakers to address meetings on campus. Student groups that have not been registered by authorized student government bodies may not invite non-University speakers to address meetings on campus. If there would likely be extensive public notice or controversy associated with the presence of any speaker on campus, prior notice should be given to the head of the Office of Marketing and Communications in the case of likely inquiries from external constituencies of the University or media; and to the Director of Campus Safety Services in the case of possible protest or disruption. Except for unusual circumstances, the notice should be at least one week before the meeting or event is to occur.

The presence of a guest speaker on the campus of Santa Clara University does not necessarily imply approval or endorsement by the University of the views expressed by the guest speaker or by anyone else present at the event.

The person or organization sponsoring a speaker around whom there would likely be extensive public notice or controversy is responsible for including the above statement in its advertisement, announcements, and news releases. If deemed appropriate, the University administration may also require the above statement be read at the beginning of the event.

Whenever the University administration considers it appropriate in furtherance of educational objectives, it may require either or both of the following:

- That the meeting be chaired by a person approved by the University administration
- Any invitation to a non-University speaker extended by a registered student organization, member of the faculty, staff, academic department, or administrative department may be rescinded only if the President, or his authorized designee, determines, after appropriate inquiry, that the proposed speech will constitute a clear and present danger to the orderly operation or peaceful conduct of campus activities by the speaker's advocacy of such actions as:
  - Willful damage or destruction, or seizure of University buildings or other property

– Disruption or impairment of, or interference with, classes or other University activities
– Physical harm, coercion, intimidation, or other invasion of the rights of University students, faculty, staff, or guests
– Violation of law
– Other disorder of a violent or seriously disruptive nature

LIABILITY AND PROPERTY INSURANCE

Except by expressed arrangement with the University, the University's insurance does not cover students' liability or students' personal property. Students may wish to seek the services of their personal insurance agent to arrange for such coverage.

STUDENT PARKING

Parking on campus requires a valid parking permit at all times. Parking permits are available for purchase at Campus Safety Services (located in the parking structure) between 8 a.m. and midnight, seven days a week. Call 408-554-4441 for further information.

Copies of the current rules are contained in the Parking Plan, which can be found at Campus Safety's website: www.scu.edu/cs.

TITLE IX AND AMERICANS WITH DISABILITIES ACT

The Americans with Disabilities Act, as amended requires that the university ensure that all students have equal access to academic and university programs. Students with disabilities who are registered with the Disabilities Resources Office may be qualified to receive an accommodation, auxiliary aid or service based on supporting documentation. The federal department of education has issued a clarification of laws associated with Title IX and class attendance. to be in compliance with Title IX, a school must offer appropriate accommodation to a student whose absence is related to pregnancy or childbirth for as long as the student's doctor deems the absence to be medically necessary.

See "supporting the academic success of pregnant and parenting students under Title IX of the Education Amendments of 1972," U.S. Department Of Education, Office For Civil Rights, June 2013.

NONDISCRIMINATION POLICY

Santa Clara University prohibits discrimination and harassment on the basis of a person's actual or perceived race, color, national origin, ancestry, sex, sexual orientation, age, religious creed, physical or mental disability, medical condition as defined by California law, marital status, citizenship status, gender identity, gender expression, genetic information, military or veteran status, or other status protected by law in the administration of its educational policies, admissions policies, scholarships and loan programs, athletics, or employment-related policies, programs, and activities; or other University-administered policies, programs, and activities. The University condemns and will not tolerate such harassment or discrimination against any employee, student, visitor, or guest on the basis of any status protected by university policy or law, and upholds a zero tolerance policy for sexual violence and sexual misconduct.

The University will take prompt and effective corrective action including, where appropriate, disciplinary action up to and including dismissal or expulsion. The university may implement interim measures in order to maintain a safe and non-discriminatory educational environment. Additionally, it is the University's policy that there shall be no retaliation against a person for alleging discrimination, harassment or sexual misconduct, cooperating with an investigation, or participating in an informal or formal resolution procedure.

The Office of EEO and Title IX is responsible for monitoring the university's compliance with federal and state nondiscrimination laws, assisting with all aspects of investigating and resolving reported violations of Policy 311: Prevention of Unlawful Discrimination, Unlawful Harassment and Sexual Misconduct. The EEO and Title IX Coordinator is also designated as the ADA/504 Coordinator responsible for coordinating efforts to comply with federal and state disability laws and regulations. The University encourages those who have witnessed or experienced any form of discrimination, harassment, or sexual misconduct to report the incident promptly, to seek all available assistance, and to pursue informal or formal resolution processes as described in this policy. Inquiries regarding equal opportunity policies, the filing of grievances, or requests for a copy of the University's grievance procedures covering discrimination and harassment complaints should be directed to:

Belinda Guthrie, EEO and Title IX Coordinator
Office of EEO and Title IX
Santa Clara University
900 Lafayette Street
Suite 100
Santa Clara, CA 95053
408-554-4113
bguthrie@scu.edu

A person may also file a complaint within the time required by law with the appropriate federal or state agency. Depending upon the nature of the complaint, the appropriate agency may be the federal Equal Employment Opportunity Commission (EEOC), the federal Office for Civil Rights (OCR), or the California Department of Fair Employment and Housing (DFEH).

DRUG-FREE POLICIES

It is the goal of Santa Clara University to maintain a drug-free workplace and campus. The unlawful manufacture, distribution, dispensation, possession, and/or use of controlled substances or the unlawful possession, use, or distribution of alcohol is prohibited on the Santa Clara University campus, in the workplace, or as part of any of the University's activities. This includes the unlawful use of controlled substances or alcohol in the workplace even if it does not result in impaired job performance or in unacceptable conduct.

The unlawful presence of any controlled substance or alcohol in the workplace and campus itself is prohibited. The workplace and campus are presumed to include all Santa Clara premises where the activities of the University are conducted.

Violations will result in disciplinary action up to and including termination of employment for faculty and staff or expulsion of students. A disciplinary action may also include the completion of an appropriate rehabilitation program. Violations may also be referred to the appropriate authorities for prosecution.

The program information is distributed on an annual basis to all faculty, staff, and students. New staff employees are given a copy in New Employee Orientation. New faculty employees are given a copy at New Faculty Orientation. The program is reviewed at least biennially by the Office of Student Life, Affirmative Action Office, and the Department of Human Resources. Contact the Office of Student Life for a complete copy of the program.

GENDER-BASED DISCRIMINATION AND SEXUAL MISCONDUCT POLICY PURPOSE STATEMENT

Santa Clara University is committed to providing an environment free of gender-based discrimination, including sexual harassment, sexual misconduct, sexual violence and assault, relationship (dating and domestic) violence, and stalking. The University provides resources and reporting options to students, faculty, and staff to address concerns related to gender-based discrimination and sexual misconduct prohibited by Title IX and University policy, and, through training and education, works to prevent its occurrence. The University seeks to provide a consistent, caring, and timely response when sexual and gender-based misconduct occurs within the University community. When the University becomes aware of allegations of sexual misconduct, it will take prompt and effective action. This action may include an initial assessment of safety and well-being, implementing interim remedies at no cost to the complainant for protection and support, discussing how the complainant wishes to proceed, initiating an investigation, and identifying appropriate avenues for resolution. The University's response will be overseen by the EEO and Title IX Coordinator.

The University's Gender-Based Discrimination and Sexual Misconduct Policy applies to all students, faculty, and staff, and includes any individual regularly or temporarily employed, studying, living, visiting, or serving in an official capacity at Santa Clara University (including volunteers and contractors). The policy applies to both on-campus and off-campus conduct and to online actions that have a potential or actual adverse impact on any member of the University community, or which substantially interfere with a person's ability to participate in University activities, or which could affect a substantial University interest or its educational mission.

POLICY STATEMENT ON WHAT CONSTITUTES CONSENT

The University adheres to California's definition of affirmative consent for sexual activity. "Affirmative consent" means affirmative, conscious, and voluntary agreement to engage in sexual activity. Under this definition, "No" always means "No." "Yes" means "Yes" only if it is a clear, knowing, and voluntary consent to any sexual activity. Affirmative consent must be ongoing throughout a sexual activity and can be revoked at any time. The existence of a dating relationship between the persons involved, or the fact of past sexual relations between them, should never by itself be assumed to be an indicator of consent. Fully informed consent means that a person understands the details of a sexual interaction (who, what, when, where, why, and how).

It is the responsibility of each person involved in the sexual activity to ensure that he or she has the affirmative consent of the other or others to engage in that activity. Consent can be given by words or action, but non-verbal consent is not as clear as talking about what a person does or does not want sexually. Consent to some form of sexual activity cannot be automatically taken as consent to any other form of sexual activity. Silence--without actions demonstrating permission--cannot be assumed to show consent. Consent is also not voluntary if forced or coerced. Coercing a person into sexual activity violates the University's policy in the same way as physically forcing someone into sexual activity. Because alcohol or drug use can impair the capacity to consent, sexual activity while under the influence of alcohol or drugs raises questions about consent. It shall not be a valid excuse that the accused (hereafter "respondent") believed that the reporting party (hereafter "complainant"), affirmatively consented to the sexual activity if the accused knew or reasonably should have known that the complainant was unable to consent to the sexual activity.

REPORTING OPTIONS

There are several ways to report an incident of gender-based discrimination, sexual misconduct, sexual violence, intimate partner violence, and stalking.

- For immediate, emergency assistance or to report a crime, students should call the City of Santa Clara Police Department: dial 911 or call Campus Safety Services: dial 408-554-4444.For immediate, emergency assistance or to report a crime, students should call the City of Santa Clara Police Department: dial 911 or call Campus Safety Services: dial 408-554-4444.
- Students wishing to seek confidential assistance may do so by speaking with professionals who have the privilege of maintaining confidentiality except in extreme cases of immediacy of threat or abuse of a minor. Confidential resources include on- and off-campus mental counselors, health service providers, advisors available through the University's Violence Prevention Program, local rape crisis counselors, domestic violence resources, and members of the clergy and chaplains.
- Students may report incidents and seek support from University officials, including the EEO and Title IX Coordinator, Office of Student Life, Residence Life (including Community Facilitators, Resident Directors, Assistant Resident Directors, Neighborhood Representatives, and Assistant Area Coordinators), Spirituality Facilitators, Housing, Athletics and Recreation, Center for Student Leadership, Drahmann Center, Disability Resources, Career Center, and Campus Ministry. Theses University resources are required to report incidents to the EEO and Title IX coordinator, who will oversee investigation and resolution process. At the time a report is made, a complainant does not have to decide whether or not to request disciplinary action.

For more information about reporting, response, and adjudication, please see the University's Gender-Based Discrimination and Sexual Misconduct Policy or contact the EEO and Title IX Coordinator, Belinda Guthrie, 900 Lafayette Street, Suite 100, 408-554-4113, bguthrie@scu.edu, or the Violence Prevention Program Coordinator, Olga Phoenix, 862 Market Street, 408-554-4409, ophoenix@scu.edu.

COMPUTING AND ELECTRONIC RESOURCES POLICY

The computing and other electronic resources at SCU are provided solely for the support of students and employees in the pursuit of their scholarly or required academic activities, and for conducting the business of the University. General guidelines for use of computing, communication, and electronic resources on campus are based upon principles of etiquette, fairness, and legality. In using these resources at SCU, community members are expected to be respectful of other individuals' ability to enjoy equal access to the resources, refrain from malicious or annoying behavior, and abide by state and national laws,

including those related to intellectual property and copyright. More details are available in the University's Acceptable Use Policy, accessible at: it.scu.edu/policies/NetPolicy.shtml, or from Information Technology.

SMOKE-FREE AND TOBACCO-FREE POLICY

Santa Clara University has adopted a smoke-free and tobacco-free policy on the University campuses in Santa Clara and Berkeley. All University faculty, staff, students, and visitors are covered by this policy. In addition, all persons using University facilities are subject to this policy.

The term "smoking" means inhaling, exhaling, burning, or carrying of any lighted or heated tobacco product, as well as smoking substances other than tobacco, or operating electronic smoking devices and other smoking instruments. "Tobacco product" means all forms of tobacco, including but not limited to cigarettes, cigars, pipes, hookahs, electronic smoking devices, and all forms of smokeless tobacco. "Tobacco-related" means the use of a tobacco brand or corporate name, trademark, logo, symbol, motto, or advertising message that is identifiable with the ones used for any tobacco product brand or company which manufactures tobacco products.

General Rules:

- Smoking is prohibited.
- The use of tobacco products is prohibited.
- Sale and advertising of tobacco products and tobacco-related products are prohibited.

POLICY FOR WITHDRAWAL FOR HEALTH REASONS

Students may experience an illness, injury, or psychological condition, herein referred to as a health condition, which significantly impairs their ability to function successfully or safely in their roles as students. In these instances, time away from the University for treatment and recovery can restore functioning to a level that will enable them to return to the University.

The Vice Provost for Student Life or designee, in consultation with the appropriate mental and medical health professionals and other staff as deemed necessary, is responsible for the implementation of the policy.

Contact the Office of Student Life for a copy of the entire Policy for Withdrawal for Health Reasons or refer to the website: www.scu.edu/studentlife/resources/policies.cfm.

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Accrediting Commission for Senior Colleges and Universities
of the Western Association of Schools and Colleges
985 Atlantic Avenue, Suite 100
Alameda, CA 94501
510-748-9001

Specialized Accreditations

Accreditation Board for Engineering and Technology
American Bar Association
American Chemical Society
Association of American Law Schools
Association of Theological Schools
Association to Advance Collegiate Schools of Business–Accounting
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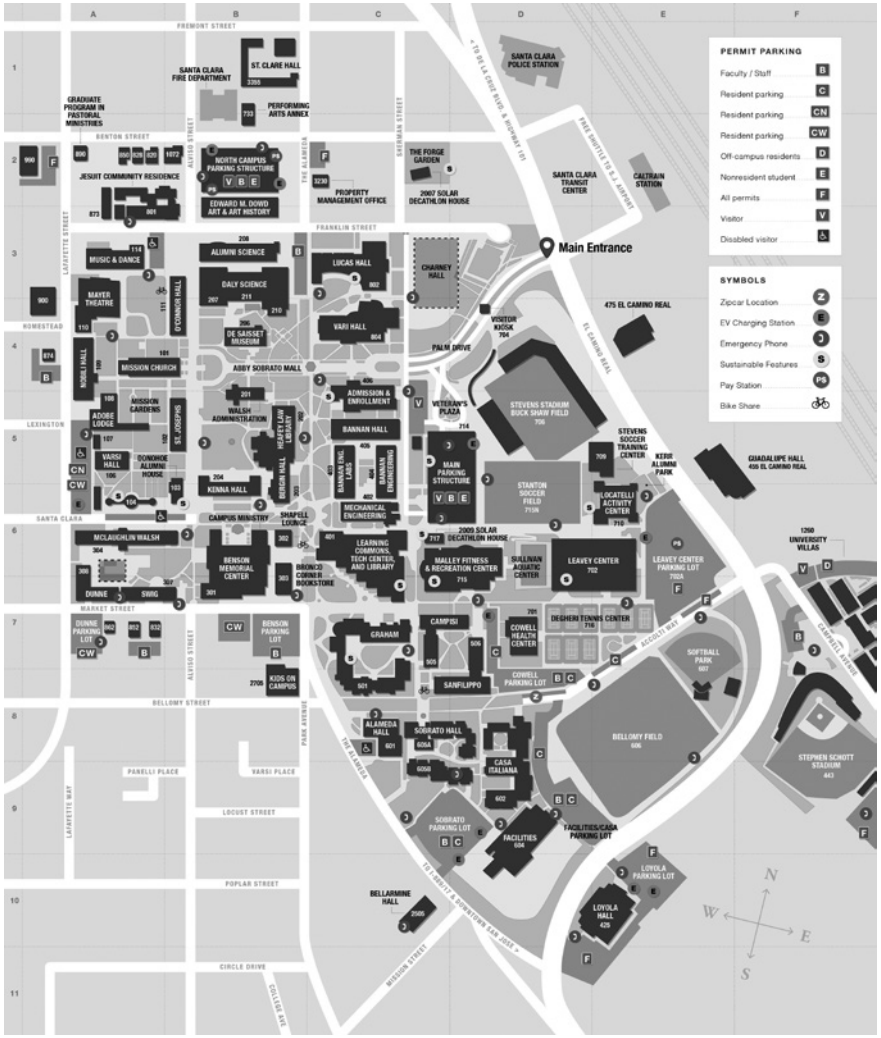
Notes

SANTA CLARA UNIVERSITY



CAMPUS MAP KEY

Organization	Building Name	Number	Map Location
Academic Departments			
Anthropology Dept	O'Connor Hall	111	B3
Applied Mathematics Dept	Bannan Engineering	404	C5
Art & Art History Dept	Edward M. Dowd Bldg.		B3
Arts & Sciences, College of	Vari Hall	804	C4
Asian Studies Program	Vari Hall	804	C4
Biology Dept	Alumni Science	208	B3
Catholic Studies Program	Kenna Hall	204	B6
Center for Innovation & Entrepreneurship	Lucas Hall	802	C3
Center for Nanostructures	Bannan Engineering	404	C5
Center for Prof. Development	Loyola Hall	425 ECR	E10
Chemistry and Biochemistry Dept	Daly Science	211	B3
Civil Society Institute	Lucas Hall	802	C3
Classics Dept	874 Lafayette St		A5
Combined Sciences Program	Daly Science	211	B3
Communication Dept	Vari Hall	804	C4
Computer Engineering Dept	Bannan Engineering	404	C5
Counseling, Psychology Dept	Guadalupe Hall	455 ECR	F6
E-Commerce Initiative	Lucas Hall	802	C3
Economics Dept	Lucas Hall	802	C3
Education and Counseling Psychology, School of	Guadalupe Hall	455 ECR	F6
Engineering, School of	Bannan Engineering	404	C5
English Dept	St. Joseph's Hall	102	B5
Environmental Studies & Sciences Dept	Varsi Hall	106	A5
Ethnic Studies	St. Joseph's Hall	102	B5
Food & Agribusiness Institute	Lucas Hall	802	C3
Gerontology Program	Alumni Science	208	B3
History Dept	O'Connor Hall	111	B3
Individual Studies Program	O'Connor Hall	111	B3
Jesuit School of Theology, (SCU office)	Kenna Hall	204	B6
Law, School of	Heafey Library	202	B5
Law, Faculty Support Services	Bergin Hall	203	B5
Law, Library	Heafey Library	202	B5
Leavey School of Business	Lucas Hall	802	C3
Liberal Studies	Varsi Hall	106	A5
Mathematics & Computer Science	O'Connor Hall	111	B3
Medieval/Renaissance Program	874 Lafayette St.		A4
Military Science Dept	Varsi Hall	106	A5
Modern Lang. & Literature Dept	Kenna Hall	204	B6
Music Dept	Music & Dance Bldg.	114	A3
Operations & Management Information Systems (OMIS)	Lucas Hall	802	C3
Osher Lifelong Learning Institute	Loyola Hall	425 ECR	E10
Pastoral Ministries, Graduate Program	890 Benton		A2
Philosophy Dept	Kenna Hall	204	B6
Physics Dept	Daly Science	211	B3
Political Science Dept	Vari Hall	804	C4
Psychology Dept	Alumni Science	208	B3
Public Health Program	Vari Hall	804	C4
Religious Studies Dept	Kenna Hall	204	B6
Sociology Dept	O'Connor Hall	111	B3
Summer Program (Undergraduate)	Vari Hall	804	C4
Theatre & Dance Dept	Mayer Theatre	110	A3
University Honors Program	St. Joseph's Hall	102	B5
Women's & Gender Studies	St. Joseph's Hall	102	B5
Young Scholars Program	Vari Hall	804	C4

Organization	Building Name	Number	Map Location
University Admin. Offices			
ACCESS Card Office	Benson Center	301	B6
Activities Programming Board (APB)	Locatelli Activity Center	710	E6
Admission & Enrollment Services	Schott Admissions & Enrollment Services Building	406	C5
Adobe Lodge	Adobe Lodge	108	A5
Alumni Relations	Donohoe Alumni	103	B6
Associated Students (ASSCU)	Locatelli Activity Center	710	E6
Athletics	Leavey Center	702	E6
Bronco Bench Foundation	Leavey Center	702	E6
Bronco Corner Bookstore	Benson Center	303	B6
Bursar's Office	Schott Admission & Enrollment Services Building	406	C5
California Legacy Project	St. Joseph's Hall	102	B5
California Studies Initiative (CASI)	Bannan Hall	405	C5
Campus Ministry	Benson Center	301	B6
Campus Safety Services	Main Parking Structure	714	C6
Career Center	Benson Center	301	B6
Center for Student Leadership	Locatelli Activity Center	710	E6
Center for Sustainability	Varsi Hall	106	A5
Counseling & Psychological Services (CAPS)	Cowell Building	701	D7
Cowell Health Center	Cowell Building	701	D7
Credit Counseling	Schott Admission & Enrollment Services Building	406	C5
Development Office	Loyola Hall	425 ECR	E10
Dining Services	Benson Center	301	B6
Disabilities Resources	Benson Center	301	B6
Drahmann Advising & Learning Resources Center	Kenna Hall	204	B6
Facilities	Support Services Bldg.	604	D9
Faculty Development Program	St. Joseph's Hall	102	B5
Finance & Administration, V.P.	Walsh Admin. Bldg.	201	B4
Financial Aid Office	Schott Admission & Enrollment Services Building	406	C5
Global Engagement	Varsi Hall	106	A5
Housing	Benson Center	301	B6
Human Resources	475 El Camino Real		E4
Information Desk	Benson Center	301	B6
Information Technology (IT)	Learning Commons	401	C6
Institutional Research	Walsh Admin. Bldg.	201	B4
International Student Services	Varsi Hall	106	A5
Jesuit Community	Jesuit Residence	801 Franklin St.	A3
Law, The Advocate & Student Bar Assoc	Bannan Hall	405	C5
Law, Development & Alumni Relations	Bannan Hall	405	C5
Media Services	Learning Commons	401	C6
Multicultural Center	Shapell Lounge	302	B6
Multicultural Learning Office	St. Joseph's Hall	102	B5
Northern California Innocence Project	900 Lafayette St.		A3
Office of EEO and Title IX	475 El Camino Real		E4
Office of Fellowships	St. Joseph's Hall	102	B5
Office of General Counsel	Nobili Hall	109	A4
Office of Marketing & Communications	Loyola Hall	425 ECR	E10
Office of the Registrar	Schott Admission & Enrollment Services Building	406	C5

Organization	Building Name	Number	Map Location
Office of Undergraduate Studies	Varsi Hall	106	A5
Planning and Projects	Support Services Bldg.	604	D9
Post Office	Benson Center	301	B6
President's Office	Walsh Admin. Bldg.	201	B4
Provost's Office	Walsh Admin. Bldg.	201	B4
Recreation	Malley Center	715	D6
Residence Life	Benson Center	301	B6
Resident Ministry	Benson Center	301	B6
Residential Learning Communities	Benson Center	301	B6
SCU Presents	Music & Dance Bldg.	114	A3
Sponsored Projects	St. Joseph's Hall	102	B5
Student Life	Benson Center	301	B6
Transportation Services	Main Parking Structure	714	D5
Undergraduate Admission	Schott Admission & Enrollment Services Building	406	C5
University Archives	Learning Commons	401	C6
University Cashier	University Finance Office		E4
University Event Planning Office	Walsh Admin. Bldg.	201	B4
University Finance Office	475 El Camino Real		E4
University Operations	Support Services Bldg.	604	D9
University Relations	Loyola Hall	425 ECR	E10
Wellness Center	Kennedy Commons	306	A6

Centers of Distinction	Building	No.	Loc.
Ignatian Center for Jesuit Education	Sobrato Hall	605A	C8
Markkula Center for Applied Ethics	Vari Hall	804	C4
Miller Center for Social Entrepreneurship	Nobili Hall	109	A4

Resident Halls	No.	Loc.
Bellarmine Residence Hall	2505 The Alameda	C10
Campisi Residence Hall	505	C7
Casa Italiana Residence Hall	602	D8
Dunne Residence Hall	308	A7
Graham Residence Hall	501	C7
McLaughlin Walsh Residence Hall	304	A6
Sanfilippo Residence Hall	506	D8
Sobrato Residence Hall	605	C8
St. Clare Residence Hall	3355 The Alameda	B1
Swig Residence Hall	307	A7
University Villas	1260 Campbell Ave.	F7

MAP LEGEND

Buildings (alphabetical)	No.	Loc.
Adobe Lodge	108	A5
Alameda Hall	601	C8
Alumni Science Hall	208	B3
Bannan Engineering	404	C5
Bannan Engineering Laboratories	403	C5
Bannan Hall	405	C5
Bellarmine Residence Hall	*	C10
Benson Memorial Center	301	B6
Bergin Hall	203	B5
Bronco Corner Bookstore	303	B6
Campisi Residence Hall	505	C7
Campus Safety Services	714	C6
Casa Italiana Residence Hall	602	D8
Commons at Kennedy Mall	306	A6
Commerce Plaza	*	A3
Cowell Health Center	701	D7
Daly Science Center	207, 210, 211	B3
de Saisset Museum	206	B4
Donohoe Alumni House	103	B6
Dunne Residence Hall	308	A7
Edward M. Dowd Art and Art History		B2
University Finance Office and Human Resources Building	*	E4
Forge Garden	*	C2
Graduate Pastoral Ministries	*	A2
Graham Residence Hall	501	C7
Guadalupe Hall	*	F6
Heafey Law Library	202	B5
Ignatian Center	605A	D8
Jesuit Residence Community	*	A2
Kenna Hall	204	B6
Learning Commons, Tech. Center, and Library	401	C6
Leavey Event Center	702	E6
Locatelli Student Activity Center	710	E5
Loyola Hall	*	E10
Lucas Hall	802	C3
Main Parking Structure	714	D5
Pat Malley Fitness & Recreation Center	715	D6
Mayer Theatre	110	A3
McLaughlin Walsh Residence Hall	304	A6
Mechanical Engineering	402	C6
Mission Santa Clara de Asis	101	A4
Music & Dance, Recital Halls	114	A3
Nobili Residence Hall	109	A4
North Campus Parking Structure	*	B2
O'Connor Hall	111	B3
Performing Arts Annex Building	*	B1
Property Management	*	C2
Ricard Memorial Observatory	104	A6
Sanfilippo Residence Hall	506	D8
Schott Admission and Enrollment Services	406	C5
Schott Stadium	*	F8
Shapell Lounge	302	B6
Sobrato Residence Hall	605A&B	C8
Softball Park	607	E7
Solar Decathlon House, 2007	712	C2
Solar Decathlon House, 2009	717	C6
St. Clare Residence Hall	*	B1
St. Joseph's Hall	102	B5
Stevens Stadium	706	D5
Stevens Soccer Training Center	709	E5
Sullivan Aquatic Center	702	D6
Support Services	604	D9
Swig Residence Hall	307	A7
University Villas	*	F7
Vari Hall	804	C4
Varsi Hall	106	A5
Varsi Restrooms	107	A5
Visitor Kiosk	704	D4
Walsh Administration Building	201	B4

Schools			
College of Arts & Sciences	Main office in Vari Hall	804	C4
Leavey School of Business	Main office in Lucas Hall	802	C3
School of Engineering	Main office in Bannan Engineering	404	C5
School of Law	Bannan Hall	405	B5
and Heafey Law Library	Bergin Hall	203	B5
202	B5		
School of Education and Counseling Psychology	Guadalupe Hall	455 ECR	F6
Jesuit School of Theology	Berkeley Campus 1735 Le Roy Ave. Berkeley, CA	Not on Map	
	Santa Clara Campus: Kenna Hall	204	B5
Centers of Distinction			
Ignatian Center for Jesuit Education		605A	C8
Markkula Center for Applied Ethics		804	C4
Miller Center for Social Entrepreneurship		109	A4

Off Campus Addresses	**Loc.**		
Bellarmine Residence Hall	2505 The Alameda		C10
Classics	874 Lafayette St.		A4
School of Education and	Not on Map		
Counseling Psychology	East San Jose Satellite Campus 14271 Story Rd. San Jose, CA 95127		
Graduate Pastoral Ministries	890 Benton St.		
Guadalupe Hall	F6		
School of Education and Counseling Psychology School of Engineering, Dean's Office	455 El Camino Real		
University Finance Office, & Human Resources	475 El Camino Real	EDC	E3
Jesuit Residence Community	801 Franklin St.	A2	
Jesuit School of Theology	Not on Map 1735 Le Roy Avenue, Berkeley, CA		
Katharine & George Alexander Community Law Center	Not on Map 1030 The Alameda		
Kids on Campus	2705 The Alameda	B8	
Loyola Hall	425 El Camino Real	E10	
Northern California Innocence Project Commerce Plaza	900 Lafayette St.	A3	
Performing Arts Annex	733 Benton St.	B1	
Schott Stadium	443 El Camino Real	F8	
St. Clare Residence Hall	3355 The Alameda	B1	
University Villas	1260 Campbell Ave.	F7	

Notes

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Belinda Guthrie
EEO and Title IX Coordinator
Office of EEO and Title IX
Santa Clara University
900 Lafayette Street, Suite 100
Santa Clara, CA 95050
408-554-4113
bguthrie@scu.edu

A person may also file a complaint within the time required by law with the appropriate federal or state agency. Depending upon the nature of the complaint, the appropriate agency may be the federal Equal Employment Opportunity Commission (EEOC), the federal Office for Civil Rights (OCR), or the California Department of Fair Employment and Housing (DFEH).

School of Engineering

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