

# **BULLETIN**

**2016-2017**







## Michigan Engineers Make a Difference

The world is facing some big challenges: from energy, to health care, to transportation and security...and the list goes on. We need bold ideas and breakthrough solutions. Michigan Engineering graduates are prepared to be leaders. They are expert problem-solvers, and are ready to tackle the challenges of the 21st century.

**Educational Programs.** The University of Michigan is the only institution with top-rated engineering, law, business, performing arts and medical schools. Michigan Engineering offers an impressive range of educational programs and options, including:

- Top-ranked graduate and undergraduate programs in nearly every engineering field
- 13 departments/divisions and 60+ fields of study
- Flexible interdisciplinary degree programs for students who choose to customize their course of study
- Combined bachelor's/master's programs that enable students to earn both degrees in just five years
- Unique global study, travel and work opportunities

For more College of Engineering facts and figures, please visit [www.engin.umich.edu/college/about/facts](http://www.engin.umich.edu/college/about/facts)

Office of Student Affairs  
Chrysler Center  
143 Chrysler Center  
Ann Arbor, MI, 48109-2092  
[www.engin.umich.edu](http://www.engin.umich.edu)

## 2016-2017 College of Engineering Bulletin

The online Bulletin reflects the most up-to-date information available and is updated as changes are made to the curriculum. To view past versions of the College Bulletin in Adobe Acrobat format, please visit our archives. Note: Archived bulletins are only applicable to that academic year's course requirements. Please visit your advisor for more information, or if you have questions regarding this.

Students follow the rules of the College of Engineering Bulletin in effect for the academic term in which they begin their studies in the College of Engineering at the University of Michigan-Ann Arbor campus. Students who are readmitted into the College of Engineering at the University of Michigan-Ann Arbor campus follow the Bulletin in effect for the academic term in which they resume their studies.

The College of Engineering Bulletin reflects yearly curricular changes in the various degree programs. A student in a degree program that has degree requirement changes in a Bulletin produced during their academic career at the College of Engineering at the University of Michigan-Ann Arbor, may follow a subsequent Bulletin. This determination should be made in conjunction with the Program Advisor.



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The University of Michigan  
College of Engineering  
2016-2017  
June 1, 2016

**The University of Michigan**

Mark S. Schlissel, President

Martha Pollack, *Provost and Executive Vice President for Academic Affairs*

Marschall Runge, *Executive Vice President for Medical Affairs*

Sally J. Churchill, *Vice President and Secretary of the University*

S. Jack Hu, *Interim Vice President for Research*

E. Royster Harper, *Vice President for Student Life*

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And Strategic Initiatives*

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Kevin P. Hegarty, *Executive Vice President and Chief Financial Officer*

Cynthia H. Wilbanks, *Vice President for Government Relations*

**College of Engineering**

David C. Munson, Jr., *Robert J. Vlasic Dean of Engineering  
and Professor of Electrical Engineering and Computer Science\**

Dawn Tilbury, *Associate Dean for Research*

Brian D. Noble, *Associate Dean for Undergraduate Education*

Alec Gallimore, *Associate Dean for Academic Affairs*

Thomas Zurbuchen, *Associate Dean for Entrepreneurial Programs*

Jennifer Linderman, *Associate Dean for Graduate Education*

**The Regents of the University of Michigan**

Michael J. Behm, Grand Blanc

Mark J. Bernstein, Ann Arbor

Laurence B. Deitch, Bloomfield Hills

Shauna Ryder Diggs, Grosse Pointe

Denise Ilitch, Bingham Farms

Andrew Fischer Newman, Ann Arbor

Andrew C. Richner, Grosse Pointe Park

Katherine E. White, Ann Arbor

Mark S. Schlissel (ex officio)

The information contained in this Bulletin is subject to change at any time. It is intended to serve only as a general source of information about the College of Engineering and is in no way intended to state contractual terms.

\*The University of Michigan Board of Regents has appointed U-M Aerospace Engineering Professor Alec Gallimore as the next Robert J. Vlasic Dean of Engineering. He takes office in July 2016.

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# Academic Calendar

## University of Michigan—ANN ARBOR CAMPUS

### FALL TERM, 2016

Labor Day (Holiday) .....	Sept 5, Mon
<b>Classes begin</b> .....	Sept 6, Tues
Fall Study Break.....	Oct. 17 - 18, Mon -Tues
Thanksgiving recess, 5:00 p.m. ....	Nov 23, Wed
Classes end .....	Dec 13, Tues
Study Days.....	Dec 14, Wed & Dec 17 - 18, Sat - Sun
<b>Examinations</b> .....	Dec 15 - 16, Thurs - Fri & Dec 19 - 22, Mon - Thurs
Fall Term ends .....	Dec 22, Thurs
Commencement.....	Dec 18, Sun

### WINTER TERM, 2017

<b>Classes begin</b> .....	Jan 4, Wed
Martin Luther King, Jr. Day.....	Jan 16, Mon
<b>University Symposia. No Regular Classes.</b>	
Winter Vacation begins 12:00 noon .....	Feb 25, Sat
Classes resume .....	Mar 6, Mon
University Honors Convocation .....	Mar 19, Sun
Classes end .....	Apr 18, Tues
Study Days.....	Apr 19, Wed & Apr 22 – 23, Sat - Sun
<b>Examinations</b> .....	Apr 20 – 21, Thurs - Fri ; Apr 24 - Apr 27, Mon – Thurs
Winter Term ends.....	Apr 27, Thurs
Commencement Activities .....	Apr 27 - 30, Thurs - Sun

### SPRING-SUMMER TERM, 2017

<b>Classes begin</b> .....	May 2, Tues
Memorial Day (Holiday) .....	May 29, Mon
Classes end (Spring Half).....	June 19, Mon
Study Days.....	June 20 - 21, Tues - Wed
<b>Examinations</b> .....	June 22 - 23, Thurs - Fri
Spring Half Term ends.....	June 23, Fri
<b>Summer Half Term classes begin</b> .....	June 28, Wed
Independence Day (Holiday) .....	July 4, Tues
Classes end .....	Aug 15, Tues
Study Day .....	Aug 16, Wed
<b>Examinations</b> .....	Aug 17 -18, Thurs - Fri
Full Term and Summer Half Term end.....	Aug 18, Fri

\*Students enrolling in Business Administration, Dentistry, Law, Pharmacy, Social Work, and Medicine should check with their respective schools for academic calendar information including registration dates. **This calendar is subject to change.** \*\*Jewish holy days begin and end at sundown on the first and last days listed. The University's policy concerning observance of religious holidays can be found at <http://www.umich.edu/~provost/dates/hdaymemo.html>  
Dearborn Campus – for registration and academic calendar information, visit: <http://www.umd.umich.edu/registration>

# General Information

## Michigan Engineering

Michigan Engineering is a place for a special kind of engineer. We welcome students from a diversity of backgrounds, who will flourish within an environment of wide-ranging possibilities. Our breadth of outstanding opportunities is unmatched.

Beyond excellent engineering research and teaching, a global footprint and significant resources, the University of Michigan College of Engineering provides the most well-rounded intellectual experience of any engineering institution. We aim to produce graduates who combine technical depth with lateral thinking and an ability to make an impact. And, we want our graduates to be globally competent engineers, through meaningful international experiences, broad exposure to diversity and development of communication and teamwork skills. We can create this unique environment because of a very special set of assets, including:

- twelve highly ranked engineering departments and divisions, and growing faculty headcount and student enrollment;
- extensive collaboration with our highly rated medical and business schools, and expanding interactions with our top-notch art and design, architecture and music programs;
- the country's first engineering/arts living-learning community;
- hundreds of student organizations and competitive teams, and the opportunity to learn under the tutelage of renowned professors of practice;
- major partnership with Shanghai Jiao Tong University, and other academic institutions on six continents;
- one of the nation's most successful centers of entrepreneurship.

Michigan Engineers are expected to become more than just great engineers. As well-balanced thinkers, they are challenged to lead teams, identify opportunities and solve complex problems requiring multidisciplinary

approaches. Faculty with unconventional ideas are welcome in this innovative, dynamic and diverse enterprise, where tradition and experience are respected, but talent and results are rewarded.

The College of Engineering is committed to not only making certain that students enjoy a high quality educational experience, but that personal interactions, classroom experiences and research activities are free from harassing and discriminatory behaviors. Our goal is a welcoming environment of respect and courtesy for all members of our campus community. Further, we are determined to investigate and address any allegations of misconduct that might occur. This can be accomplished through increased awareness of issues, access of information and prompt action. To insure that our students understand the consequences of strategies for the prevention of harassment and discrimination, we ask each member of the College of Engineering to commit to understanding, preventing, responding and reporting harassment and discrimination. We are certain that through awareness, knowledge and diligence, our College can become a safer community for all of us. For more information and to learn how to report an incident, please visit the Office of Student Affairs at 143 Chrysler Center.

## Michigan Engineering Mission

To be the place of choice for engineering education and research...A Michigan institution that challenges its students, faculty and staff to learn, to grow, to achieve and to serve the needs of society...A place where excellence, excitement, innovation and impact define the style and substance of its activities.

## Michigan Engineering Goals

1. To provide a continuously improving educational and research environment in which faculty, administrators, students and staff work together to educate our students to lead, to have impact and to make significant contributions to their professions, industry, government, academia and society.
2. To attract diverse, outstanding students and to motivate and educate them to reach their full potential as leaders in engineering professions.

## Degree Programs

The College of Engineering offers undergraduate and graduate programs through the doctoral level. The undergraduate program consists typically of a four-year schedule leading to a bachelor's degree. There are 17 courses of study that lead to the Bachelor of Science in Engineering degree (B.S.E.). By careful planning, an additional bachelor's degree (B.S. or A.B.) can be earned within the College of Engineering or in combination with another college within the University of Michigan in about one year beyond the time required for a single degree. Completion of both an engineering baccalaureate and a master's degree in approximately five years is also possible.

### Areas of undergraduate study at the College of Engineering include:

- Bachelor of Science in Engineering
  - Aerospace Engineering
  - Biomedical Engineering
  - Chemical Engineering
  - Civil Engineering
  - Climate and Meteorology
  - Computer Engineering
  - Computer Science
  - Data Science
  - Electrical Engineering
  - Engineering Physics
  - Environmental Engineering
  - Industrial and Operations Engineering
  - Materials Science and Engineering
  - Mechanical Engineering
  - Naval Architecture and Marine Engineering
  - Nuclear Engineering and Radiological Sciences
  - Space Sciences and Engineering

### Areas of graduate study include:

- Master of Science (M.S.)
- Master of Science in Engineering (M.S.E.)
- Master of Engineering (M.Eng)
- Doctor of Philosophy (Ph.D.)
- Doctor of Engineering (D.Eng)

## Departments:

- Aerospace Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil and Environmental Engineering
- Climate and Space Sciences Engineering (formerly known as Atmospheric, Oceanic and Space Sciences) (name change effective September 2015)
- Electrical Engineering and Computer Science
- Industrial and Operations Engineering
- Materials Science and Engineering
- Mechanical Engineering
- Naval Architecture and Marine Engineering
- Nuclear Engineering and Radiological Sciences

## Programs:

- Integrative Systems and Design:
  - Automotive Engineering
  - Design Science
  - Energy Systems Engineering
  - Global Automotive and Manufacturing Engineering
  - Manufacturing Engineering
  - Pharmaceutical Engineering (Please note: The Master of Engineering in Pharmaceutical Engineering degree is currently under review and revision by the College of Engineering. It is currently closed for the Fall 2015 and beyond.)
    - Systems Engineering + Design
- Applied Physics
- Concentrations in Environmental Sustainability (ConsEnSus)
- Engineering Sustainable Systems Dual Degree Program
- Macromolecular Science and Engineering
- Robotics

## Accreditation

The Computer Science program is accredited by the Computing Accreditation Commission of ABET, <http://www.abet.org>.

The Aerospace, Biomedical, Chemical, Civil, Computer Engineering, Electrical, Environmental, Industrial and Operations, Materials Science and Engineering, Mechanical, Naval Architecture and Marine Engineering and Nuclear Engineering and Radiological Sciences programs are accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>.

## The University of Michigan Nondiscrimination Policy Statement

The University of Michigan, as an equal opportunity/affirmative action employer, complies with all applicable federal and state laws regarding nondiscrimination and affirmative action. The University of Michigan is committed to a policy of equal opportunity for all persons and does not discriminate on the basis of race, color, national origin, age, marital status, sex, sexual orientation, gender identity, gender expression, disability, religion, height, weight, or veteran status in employment, educational programs and activities, and admissions. Inquiries or complaints may be addressed to the Senior Director for Institutional Equity, and Title IX/Section 504/ADA Coordinator, Office for Institutional Equity, 2072 Administrative Services Building, Ann Arbor, Michigan 48109-1432, 734-763-0235, TTY 734-647-1388, [institutional.equity@umich.edu](mailto:institutional.equity@umich.edu). For other University of Michigan information call 734-764-1817.

## Important Residency Information for Tuition Assessment Purposes

The University of Michigan's tuition structure is two-tiered, reflecting resident and nonresident rates. To be eligible to pay resident classification rates, a student must demonstrate compliance with the University's Residency Classification Guidelines, which can be

found at <http://ro.umich.edu/resreg.php>. The University's Guidelines differ from those of other schools and are independent of guidelines used by state authorities to determine residency for purposes such as tax liability, driving, voting, etc. Therefore, all students who believe they are eligible to pay resident rates must review "Circumstances Under Which You Must File A Residency Application" in the Guidelines to determine if they are required to file a separate Application for Residency Classification. An Application for Resident Classification can be downloaded from the web site.

## Who May Apply

### Undergraduate Admissions

To be admitted at the first year level, an applicant must be at least 16 years old and a graduate of an accredited secondary school. Graduates of unaccredited schools will be asked to take College Board Achievement Tests or the American College Test.

Home-schooled students and students attending unaccredited high schools should contact the Office of Undergraduate Admissions prior to September of their senior year to determine if additional credentials such as SAT II Subject Exams should be submitted.

For older students, the results of the General Education Development (GED) test may be presented in place of a high school diploma.

### First-Year Undergraduate

#### Advanced Placement

Many students take Advanced Placement courses through the Advanced Placement Program in their high schools. Credit for these courses can be applied toward a degree, provided the student has performed satisfactorily on the Advanced Placement Program examination conducted nationally by the College Entrance Examination Board.

Any questions regarding the examination, scores or results should be directed to the Advanced Placement Program.

**Website:**

<https://apstudent.collegeboard.org/home> (U-M code is 1839)

See information of how credit will be awarded at this website: <http://www.admissions.umich.edu/ap-guidelines>

**By Mail:**

Advanced Placement Program  
PO Box 6671  
Princeton, NJ 08541-6671

**By Telephone:**

(609) 771-7300 or (888) CALL-4AP

**By Fax:**

(609) 530-0482

**By TTY:**

(609) 882-4118 (for the hearing impaired)

**By Email:**

[apexams@info.collegeboard.org](mailto:apexams@info.collegeboard.org)

All other questions about Advanced Placement should be referred to Engineering Advising Center, 230 Chrysler Center, College of Engineering, University of Michigan, Ann Arbor, MI 48109-2092. (Phone: 734-647-7106)

The following Web site lists the satisfactory scores required to receive credit in the College of Engineering:

<http://admissions.umich.edu/apply/freshmen-applicants/ap-ib-credit>

### College Level Examination Program (CLEP)

The faculty at U-M will not accept any of the CLEP general exams. However, CoE students can earn credit by taking the following CLEP subject exams:

- General Chemistry: a minimum score of 47 would allow 3 hours of Chemistry 100-level departmental credit (CHEM 101x)
- General/Introductory Psychology: a minimum score of 47 would allow 4 hours of Introductory Psychology credit (PSYCH 111)
- Human Growth and Development: a minimum score of 45 would allow 3 hours of Psychology departmental credit (PSYCH 101x)
- Introductory Sociology: a minimum score of 47 would allow 4 hours of Introductory Sociology credit (SOC 100)

Note that only the objective test needs to be taken. The

test score must come on an official CLEP score report from the testing agency. U-M is NOT a testing center for any CLEP exams. Similar to AP exams, the four CLEP exams outlined above must be taken by the student before entering college in order to qualify. For any questions, the Transfer Credit Evaluation Office should be consulted at [engincredit@umich.edu](mailto:engincredit@umich.edu).

## University Placement Examinations

There are a number of courses for which credit may be received by getting a satisfactory score on a Placement Examination offered by a department of the University. Language credit earned by U-M examination will be posted under the admitted term, even though the student may choose to take the exam during a later term.

Note: No credit is granted for math and chemistry placement exams given before or during orientation. The purpose of these exams is to determine your preparation for these entry level courses.

## Foreign Languages

Credit by test (e.g. Advanced Placement, A-Level and International Baccalaureate) can be used to satisfy Intellectual Breadth requirements except for the 3 credit humanities requirement. Foreign language credit by test at the 200-level or higher can count toward the LAC requirement but not the 3 credit humanities requirement. Foreign language credit by test at the 100-level can be used for General Electives only. In addition, language credit by test is limited to 8-credits.

CoE will grant credit for students passing a language placement test offered by the College of LSA provided the student has previously studied that language in a course in their secondary education. This will be verified using their high school or college transcripts.

"Study of a language in a course" means a student took coursework designed to teach them the fundamental vocabulary, grammar, pronunciation, and writing system of that language as a foreign language, as opposed to a class in literature, argumentative or essay writing,

or creative writing in a language whose fundamentals they already knew.

The CoE values the study of language, so even when credit might not be granted students are encouraged to take any language placement test for which they may be qualified, so that they can be properly placed in a more advanced language course.

## Transfer Credit for Entering First-Year Students

Incoming freshmen who took a course(s) at a college or university while dually enrolled in high school may potentially receive transfer credit. The guidelines for transferring credit in these situations include that the course(s) must:

1. be taken on the physical campus of an accredited college/university
2. be taught by college/university instructors
3. be taken with other college/university students

Students seeking approval to transfer credit must request an official transcript from the institution. An official transcript should be mailed directly to the Office of Recruitment and Admissions - TC, 153 Chrysler Center, 2121 Bonisteel Boulevard, Ann Arbor, MI 48109-2092.

More info at our website: <http://www.engin.umich.edu/college/academics/undergrad/transfer/dual-enroll>

## Undergraduate Transfer

### Transfer Credit

An evaluation of the previous record from the transfer institution will be made at the time of application review to provide a preliminary assessment of the credit that will be transferred toward a bachelor's degree in the program specified by the applicant. This appraisal is subject to review by representatives of the departments involved and by the student's intended program advisor. The transfer credit may be revised if the aca-

demic progress of the student indicates that the student is unable to continue successfully because of an inadequate preparation.

Credits are granted only for transferable courses in which a grade of "C" or better is earned. A "C-" will be accepted only if earned on the University of Michigan-Ann Arbor Campus for courses other than math, science, engineering, or other prerequisites for admission. Classification level is determined by the number of hours transferred. Most transfer students enroll with approximately 60-65 credit hours.

Students should be aware that receiving test or transfer credit can have an impact on tuition, because tuition increases once a student has Junior or Senior standing (55 credit hours or more). Credit will not be removed from the transcript for the purpose of lowering tuition. Students are responsible for reviewing their transcript when credits are posted and asking for removal of any credits within their first term at the University of Michigan. Note also that credit is always posted for the term in which it was earned, not the term in which it was posted; the posting of credit can therefore have a retroactive impact on tuition owed. Current students should carefully consider this issue before asking for credit to be posted on their transcript.

The U-M transcript of transfer students will not reflect grades earned while enrolled in an external institution. The transfer student's GPA is determined solely by the grades earned while enrolled in the College of Engineering. This does not apply to students transferring from other academic units located on the Ann Arbor campus of the University. If, at any time, a transfer student has questions regarding the transfer of credit, the Transfer Credit Evaluation Office should be consulted at [engincredit@umich.edu](mailto:engincredit@umich.edu).

## Cross-Campus Transfer Re-Registration Policy

Admitted cross-campus transfer students to the CoE are held accountable to the following policy:

1. Admitted cross-campus students must re-register

under their Engineering program status. The re-registration of courses must be done no later than 3 weeks after the first day of classes of the admitted term:

- Students who do not re-register their classes may have their enrollment discontinued from the College of Engineering.
- Once a student is discontinued they will then have to reapply to the College of Engineering, which may involve being held accountable to new admissions standards.
- A student who reapplies after being discontinued and is admitted must be reinstated to the original term of the College of Engineering admission. This will involve having all of the student's classes re-registered to that original term of admission and the student being billed for the differences in tuition and College of Engineering fees accordingly.

2. Students who want to be admitted to the College of Engineering who are near graduation and receive approval from an engineering department are held to the following:
  - The engineering department will determine under which past term the student should have been admitted. The student's classes will then be re-registered back to that term for admission and the student will be billed for the differences in tuition and College of Engineering fees accordingly.
  - A department will have the authority to go back as many past terms as they deem appropriate for the student's admission.

## Bachelor's Degree Holders Seeking a Second Bachelor's Degree

The College of Engineering welcomes students already in possession of a bachelor's degree, who are seeking a second bachelor's degree in engineering. Students who already possess a bachelor's degree in engineering or closely aligned field such as physics should consider a

master's degree in an engineering discipline.

For students who have previously earned a bachelor's degree and elect to pursue admission for an additional bachelor's degree, the following rules and policies apply:

Students may not be admitted to pursue a CoE bachelor's degree that is substantially similar to a degree of the same or lower level (bachelor's or master's) as they already hold, or declare into such a similar degree program after admission. The Office of the Associate Dean for Undergraduate Education will have ultimate authority to decide if a candidate's prior degrees are too similar to a proposed degree to allow admission or declaration.

In order to be qualified for a second bachelor's degree, candidates should have taken Calculus 1 and 2, Physics 1, Chemistry, English Composition and/or introductory Technical Communications, and Introductory Programming at an institution of higher education and have an academic record that suggests high levels of accomplishment. These courses can have been completed as part of their original degree, but could also have been taken for other reasons. They should have been completed no more than ten (10) years before admission, and ideally less than seven (7) years prior to admission. Coursework from the student's previous academic record, including credits used to satisfy requirements for a previous degree, will be eligible for entry on the UM academic record. Credits will not be transferred if they were used to satisfy more than one prior degree (no counting of credits between three (3) or more degrees).

To graduate, students must successfully complete all of the degree requirements in place at their term of admission, using the appropriate combination of transfer and UM credit. Program advisors can allow substantially equivalent substitutions from transferred courses. Students with a previous engineering degree must complete an additional fourteen (14) credits hours in pertinent technical subjects in addition to meeting all degree requirements.

A bachelor's degree holder admitted into the College of Engineering seeking a second bachelor's degree will be

a senior when there are thirty-five (35) hours or fewer to complete.

## Undergraduate Readmission

A student who is not enrolled for twelve (12) months or more must request an Application for Readmission from the Office of Recruitment and Admissions, and should do so at least two months before the date of desired enrollment.

Students who are readmitted into the College of Engineering at the University of Michigan-Ann Arbor campus follow the Bulletin in effect for the academic term in which they resume their studies. A student whose enrollment has been withheld because of poor academic performance must first petition for Reinstatement to the Scholastic Standing Committee:

[ossa.engin.umich.edu/scholastic-standing-committee/petitions/](http://ossa.engin.umich.edu/scholastic-standing-committee/petitions/)

Readmitted international students requesting F-1 or J-1 Visa status must also submit required documentation. For additional information on required documentation or to request an Application for Readmission, please contact the Office of Recruitment & Admissions, 153 Chrysler Center, 2121 Bonisteel Boulevard, Ann Arbor, MI 48109-2092 (734) 647-7101 or at [enginrta@umich.edu](mailto:enginrta@umich.edu).

Students who have graduated from the College and wish to elect courses for an additional term must seek readmission through the Office of Recruitment and Admissions.

## Special Student Status

### Undergraduate Non-Candidate for Degree (NCFD)

The NCFD status is for those individuals who are approved to take courses in the College of Engineering in a non-degree capacity. Such students are designated as unclassified. Except in the case of international exchange students, NCFD admission is for one term and

is granted only if space is available after all degree-seeking students have been accommodated.

## **NCFD Status for Students from Other Colleges and Universities**

A student from another college or university who seeks enrollment as a non-candidate for degree (NCFD) must meet the same academic standards of admission as a degree-seeking application for transfer admissions.

NCFD applicants should contact the Office of Recruitment and Admissions to request an application. A complete application will include:

- a completed application form
- official transcripts from previous colleges or universities
- written permission from instructors of classes in which you intend to enroll (applicant is responsible for obtaining this documentation).

Once an applicant has been evaluated and approved for admission, the applicant will be notified of their NCFD admission status by the Office of Recruitment and Admissions.

Registration for courses can only be done on or after the first day of classes for the term of admission. If more than one term is requested, the student cannot register for the subsequent term until his or her academic record has been reviewed and approved by an admissions counselor and the engineering departmental program advisor.

## **NCFD Status for Graduates of the College of Engineering**

A graduate with a conferred bachelor's degree from the College of Engineering who desires to take courses with NCFD status can request processing for enrollment by obtaining written approval from the program advisor for the department in which they intend to take course(s) and submitting an application for readmission to the Office of Recruitment and Admissions. The instructor(s) of the course(s) in which the student intends

to enroll must also grant written permission. Approval to register is granted for one term only. The enrollment status is designated as unclassified. Course registration for individuals with special student status should not be done prior to the first day of classes. The engineering department from which the degree was conferred will also be notified of the NCFD status.

## **Unclassified Status**

When a student is no longer a candidate for a degree from the College of Engineering but is planning to transfer into another field of study, the student will be advised by the Engineering Advising Center to arrange for registration for an additional term in the College of Engineering on an "Unclassified" status.

## **International Exchange Students from CoE Partner Institutions**

Undergraduate students from CoE partner institutions may apply to study at the U-M for one or two terms. The CoE also accepts exchange student applications through the Global Engineering Education Exchange (GE3) program. Prospective exchange students must be nominated by their home institutions and all applications are coordinated by the International Programs in Engineering (IPE) office, 245 Chrysler Center, 2121 Bonisteel Boulevard, Ann Arbor, MI 48109-2092. Prospective students should inquire with their home institution's International Exchange office.

# Academic Rules, Rights and Responsibilities

## General Standards of Conduct for Engineering Students

In establishing a standard of student conduct, the University of Michigan is committed to the basic principles of entrusting each student with a high degree of freedom to govern his or her life and conduct while enrolled at the University.

Being a successful member of the College of Engineering community involves intense, spirited and innovative collaboration with groups of people from diverse backgrounds. Therefore, the College of Engineering embraces a spirit of acceptance and understanding so that our community enjoys a high quality educational and work experience that contributes not only to our technical expertise and accomplishments, but to our ability to interact effectively as a team across disciplines, perspectives, cultures and around the globe. Our goal is a welcoming environment of respect and courtesy for all members of our campus community. This goal takes the active involvement of all of our community members to create an environment that values our diverse community and fosters intercultural skills.

The College of Engineering encourages its students to protect and use this freedom with wisdom and good judgment, and to accept and discharge the responsibility inherent to such freedom.

Students are expected to respect the rights and property of others and to comply with University regulations and public laws.

The College of Engineering welcomes the participation of students in decision-making relevant to their affairs and provides channels of communication, both at the college and department level, for that purpose. To benefit from such activity, each student should recog-

nize his or her responsibility to fellow students and to the faculty and staff, and should discharge all duties with the standards that make such student-college relationships effective and valuable.

The College of Engineering reserves the right to discipline, exclude from participation in relevant activities, or dismiss any student whose conduct or performance it considers in violation of its standards. Such a decision will be made only after review by the appropriate student and faculty committees. During this review, the student will have full opportunity to present his or her position. A student also has the right of appeal to the Executive Committee of the College.

The Honor Code of the College of Engineering (below) bears witness to the deep trust that characterizes the student-faculty relationships in one of the most important aspects of student conduct.

## Honor Code

The engineering profession has a long-standing record of fostering high standards of integrity in the performance of professional services. Not until the 1930s, however, was the first Canon of Ethics for Engineers developed and adopted by national professional engineering societies. The Fundamental Canons, as they appear on the National Society of Professional Engineers website (<http://www.nspe.org/Ethics/CodeofEthics/index.html>) states "Engineers, in the fulfillment of their professional duties, shall:

## Fundamental Canons

1. Hold paramount the safety, health and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically and lawfully so as to enhance the honor, reputation and usefulness of the profession."

In 1915, the students of the College of Engineering proposed an Honor Code. This was approved by the faculty in 1916 and has been in effect since its inception. The Honor Code is a distinguishing feature of the College of Engineering.

## Applications of the Honor Code

The Honor Code holds that students are honorable, trustworthy people and encourages them to behave with integrity in all phases of university life. By conforming to the Code, students do their work in an environment conducive to establishing high standards of personal integrity, professional ethics, and mutual respect.

As a basic feature of the Code, students are placed upon their honor during all examinations, written quizzes, computer questions, homework, laboratory reports, and any other work turned in for credit, as required by the instructor. During examinations, the instructor is available for questions, but the examination is not proctored. As a reminder of the Honor Code, the student is asked to write and sign the following pledge on the examination paper:

"I have neither given nor received aid on this examination, nor have I concealed a violation of the Honor Code."

The Honor Code remains in force whether or not the student signs the Pledge, but an instructor is not obligated to grade an examination without a signature.

With regard to assignments made in class, each class/professor may have a different policy regarding what constitutes an Honor Code violation and this policy should be clearly outlined in the syllabus for the course. If a student is in doubt, the professor responsible for the course should be asked for clarification. In particular, be aware that some professors allow and/or encourage group work, while others may not even allow discussion of homework problems.

In general, the principles of the Honor Code also apply to homework when the instructor requires that the material be turned in for grading. While independent study

is recognized as a primary method of effective learning, some students may find that they benefit from studying together and discussing homework assignments and laboratory experiments. When any material is turned in for inspection and grading, the students should clearly understand whether, and to what degree, collaboration among students is permitted by the instructor. In some courses, full collaboration is allowed, while in other courses each student must work completely independently. The instructor may require the signing of the Pledge on homework assignments and expect the same high standards of integrity as during examinations.

It is always required that ideas and materials obtained from another student or from any other source be acknowledged in one's work. The latter is particularly important, because material is so freely available on the Internet. According to Merriam-Webster online dictionary, to plagiarize is "To steal and pass off (the ideas or words of another) as one's own." To avoid plagiarism, it is necessary to cite all sources of both ideas and direct quotations, including those found on the Internet. The Department of English website and the University Library handout provide thorough discussions of plagiarism: <http://www.lsa.umich.edu/english/undergraduate/advising/plagNote.asp>.

## The Honor Code Process

Either a student or the instructor may report a suspected Honor Code violation by contacting the Honor Code Representative to the Associate Dean for Undergraduate Education: Office of Student Support and Accountability, 129 Chrysler Center, [honorcouncil@umich.edu](mailto:honorcouncil@umich.edu). Suspected Honor Code violations must be reported no later than two months after the term in which the violation occurred.

The accusation is then investigated by the Engineering Honor Council, and if wrongdoing is found, a recommendation is sent to the Faculty Committee on Discipline (FCD). The FCD holds a hearing at which the student is asked to appear and testify on his/her own behalf. After the hearing (whether or not the student attends), the FCD reviews the recommendation made by the Honor Council, decides if an Honor Code viola-

tion has occurred, and determines an appropriate sanction, if so. The Honor Code Representative to the Associate Dean for Undergraduate Education then notifies the student of the FCD's decision.

Typical sanctions for a first violation may include a zero on the assignment, a reduction in grade for the course, and community service. For especially serious or repeated violations of the Honor Code, the sanctions may also include suspension or expulsion from the College of Engineering. The student may appeal the FCD's decision to the Executive Committee of the College of Engineering.

The Honor Council has prepared a booklet that explains the principles and operation of the Honor Code. The Honor Code booklet is available in the Office of Student Support and Accountability, 129 Chrysler Center and on the College of Engineering website: <http://ossa.engin.umich.edu/honor-council/>

## Statement of Student Rights and Responsibilities

### Introduction

The University of Michigan-Ann Arbor (the University) is dedicated to supporting and maintaining a scholarly community. As its central purpose, this community promotes intellectual inquiry through vigorous discourse. Values which undergird this purpose include civility, dignity, diversity, education, equality, freedom, honesty, and safety.

When students choose to accept admission to the University, they accept the rights and responsibilities of membership in the University's academic and social community. As members of the University community, students are expected to uphold its previously stated values by maintaining a high standard of conduct. Because the University establishes high standards for membership, its standards of conduct, while falling within the limits of the law, may exceed federal, state, or local requirements.

Within the University, entities (such as schools and colleges; campus, professional, and student organizations) have developed policies that outline standards of conduct governing their constituents and that sometimes provide procedures for sanctioning violations of those standards. This Statement of Student Rights and Responsibilities (the Statement) does not replace those standards; nor does it constrain the procedures or sanctions provided by those policies. This Statement describes possible behaviors which are inconsistent with the values of the University community; it outlines procedures to respond to such behaviors; and it suggests possible sanctions which are intended to educate and to safeguard members of the University community.

### Student Rights

Students at the University have the same rights and protections under the Constitutions of the United States and the State of Michigan as other citizens. These rights include freedom of expression, press, religion, and assembly. The University has a long tradition of student activism and values freedom of expression, which includes voicing unpopular views and dissent. As members of the University community, students have the right to express their own views, but must also take responsibility for according the same right to others.

Students have the right to be treated fairly and with dignity regardless of age, color, creed, disability, marital status, national origin or ancestry, race, religion, sex (including gender identity and gender expression), sexual orientation, or veteran status. The University has a long-standing tradition of commitment to pluralistic education. Accordingly, the University, through this Statement, will not discriminate on the basis of group status.

Students have the right to be protected from capricious decision making by the University and to have access to University policies which affect them. The University has an enduring commitment to provide students with a balanced and fair system of dispute resolution. Accordingly, this Statement will not deprive students of the appropriate due process protections to which

they are entitled. This Statement is one of the University's administrative procedures and should not be equated with procedures used in civil or criminal court.

## Student Responsibilities

Along with rights come certain responsibilities. Students at the University are expected to act consistently with the values of the University community and to obey local, state, and federal laws.

For complete information on Students Rights and Responsibilities see the Office of Student Conflict Resolution, Division of Student Affairs at: <http://www.oscr.umich.edu/>.

## Registration, Grades and Policies

### Registration (Official Enrollment)

All students must register to be officially enrolled in classes. This process includes meeting with a departmental advisor (for students, advising is mandatory) so that appropriate classes are selected. This is followed by the actual registration process on Wolverine Access. To be considered as full-time students, undergraduate students must enroll for a minimum of 12 hours per semester.

Completion of both the advising and registration procedures are required before a student attends any classes or uses any University facilities. The tuition and registration fees for fulltime enrollment as an undergraduate student in the College of Engineering may be found on the Registrar's website . As of the first day of class, a late registration fee of \$50 will be assessed. Exceptions to the Late Registration Fee are late admissions, non-degree students, Ph.D. students registering to defend their dissertations, or students who have an official waiver based on a University action. The Late Registration Fee is increased by \$25 at the beginning of each subsequent month.

Unless a student is registered, there is no obligation on

the part of faculty members to permit attendance in their classes.

A student who completes the registration procedure (including early registration) and fails to attend classes must officially withdraw at the Registrar's Office of the College of Engineering, for undergraduate students, 145A Chrysler Center. The student is responsible for the usual registration and disenrollment fees as stated in the current Schedule of Classes.

Students should be aware that receiving test or transfer credit can have an impact on tuition, because tuition increases once a student has Junior or Senior standing (55 credit hours or more). Credit will not be removed from the transcript for the purpose of lowering tuition. Students are responsible for reviewing their transcript when credits are posted and asking for removal of any credits within their first term at the University of Michigan. Note also that credit is always posted for the term in which it was earned, not the term in which it was posted; the posting of credit can therefore have a retroactive impact on tuition owed. Current students should carefully consider this issue before asking for credit to be posted on their transcript.

### Class Standing

The number of credit hours accumulated toward graduation at the close of a given term is used to determine a student's class standing for statistical purposes.

Questions concerning class-level designations for undergraduate students should be referred to the CoE Registrar's Office, 145A Chrysler Center:

Class	Hours
Lower Division	Freshman 0 to 24
	Sophomore 25 to 54
Upper Division	Junior 55 to 84
	Senior 85 or more

## Indebtedness to the University

Students shall pay all accounts due the University in accordance with regulations set forth for such payments by the Executive Vice President and Chief Financial Officer. When a student's account shows indebtedness, no transcript of academic record or diploma will be issued, nor will future registration be permitted.

## Half Term Courses During Fall or Winter Terms (2 credits)

Begin and End dates:

- All departments will have the same begin and end dates for classes.
- For Fall and Winter Terms the first half-term course will begin on the regular first day of classes.
- For Fall, the second half term will start at the beginning of the 8th week whenever possible.
- For Winter, the start of the second half term will be the Monday immediately following Spring Break.
- Beginning days will be adjusted so that no class will begin on a Friday.

*Drop/Modify Schedule:* Drop/Modify periods without a "W" will end by the end of the 2nd week for both half terms. Students must petition the Scholastic Standing Committee to drop or modify a class after the fifth week of a half term.

*Fee Adjustments:* There is a two-week deadline (coinciding with Drop/Modify deadlines) for fee adjustments. Documentation is needed for fee adjustments after the deadline. Fee adjustments are finalized through the University of Michigan Registrar's Office.

**Important Note:** Students should register for second half-term classes during the normal full-term registration period.

## Add/Drop/Modify & Course Withdrawals

### Add/Drop/Modify Policy (Change of Elections)

During the first three weeks of classes (first two weeks in a Spring or Summer half term), students may drop without a "W" or add courses using Wolverine Access.

#### Third week through ninth week:

After the third week deadline through the ninth week of classes (second week through fifth week in a Spring or Summer half term), students must obtain Add/Drop forms from their program advisor (for undeclared students, these forms must be signed by an advisor in the Engineering Advising Center) to add or drop courses. These forms must be signed by the program advisor and instructor, and must be submitted to the College Registrar's Office, for undergraduate students, 145A Chrysler Center. A "W" will appear for courses dropped during this time period. To modify a course to pass/fail only an advisor's signature is necessary on the form.

#### Ninth week through last day of classes:

After the ninth week (fifth week for a Spring or Summer half term), course additions, section changes, credit modifications and cross-list changes are processed using an Add/Drop form obtained from the program advisor (for undeclared students, these forms must be signed by an advisor in the Engineering Advising Center). Forms must be signed by the program advisor and instructor. Students should submit them to the College Registrar's Office, for undergraduate students, 145A Chrysler Center.

For drop, pass/fail or audit modifications after the ninth week (fifth week for a Spring or Summer half term), students will need to petition the Scholastic Standing Committee (SSC) 129 Chrysler Center. Documentation will need to be submitted with the Exceptions to College Rules Petitions requesting drop, pass/fail and audit modifications. Petitions are available online at: <http://ossa.engin.umich.edu/scholastic-standing-committee/petitions/>.

International students need to meet with the International Center (Central Campus: 515 E. Jefferson St.) to determine if a withdrawal will impact their visa status. Student athletes must contact their advisor in the Academic Success Program regarding all changes to their election for written approval. This is in addition to the signatures required by the College of Engineering (advisor & instructor signatures).

## Course Withdrawals

1. The incomplete (I) should be the default mechanism for addressing a disruption that arises late in the term.
2. Only the most serious circumstances warrant dropping a course after the ninth week of the term. In order for the SSC to grant a drop at this time, some non-academic, extraordinary event (like severe health issues, prolonged family illness or a severe personal disruption) would have occurred after the ninth-week (fifth week of a half-term) drop deadline and would make completion of a course or courses very difficult if not impossible; the SSC assumes that the student's academic performance up to the point of the disruptive event has been satisfactory.
3. Approved drops will be posted to the official record with a "W."

Petitions are available online at <http://ossa.engin.umich.edu/scholastic-standing-committee/petitions/> and will need to be submitted to the Scholastic Standing Committee in 129 Chrysler Center.

### After the last day of classes, or after the term has ended:

Individual course additions, section changes, credit modifications and cross-list changes are processed using an Add/Drop form obtained from the program advisor (for undeclared students, these forms must be signed by an advisor in the Engineering Advising Center). Forms must be signed by the program advisor and instructor. Students should submit them to the College Registrar's Office, for undergraduate students, 145A Chrysler Center.

Pass/fail or visit modifications after the last day of classes or the term has ended, students will need to petition the Scholastic Standing Committee (SSC). Documentation will need to be submitted with the Exceptions to College Rules petition. Petitions are available at 129 Chrysler Center or on the web at <http://ossa.engin.umich.edu/scholastic-standing-committee/petitions/>.

Late withdrawal of courses after the term has ended:

- Will be rare and discouraged.
- Only the most serious circumstances warrant dropping a course **after the end of a term**. In order for the SSC to grant a withdrawal at this time, some non-academic, extraordinary event (like serious illness or a severe personal disruption) must have occurred after the ninth-week (fifth week of half-term) drop deadline and that would make completion of a course or courses very difficult if not impossible; the SSC assumes that the student's academic performance up to the point of the disruptive event has been satisfactory.
- Adverse circumstances that occur during most of a term generally have foreseeable consequences on performance that should be addressed by students' seeking advice and help, by advisors and faculty reaching out to students, and when necessary through the rules for dropping courses during the term. In addition, the incomplete (I) should be the default mechanism for dealing with a disruption that arises late in the term.
- Additional documentation will need to be provided regarding the reason the petition for a late withdrawal was not submitted during the term in which the student took the courses.
- A clear rationale should be provided for not giving a "W" in all courses, addressing why the extenuating circumstances did not impact all work.
- A 12-month deadline will apply to petition for retroactive withdrawal from courses from a past term.
- If a petition to late withdraw after the end of term is granted, the instructing faculty member whose grade has been changed to "W" will be notified.

The grade for any course dropped without completing the proper procedures will be recorded as

"ED" (unofficial drop) and computed as "E" in grade-point averages.

Junior and senior students enrolled in a Military Officer Education Program must also have approval of the Chair in charge of the unit before they can drop a Military Officer Education Program course or be relieved of the obligation assumed when enrolling in the program.

## Pass/Fail Information

### Elective Pass/Fail Basis

Elective courses used to satisfy the Intellectual Breadth requirement or courses to be used as General Electives can be taken on an elective pass/fail basis. A maximum of fourteen (14) credit hours can be used toward CoE degree(s) requirements. Pass/fail course elections are limited to two courses per full term (Fall or Winter) or one course in a half term (Spring or Summer). Course elections exceeding the full/half term limits will be reverted to the grade earned. Course/credit limits will be calculated in academic term order of election. Any course that is offered only on a mandatory pass/fail basis will not be counted in the above totals.

1. The decision to elect a course on a pass/fail basis or on a graded basis must be made within the first nine weeks of the term (or first five weeks of a Spring or Summer half term). No changes in election as a graded course or as a pass/fail course can be made after the ninth week of a term, (or first five weeks of a half term).
2. Instructors are not notified of pass/fail elections; they will report grades as usual, "A+" through "E." The University of Michigan Registrar's Office will then translate grades as follows:
  3. A grade of "C-" through "A+" in a course elected on a pass/fail basis is considered satisfactory and will be recorded as "P" (pass—for credit toward the degree and no effect on the grade point average).
  4. A grade of "D+" or lower in a course elected on a pass/fail basis is considered unsatisfactory and will be recorded as "F" (fail—no credit and no effect on grade point average).

3. To be eligible for the Dean's Honor List, a minimum of 12 credit hours (6 for a half term) must be elected for letter grades, with a grade point average of 3.5 or better.
4. To be eligible for Recognition on the Diploma, a minimum of 45 hours of credit with grades must be completed with a grade point average of 3.2 or better.
5. If a student completes a course for pass/fail and subsequently changes the degree program of study to one in which the course comes into conflict with the stated constraints for pass/fail elections in the new program, the course will be accepted in the new program as follows:
  1. A record of "P" (pass) is regarded as a satisfactory completion of the program requirement.
  2. A record of "F" (fail) is regarded as unsatisfactory completion and the course must be repeated for grades.

### Courses Offered on a Mandatory Pass/Fail Basis

A department or instructor may offer an undergraduate course on a mandatory pass/fail basis:

1. The instructor will report the grade as pass/fail for each student enrolled.
2. The grade will be treated the same as when the student chooses to elect a course on a pass/fail basis if the following conditions are satisfied:
  1. The course is not required for any program or department.
  2. It is the type of course which might be considered appropriate to a pass/fail grading system. Examples of such courses may include: design, survey-type, individual directed research, laboratory, or undergraduate seminars.
3. The mandatory pass/fail basis of the course is announced by the instructor at the beginning of the term, with the exception of individual instruction courses. See the University Registrar's Office schedule of classes website (<http://www.umich.edu/~regoff/schedule>).

## Academic Definitions

### Visit

With permission of the advisor and course instructor, a student may enroll in a course as a visitor. In such a case, the course will be entered on the permanent record with a "VI" instead of a letter grade. The same fee will be charged whether the student enrolls for credit or as a visitor. A course elected as "VI" does not count toward a student's full time status.

A change in elections from credit to visit must be made during the first nine weeks of a term. Note that advisors typically will not approve changes in Visit elections after the third week (second week in Spring and Summer half terms). In such cases, withdrawing or changing to an election of Pass/Fail is generally more appropriate. After the ninth week, students must petition for an exception to College Rules to change Visit status. Required courses may not be elected as a visit.

### Term

A term (semester) extends over approximately four months, including examinations. The University's year-round calendar, by months, is approximately as follows:

<b>Term</b>	<b>Months</b>
Fall	Sept., Oct., Nov., Dec.
Winter	Jan., Feb., Mar., Apr.
Spring/Summer	May, June, July, Aug.

The Spring-Summer term may be scheduled as two half terms, approximately as follows:

<b>Term</b>	<b>Months</b>
Spring	May, June
Summer	July, Aug.

## Course Offerings

The appropriate Bulletin and the Schedule of Classes (<http://www.umich.edu/~regoff/schedule/>) prepared for each term will serve the student as a guide in planning each term's schedule. The College of Engineering reserves the right to withdraw the offering of any elective course not chosen by at least eight students.

### Credit Hour

A credit hour (semester hour) generally represents one hour of recitation or lecture per week for a term, or two for a half term; preparation for each credit hour normally requires a minimum of three hours of study per week. Generally, one period of laboratory work is considered to be equal to one hour of credit.

### Work Load

The number of credit hours a student is able to carry in any one term depends upon a number of factors—including abilities, health, and the amount of time devoted to extracurricular activities or to outside work. Twelve credit hours are considered a minimum full-time academic schedule for a full term (six for half term). Reduced program fees apply to 11 credit hours or less for undergraduate students.

Unless approved by the program advisor (for undeclared students, the Director of the Engineering Advising Center), the student may not elect courses (or change elections) for which the total number of hours for a term is less than 12 or more than 18, and for a half term, less than six or more than nine. A student should have a 3.0 average or more for the previous term to be permitted to carry a term load of more than 18 hours. Attention is called to the section on "Time Requirements" for a statement on estimating the time needed for a bachelor's degree.

### Attendance and Absences

Regular and punctual attendance in classes is one of a number of expressions of interest and maturity. The reasons for good attendance should be obvious, and

students may expect unexcused absences to be reflected in their final grade.

All students should account for their absences to their instructors. A student who has been absent from studies for more than one week because of illness or other emergency should consult the program advisor to determine the advisability of reducing course loads.

## Examinations

Examinations may be given at any time, with or without notice, on any part of the work. An examination at the end of the term is an essential part of the work of the course. The instructor is required to observe the official final examination schedule established by the University.

Any student absent from an examination should report to the instructor as soon thereafter as possible. If a student presents a valid excuse for being absent, a make-up examination may be arranged by the instructor for another time.

## Transfer Credit Information

### Transfer Credit for Enrolled Students (Transfer Credit Approval Form)

Currently enrolled students can receive transfer credit from classes taken at other institutions by following the instructions on the website for the Transfer Credit Approval Form. The Transfer Credit Approval Form can be accessed online at <http://tcaf.engin.umich.edu/>. The form itself must only be completed if a course needs to be evaluated for transfer credit. An evaluation typically takes two to four weeks and results in the notification of course transferability and the credit hours that will be earned upon completion of the course(s) with a grade of "C" or better. Online courses will be evaluated for transfer credit in the same manner and should also be submitted for approval via the Transfer Credit Approval Form. The College of Engineering allows a maximum of 12 credits for online transfer

coursework. Transfer evaluations are generally conducted by the Department that owns the equivalent course. Note that some Departments do not accept online courses.

For CoE undergraduate enrolled students, please send your official transcript to:

College of Engineering, Office of Recruitment  
and Admissions  
153 Chrysler Center  
2121 Bonisteel Boulevard  
Ann Arbor, MI 48109-2092

This information along with important rules to keep in mind can be found on the website shown above. Questions can be emailed to Credit Evaluation at [engincredit@umich.edu](mailto:engincredit@umich.edu) or answered in-person at Suite 145C Chrysler Center.

### Transfer Credit for International Programs

Currently enrolled students must consult with the International Programs in Engineering (IPE) office regarding course approvals, transfer credit and registration for all study abroad programs. Any student participating in an international experience must have a record in M-Compass.

Transcripts for IPE-Sponsored Programs should be sent to:

International Programs in Engineering  
245 Chrysler Center  
2121 Bonisteel Boulevard  
Ann Arbor, MI 48109-2092

### Declaring (or Changing) Major

Students may declare a major as early as their second term in the College, and are urged to declare a specific engineering major by the start of their 3rd term of enrollment. Undeclared students cannot register for a 4th term in the College unless they have met with an advi-

sor and developed a plan to select and declare a major within a reasonable time. This plan can be developed in coordination with the EAC advisors and departmental program advisors.

Students who meet all of the criteria below can declare any undergraduate engineering major. Students not meeting these criteria must meet with a departmental program advisor to establish any specific steps they must take in order to declare that major.

Students can declare or change into any undergraduate engineering major if they:

1. Have completed at least one full term of courses on the U-M Ann Arbor campus.
2. Have an overall U-M GPA of 2.0 or better in courses taken at the U-M Ann Arbor campus and are in good standing.
3. Have completed or earned credit by exam or transfer for one or more courses in each of these categories:
  - Calculus (e.g. Math 115, 116, 156)
  - Calculus-based physics lectures (e.g. Physics 140, 160) or chemistry lectures (e.g. Chemistry 130)
  - Required engineering courses (Engr 100, 101, 151)

**A student must have a grade of C or better in every math course, science lecture and engineering course taken at U-M Ann Arbor to declare, unless waived by the program advisor, including 1-3 above. For repeated courses the most recent grade counts.**

## Transfers and Withdrawals, Readmission

### Transferring Out

A student who wishes to pursue studies in another unit of the University must apply for admission to that unit and be accepted in order to continue enrollment in the University. In most cases, a student must be in good scholastic standing to be eligible for admission to other

colleges/schools.

## Term Withdrawals

The rules and procedures for term withdrawals vary based on when the withdrawal takes place, as outlined below:

- ***Before the first day of classes:*** Students must withdraw through the University of Michigan Office of the Registrar. This may be done in-person at B430 LL Pierpont Commons or Rm 1207 LSA Bldg., 500 S. State Street; via e-mail (ro.registration.questions@umich.edu); by fax (734-763-9053 or 734-763-7961); or by mail (University of Michigan Office of the Registrar, Room 1207 LSA Building, Ann Arbor, MI 48109-1382). The term in question is fully removed from the academic record.
- A student who withdraws after registration shall pay a disenrollment fee according to the rules in effect at the time of withdrawal as found on the Office of the Registrar's website.
- ***First day of classes to third-week deadline:*** Student must report to the College Registrar's Office, for undergraduate students, (145A Chrysler Center); The term is fully removed from the academic record. No documentation is needed.
- ***Third-week deadline to ninth-week deadline:*** Student must report to the College Registrar's Office, for undergraduate students (145A Chrysler Center); a "W" will appear for each course. No documentation is needed.
- ***Ninth-week deadline to last day of classes:*** Student must report to the Scholastic Standing Committee Office (129 Chrysler Center); a "W" will appear for each course. No documentation is needed. The student is not eligible to enroll in next full term. "Not to Register" is denoted on the record.
- ***After last day of classes (retroactive):*** Student must petition the Scholastic Standing Committee (129 Chrysler Center).
  - Late drop of courses after the last day of classes:
    - Will be rare and discouraged.
    - Only the most serious circumstanc-

es warrant dropping a course after the end of a term. In order for the SSC to grant a withdrawal at this time, some non-academic, extraordinary event (like serious illness or a severe personal disruption) must have occurred after the ninth-week (four and a half week of a half-term) drop deadline and that would make completion of a course or courses very difficult if not impossible; the SSC assumes that the student's academic performance up to the point of the disruptive event has been satisfactory.

- Adverse circumstances occurring during most of a term generally have foreseeable consequences on performance that should be addressed by students' seeking advice and help, by advisors and faculty reaching out to students, and when necessary through the rules for dropping courses during the term. In addition, the incomplete "I" should be the default mechanism for dealing with a disruption that arises late in the term.
- Additional documentation will need to be provided regarding the reason the petition for a late withdrawal was not submitted during the term in which the student took the courses.
- If the student wishes to withdraw from only some of the courses in the term, a clear rationale should be provided for not giving a "W" in all courses, addressing why the extenuating circumstances did not impact all work. Such partial withdrawals are approved very rarely.
- A 12 months deadline will apply to petition for retroactive withdrawal from courses from a past term.
- If a petition to late withdraw after the end of term is granted, the in-

structing faculty member whose grade has been changed to "W" will be notified.

Petitions are available on the web at <http://ossa.engin.umich.edu/scholastic-standing-committee/petitions/>.

Students withdrawing after the ninth-week deadline are not eligible to enroll in the next full term. A "Not to Register" designation will be placed on their academic record. If they are already registered they will be disenrolled. When they are eligible to return a "Permission to Register" designation will be placed on their academic record.

**All students withdrawing from the College of Engineering will be asked to complete an exit survey.** Tuition and fee adjustments are in accordance with the Office of the Registrar.

International students need to meet with the International Center (Central Campus: 515 E. Jefferson St.) to determine if a withdrawal will impact their visa status.

Student athletes must contact their advisor in the Academic Success Program regarding the term withdrawal.

## Unofficial Transcript

Each student's transcript is the cumulative record of courses elected and grades earned while enrolled at the University of Michigan.

Unless withheld for infringement of rules, an individual may obtain an official copy of his or her transcript from the University Office of the Registrar at no charge. An unofficial copy of the transcript may be obtained through Wolverine Access.

## Grades

The grades are valued per hour of credit as follows:

Letter Grades	Honor Points
A+	4
A (excellent)	4
A-	3.7
B+	3.3
B (good)	3
B-	2.7
C+	2.3
C (satisfactory)	2
C-	1.7
D+	1.3
D	1
D-	0.7
E (not passed)	0
ED (unofficial drop)	0

These items do not affect grade point averages:

- **Pass/Fail**
  - P (passed) credit, no honor points
  - F (failed) no credit, no honor points
- **Credit/No Credit**
  - CR (credit) credit, no honor points
  - NC (no credit) no credit, no honor points
- **Satisfactory/Unsatisfactory**
  - S (satisfactory) credit, no honor points
  - U (unsatisfactory) no credit, no honor points
- **Withdrawal/Drop**
  - W (official withdrawal) no credit, no honor points
  - ED (dropped unofficially) no credit, no honor points  
(A notation of ED for a graded election has the same effect on the grade point average as does an E.)

- **Incomplete/Work in Progress**
  - I\*(incomplete) no credit, no honor points
  - Y\*(work in progress for no credit, no honor points, project approved to extend for two successive terms)  
("Y" can only be used with courses specially approved by College of Engineering Curriculum Committee as "two-term" sequence courses.)
- **Official Audit (VI)**
  - VI (Visitor) no credit, no honor points
- **Miscellaneous Notation (NR)**
  - NR\*\*(no report) no credit, no honor points

\*A notation of "I," if not replaced by a passing grade, lapses to "E" the last day of classes for the next full term and, for graded elections, is computed into the term and cumulative grade point average.

\*\*A notation of "NR" becomes an "ED" and has the same effect on the grade point average as does an "E." In the remainder of this section of the Bulletin, the term "a grade" applies to any of the grades "A+" through "E."

## C- and D Grades

Credit is generally allowed for a course in which a grade of "C-" or "D" is earned while enrolled in the College of Engineering, but there are restrictions:

- The "D" level of performance ("D+" or lower) is not considered satisfactory for a course that is a prerequisite for a later-elected course; in this case, the course must be repeated before electing the next course unless waived by the program advisor.
- A grade of "D+" and lower is not acceptable in any program for Engineering 100, Engineering 101.
- A grade of "C-" is not a satisfactory level of performance in some programs for any required course.
- "C-" grades in math, science or introductory engineering courses may negatively impact a student's eligibility to declare a degree program. Please consult the rules for declaring a major.
- It is the student's responsibility to review course performance with their advisor as soon as the grade

is known in order to make any changes that may be necessary in future course elections.

Transfer credit will be granted for courses taken outside the University of Michigan, Ann Arbor campus, provided a grade of "C" or better is earned. Transfer credit will be granted for courses, other than math, science, engineering, or other prerequisites for admission into the College of Engineering, taken in any academic unit at the University of Michigan, Ann Arbor campus, provided a grade of "C-" or better is earned.

Students should be aware that some programs limit the number of "C-" grades or require that courses completed with a "C-" or lower grade be repeated. Some programs may have a higher minimum grade requirement for some courses.

## E Grades

Neither credit nor Michigan Honor Points are granted for a course in which a student earns the grade of "E." A course required by the student's program must be repeated as soon as possible.

## Incompletes

When a student is prevented by illness, or by any other cause beyond the student's control, from taking an examination or from completing any part of a course, or if credit in a course is temporarily withheld for good reason, the mark "I" may be reported to indicate the course has not been completed. This mark should be used only when there is a good probability that the student can complete the course. The instructor and student should mutually understand the reasons for the "I" mark and agree on methods and timeline for completing the work.

No qualifying grade will be recorded on the student's academic record. The "I" mark will not be used in computing either the term or cumulative grade point averages. Scholastic standing at the end of any term is determined on the basis of work graded as "A+" through "E," or "ED."

The required work may be completed and the grade submitted by the instructor whether or not the student is enrolled in the subsequent term. The student should plan to complete the work as soon as possible. To secure credit, the required work must be completed by the end of the first full term (not including Spring or Summer terms) in which the student is enrolled after the term in which the "I" mark was recorded. It is the student's responsibility to remind the instructor to submit a grade report through the grading system in Wolverine Access when the work is completed. If the final grade is not reported by the last day of classes, the University Registrar will automatically change the "I" to an "ILE." Incomplete extensions must be arranged with the instructor. Forms are available at the Office of the Registrar for Undergraduate Students, 145A Chrysler Center.

Any grade changes made to the student record as a result of Incompletes either being completed or lapsed will result in reevaluation of a student's academic record by the Scholastic Standing Committee and may result in changes to their academic standing.

## Other Irregularities

Irregularities associated with a failure to submit changes in academic status are identified on the student's transcript by an appropriate designation such as "ED" (unofficial drop) or "NR" (no report). "NR" (no reports) are automatically converted to "ED" when entered into the grading system in Wolverine Access. An unofficial drop will be considered the same as an "E" in computing the term and cumulative averages and will affect the scholastic standing.

## Repeating Courses

For "C-," "D" and "E" grades, see above. Except as provided for grades "C-" through "D-," a student may not repeat a course he or she has already passed. In exceptional cases, this rule may be waived by the student's program advisor (for undeclared students, the Director of the Engineering Advising Center) after consultation with the department of instruction involved. If the rule is waived, the course and grade will appear on the transcript, but no additional credit or Michigan

Honor Points (MHPs) will be granted.

A student repeating a course in which a "C-" through "D-" was previously earned will receive MHPs but no additional credit. All attempts at a course are used in computing the overall grade point average.

## Grade Point Averages

The term grade point average (GPA) and the cumulative GPA are computed for each student at the end of each term and become part of the academic record.

The grade point average is computed by dividing the grade points (Michigan Honor Points or MHP) by the graded hours attempted (Michigan Semester Hours or MSH).

Grades associated with transfer credit are neither recorded nor used in computing the cumulative average. The only exception to this rule is for courses elected on the Ann Arbor campus (effective November 1986).

## Honor Point Deficit Calculator

### (Michigan Semester Hours \* 2) - Michigan Honor Points = Honor Point Deficit

Use cumulative totals to calculate cumulative deficit; use term totals to calculate term deficit. The result reflects the number of "B" credits needed to raise cumulative or semester GPA above 2.0.

The GPA is figured by dividing Michigan Honor Points (MHP) by Michigan Semester Hours (MSH):  $25.6 \text{ MHP} / 16.00 \text{ MSH} = 1.600 \text{ GPA}$ .

The term honor point deficit is calculated by multiplying MSH by 2 and subtracting MHP:  $(16.00 \text{ MSH} \times 2) - 25.60 \text{ MHP} = 6.4 \text{ honor point deficit}$ .

Thus, this student needs 6.4 credits of "B" grades to raise his/her term GPA above 2.00.

## Academic Honors and Awards

### The Dean's List (College of Engineering)

Students pursuing an undergraduate degree who elect courses and complete a minimum of 12 credit hours with grades (6 for a half Spring or Summer term) and earn a 3.50 GPA term average or better, attain the distinction of the Dean's List for the term.

### University Honors (University of Michigan)

Students who earn a minimum of 14 credits in courses which include 12 credits elected on a graded basis ("A" through "E"), and who earn a 3.5 grade point average are eligible for University Honors. This Honor will be awarded each full term of classes (Fall & Winter terms). This distinction is posted on a student's transcript by the University of Michigan Registrar's Office. Students who receive this honor for two consecutive terms will be invited to attend the annual Honors Convocation.

### James B. Angell Scholars (University of Michigan)

James B. Angell Scholars are students who earn all "A+," "A," or "A-" grades for two or more consecutive terms based on a minimum of 14 credits earned in courses which include 12 credits earned on a graded ("A"- "E" basis elected each term); all other grades must be "P," "S," or "CR". Terms of fewer than 14 credits completed with grades of "A+," "A," "A-," "P," "S," or "CR" enable a student to maintain standing as an Angell Scholar. Any other grades earned during a full or half-term make a student ineligible for this honor. Angell Scholar Honors are posted on a student's transcript by the University Office of the Registrar, and recipients of this honor are invited to attend the annual Honors Convocation. Angell Scholars are selected and honored annually.

### William J. Branstrom Freshman Prize (University of Michigan)

Students in the top five percent of the freshman class are eligible for this honor, administered by the University Registrar's Office, if they have earned at least 14 graded credits at Michigan. A book with an inscribed nameplate is presented to each student. Recipients of this award are invited to attend the annual Honors Con-

vocation.

### **Marian Sarah Parker Scholars (College of Engineering)**

The Marian Sarah Parker Scholars Program is a joint program of the College of Engineering and the U-M Women in Science and Engineering (WISE) Program. The Marian Sarah Parker Scholars Program invites high-achieving women, by Fall Term of their junior year, to participate in a two-year exploration of graduate school. Participation as a Marian Sarah Parker Scholar leads to a greater understanding of the graduate school process by means of seminars, panel discussions, and an academic research project.

### **Special Awards (College of Engineering)**

The College gives special recognition to students with high scholastic achievement, with records of service to the College and its student organizations, or with evidence of extraordinary potential for leadership. Information on qualification requirements can be obtained in the Office of Student Affairs, 143 Chrysler Center.

### **Society Recognition (College of Engineering)**

Distinguished scholarship and service to the College are also recognized by election to a number of honor societies that are listed under "Student Activities and Co-Curricular Opportunities."

### **Recognition on Diploma (College of Engineering)**

A student graduating with at least 45 hours of credit completed, with grades, while enrolled in this College will be recommended for a degree(s) with recognition on the diploma if the student qualifies according to the following:

#### **Grade Point Average Distinction (no rounding up)**

3.20-3.49..... cum laude

3.50-3.74..... magna cum laude

3.75-4.00..... summa cum laude

## **Grievances Procedures**

### **Grade Grievances Procedure**

If there is justification to question the accuracy of an

assigned grade, the student should first pursue the matter with the instructor. The responsibility for the assignment of grades is primarily that of the instructor and should be settled between the student and instructor whenever possible. Further pursuit of a grade grievance should be addressed with the instructor's Department Chair. The final appeal at the College level is by petition to the Associate Dean for Undergraduate Education or the Associate Dean for Graduate Education.

## **Student Grievances**

The College of Engineering has a grievance procedure to address student complaints.

Undergraduate and Graduate students should follow these steps until a resolution is achieved:

1. Attempt to resolve the grievance directly with the individual involved (faculty member, staff member, or fellow student).
2. If the matter is unresolved, and the grievance is with a faculty member or teaching assistant, discuss the grievance with the appropriate Department Chair.
3. If the issue is still unresolved, undergraduate students should see the Associate Dean for Undergraduate Education and graduate students should see the Associate Dean for Graduate Education who are both located in the Robert H. Lurie Engineering Center.
4. All students have the right to appeal to the Dean of the College if they feel their grievances have not been resolved satisfactorily by another dean.

## **Scholastic Standing Committee**

129 Chrysler Center

Phone: (734) 647-6955

Fax: (734) 763-5345

sscresponse@umich.edu

The Scholastic Standing Committee (SSC) is comprised of faculty representatives and academic services

staff members. Faculty members are appointed for a three-year term. The SSC studies problems related to, and defines criteria for, scholastic performance. In addition the SSC reviews all petitions within the College, including the Petition for Reinstatement, the Petition for Late Drop, the Petition for Exception to College Rules, and the Petition for Retroactive Term Withdrawal.

## Standards Governing Scholastic Standing for Unsatisfactory Performance

All students will be in one of the following classifications:

- **Good Standing:** 2.00 GPA or better for both the term and the cumulative average.
- **Probation:** a deficiency of up to 10 MHP for the term or cumulative average.
- **Enrollment Withheld:** a deficiency of 10 MHP\* or above for the term or cumulative average; or the third or greater incidence of probation.
- **Reinstated on Probation:** Enrollment Withheld, but reinstated by the Scholastic Standing Committee.
- **Enrollment Withheld Continued:** Enrollment Withheld status remains to allow the student more than one term to return to good academic standing.
- **Mandatory Leave:** SSC decision requiring a leave from the College of Engineering based upon unsatisfactory academic performance. Students will have to petition for reinstatement to return after their required leave has been fulfilled.
- **Dismissal:** SSC decision based upon failure to meet the conditions of reinstatement. Student is no longer eligible to enroll in the College of Engineering or petition the Scholastic Standing Committee for reinstatement.

Scholastic standing action will be determined as follows:

## Probation

When a student has a deficiency between 0 and 10 MHPs for either the term or cumulative GPA, the student is placed on probation. The notation "Probation" will be entered on the unofficial transcript.

A student on probation may continue enrollment, but is required to meet with a program advisor (undeclared students are required to meet with an advisor in the Engineering Advising Center) regarding course selection for the following term. Failure to do so will result in an academic hold on his or her account, preventing enrollment in future terms. Probation is a serious warning that there is a need to improve scholastic performance or further enrollment may be jeopardized.

## Enrollment Withheld

A student will have the notation "Enrollment Withheld" placed on his/her transcript and will not be allowed to enroll in classes if: a) on Probation for the third or greater time; or, b) a deficiency of 10 MHP or more in either the term or the cumulative GPA.

When a student is on Enrollment Withheld, the student must submit a petition to the Scholastic Standing Committee (SSC, <http://ossa.engin.umich.edu/scholastic-standing-committee/petitions/>) requesting reinstatement. The student must meet with his/her program advisor to discuss the petition (undeclared students must meet with their advisor in the Engineering Advising Center). The petition must document the reasons for the unsatisfactory performance, and it needs to offer sufficient and convincing evidence that another opportunity is warranted. If illness has been a factor, students must include supporting information, including a statement (with dates) from their physician. Documentation supporting other contributing factors must also be included.

Reinstatement petitions must be submitted to the Scholastic Standing Committee via the online petition system. Failure to petition the SSC in time and follow the correct procedure will result in a forfeiture of the right to petition for reinstatement for that term and disenroll-

ment from the College.

Students who were enrolled in the previous term must submit their reinstatement petitions in accordance with the following deadlines:

Fall Term 2016	July 1, 2016
Winter Term 2017	January 6, 2017
Spring Term 2017	May 8, 2017
Summer Term 2017	July 13, 2017
Fall Term 2017	July 1, 2017

Students returning after time away from the College must submit their reinstatement petitions in accordance with the following deadlines:

Fall Term 2016	July 1, 2016
Winter Term 2017	November 1, 2016
Spring Term 2017	March 1, 2017
Summer Term 2017	May 1, 2017
Fall Term 2017	July 1, 2017

Reinstatement petitions will not be accepted after the deadline.

It is the policy of the College and the SSC not to reinstate students with 128 credit hours solely for the purpose of improving their grade point average or removing an honor point deficiency to meet the 2.0 cumulative grade point average requirement for the baccalaureate (B.S.E.) degree requirements.

Students seeking reinstatement may be required to meet the SSC, where two committee members hear the student's case. The Committee will either approve the student's reinstatement, or require a permanent or temporary dismissal. When a student is reinstated, he or she is required to sign a contract that states the conditions he or she must meet in order to continue in future terms.

Reinstated students are not permitted to register for future terms unless they can demonstrate they have met their conditions of reinstatement. Students must wait until grades are posted or complete a progress report, before early registration, available at <http://ossa.engin.umich.edu/scholastic-standing-committee/progress-reports/>. The Progress Report

must be submitted to the SSC, 129 Chrysler Center, once completed.

Questions, appointments and petition forms are handled by the SSC, 129 Chrysler Center, (734) 647-6955. All petitions are available online at <http://ossa.engin.umich.edu/scholastic-standing-committee/petitions/>. It is required that you submit petitions and documentation via the online petition tool.

Students who are not reinstated will be placed on suspension and disenrolled.

## Mandatory Leaves

Two (2) Enrollment Withheld (EW) notations require a student to take a leave from the College of Engineering for one (1) full term (Fall or Winter).\* A student may also be required to take a mandatory leave with less than two EW notations if they have a very large deficit and/or have issues that need immediate attention.

If a student with two EW's intends to return to the College after the required leave, he/she is required to petition the Scholastic Standing Committee for reinstatement. The deadlines for submitting reinstatement petitions are:

Fall Term 2016	July 1, 2016
Winter Term 2017	November 1, 2016
Spring Term 2017	March 1, 2017
Summer Term 2017	May 1, 2017

\*Students receiving their second EW at the end of the Winter term will not be eligible to enroll in the Spring, Summer, Spring-Summer or Fall terms at the University of Michigan.

## Dismissal

Permanent dismissal from the College of Engineering is a Scholastic Standing Committee decision based upon a student's failure to meet the conditions of reinstatement. Students are no longer eligible to enroll in or attend the College of Engineering. Students also lose

the privilege of petitioning the Scholastic Standing Committee for reinstatement.

## Degree Requirements

### Requirements for a Bachelor's Degree

To obtain a bachelor's degree in the College of Engineering, Ann Arbor campus, 128 credit hours must be earned and a student shall meet the following requirements, subject to approval of the program advisor:

1. The student must achieve a satisfactory level in those subjects specified by the program of his or her choice. A grade of "D" in a required course may not be considered satisfactory unless approved by the program advisor. In some programs, a grade of "C-" is likewise not considered satisfactory. A student may receive credit toward a degree in one or more of the following ways:
  - By passing a course for credit on the Ann Arbor campus ("C-" or "D" grades may not be acceptable as a proper level of attainment for a required course, as noted above.)
  - By Advanced Placement Program examination for college-level work completed in high school (See "Advanced Placement," under "Admission.")
  - By an examination regularly offered by a department of the University, or by a recognized testing service.
  - By transfer of equivalent credit from another recognized college (See "Adjustment of Advanced Credit")
  - By demonstrating competence in a higher-level course or series covering similar material (e.g., honors-level).
  - By demonstrating equivalent and parallel knowledge that enables the student to enroll at an advanced level. In this case, the student will not be allowed credit hours on the transcript, but may be excused from enrolling in courses in which the program advisor judges the student proficient. To qualify, the student must petition the program advisor and, as a condition, may be required to demonstrate his or her proficiency by an appropriate examination.
2. The student must accumulate a final grade point average of 2.00 or more for all credit hours not taken under the pass/fail option while enrolled in the College of Engineering. In addition, a student must earn a cumulative grade point average of 2.00 or higher in all courses taken within the student's academic department. Consult your department for additional information.
3. The student must complete at least 50 credit hours of course work offered by the University of Michigan-Ann Arbor campus. This course work must generate credits towards program (CTP) on the student's transcript. A few courses, for example, ENGR 196, ENGR 301 and ENGR 400, do not generate CTP.
4. The student must complete a minimum of 30 credit hours of advanced level (300 or higher) technical courses, as required by the degree program, offered by the College of Engineering, Ann Arbor campus. This course work must generate credits towards program (CTP) on the student's transcript. A few courses, for example, ENGR 301 and ENGR 400, do not generate CTP.
5. The College of Engineering does not allow a single class to meet the program requirements of both a CoE degree program and two or more other degree programs, regardless of school or college in which the latter degrees are offered.
6. The student must file formal application for the diploma. (See "Diploma and Commencement" below.)

### Time Requirement

The time required to complete a degree program depends on the background, abilities, and interests of the individual student. Note: A full-time schedule averaging 16 hours of required subjects will allow a student to complete the degree requirements (128 credit hours) in eight terms as noted in the sample schedules appearing with the program descriptions.

A student who is admitted with advanced preparation, with demonstrated levels of attainment, or with ability to achieve at high levels may accelerate his or her progress. A student who is partially self-supporting while at the campus may find it desirable to plan a schedule longer than eight terms.

A student who plans to continue studies beyond the bachelor's degree may (after attaining senior standing) elect a limited number of graduate-level courses concurrently with the courses required for the bachelor's degree. A course required for the bachelor's degree generally cannot be used for graduate credit also, except as allowed by the Sequential Undergraduate/Graduate Studies Program. For details, refer to the regulations published by the University of Michigan Horace H. Rackham School of Graduate Studies.

## Requirements for an Additional Bachelor's Degree

Additional bachelor's degrees can be conferred in the College of Engineering, Ann Arbor campus.

1. To obtain additional bachelor's degrees in the College of Engineering, a student must complete the requirements of each of the degree programs. Furthermore, for each additional degree, the student must complete at least a minimum of 14 additional credit hours in pertinent technical subjects. Approval by involved departments is required.
2. Students are encouraged to carefully consider whether a relevant graduate degree would be more appropriate than a second undergraduate degree. Students are strongly discouraged from declaring three (or more) undergraduate majors, and may not use the same course to meet the program requirements of both an Engineering degree program and two or more other degree programs, regardless of school or college in which the latter degrees are offered.
3. To obtain an additional bachelor's degree with a school or college on the University of Michigan-Ann Arbor campus, refer to the program requirements under Combined Programs for details.

## Substitution

Substitution of a course for one which is a requirement for graduation must be approved by the program advisor of the student's degree program.

## Diploma and Commencement

For the College of Engineering to recommend the granting of a degree, a student who satisfies all other requirements must apply for graduation through Wolverine Access. A student completing the requirements for a College of Engineering degree and a second degree in one of the other schools/colleges on the University of Michigan-Ann Arbor campus must apply for graduation for each of the degrees for the same graduation date.

A student should apply for graduation at the beginning of the term in which the student is reasonably certain of completing the work for the degree.

When a student does not meet the requirements as planned, the student must re-apply at the appropriate time. Degrees are awarded at the end of the fall, winter, and summer terms.

All students who are entitled to receive diplomas are welcome at the Commencement exercises appropriate to the date of graduation.

# Undergraduate Education

## Mission Statement

### Objectives

A University of Michigan undergraduate engineering graduate will be prepared to generate value for society through a lifetime of technical and professional creativity. Our graduates will display reasoning skills and proficiency in problem definition, problem solving and quantitative expertise, a respect for measurement and data and the wisdom of experience. Our graduates will use these skills to achieve the following objectives within a few years of graduation:

- Contribute to technical engineering practice
- Pursue graduate education in engineering or science, either following a path towards a professional masters degree and practice, or a doctoral degree
- Pursue careers in law, medicine, education or other fields, bringing engineering problem solving skills — honed through practice in problem definition and quantitative problem solving — to bear in those disciplines

Michigan Engineers will excel in all of these areas of endeavor. They will also be prepared to become successful leaders, managers, entrepreneurs and humanitarians.

Our graduates must understand that solutions, especially for society's most critical needs, are not just technical in scope but depend on many disciplines working together and that as engineers their core contribution will include bringing data-driven, quantitative problem solving skills to the table. We also understand that our students have many varied aspirations and that our primary duty is to provide them with a foundational education that they can carry forward into any of the career paths they may follow over the decades of their careers.

To prepare our students for the careers of the 21st century, whether they continue in engineering or pursue other paths after graduation, our undergraduate pro-

grams support our students in developing:

- An understanding of the fundamental knowledge in a discipline
- An ability to recognize and define a problem, and the vision to see a solution
- An ability to identify, understand, and solve ill-defined problems even in the face of uncertainty and imperfect information
- Strong quantitative and qualitative problem solving skills
- A mindset and skills that support continued learning both during and long after their CoE career
- Personal attributes of success including:
  - high personal expectations
  - persistence
  - the ability to work in teams
  - the ability to plan a project and carry it out
  - the ability to gather resources and overcome barriers to success
  - the ability to manage risk
  - the ability to communicate professionally
- An understanding of the human, social, and environmental dimensions of engineering practice
- A drive and capability to make a difference by bringing their solutions into production

Many of the College's undergraduate degree programs are accredited by the Accreditation Board for Engineering Education and Technology (ABET). Each such program has statements of educational objectives and outcomes that are based on the College's mission and on the needs of its constituents. Those constituents include our alumni, students, employers of our students and the graduate schools at which many of our students later study.

## Outcomes

Graduates of the College's undergraduate programs will be able to:

1. Apply their knowledge of mathematics, science and engineering within their chosen field. (a)
2. Recognize and define engineering problems and develop practical solutions using the techniques

- and skills of modern engineering practice. (e,k)
3. Design products and processes applicable to their chosen field. (c)
  4. Design, conduct and interpret the results of engineering experiments. (b)
  5. Work effectively in diverse teams and provide leadership to teams and organizations. (d)
  6. Communicate effectively using oral, graphic and written forms. (g)
  7. Understand the impact of engineering decisions in global, social, economic and environmental context. (h)
  8. Understand professional and ethical responsibility and apply ethical reasoning to the work. (f).
  9. Engage in life-long learning and recognize the importance of doing so. (i)
  10. A broad education necessary to contribute effectively beyond their professional careers.
  11. Understand and make a contribution to society. (j)

(letters) are references to ABET Engineering Accreditation Commission outcomes a through k.

## Curricular Information in the Bulletin

In this edition of the College of Engineering Bulletin, our traditional "Sample Schedule for Required Programs" has been updated to reflect the current undergraduate engineering curriculum and curricular plans in each department and program. It is important to note that the curriculum revision process is an ongoing one; therefore, the program requirements and specific course requirements, especially upper-division courses, listed here should be viewed as works-in-progress. Always confirm your course plan with your academic advisor. Upon entering the College, undeclared students will be assigned an advisor in the Engineering Advising Center. After declaring a degree program, a student's advising home moves to that program's Advising Office. Each department's Program Advising Office and Web site information has been provided for your assistance in determining specific program changes.

## Core Requirements

### Planning the Student's Program

Students vary in their goals and objectives, in their level of achievement and in their high school or pre-engineering preparation. Considerable variety and flexibility are provided to plan each student's schedule so that the individual may reach graduation as efficiently as possible. The objective is to place each new student in courses commensurate with his or her academic profile, previous experience and potential for academic success.

Most courses have prerequisites. The completion of courses on schedule and with satisfactory grades is essential to the student's progress.

The appropriate schedule for each student in each term will depend on a number of factors such as: past scholastic record; placement test results; extracurricular activities; election of co-op, international or Military Office Education Programs; health; and need for partial self-support. A schedule of 12 to 18 hours is considered full-time.

All College of Engineering B.S.E. programs require successful completion of a program of 128 credit hours. An average of 16 credit-hours per term allows a student to complete these programs in 8 terms, generally requiring 4 years of study.

### First- and Second-Year Programs

At the time of each student's first advising session, all of the high school and advance placement records may not yet be in the student's file. It is the entering student's responsibility to make certain that all pertinent information is brought to the attention of an Engineering Advising Center (EAC) Advisor. Any changes in test scores or transfer credits will affect final course selection and need to be discussed with an advisor. With complete information available, the advisor and the student will be able to make carefully considered adjustments in course elections for the first-term course schedule.

## First-Year

Assuming the necessary academic preparation and no advanced placement credit, each student will be expected to complete some combination of the following courses:

1. Mathematics 115 and 116 or one of the honors Math sequences.
2. Chemistry 130 and 125/126, or, for some, 130, 210, and 211.
3. Engineering 100
4. Engineering 101 or Engineering 151 (ENGR 151 is an approved alternative to ENGR 101 for all CoE programs)
5. Physics 140 and 141

Additional course information will be available during the advising session.

## Second Year

All students will continue with the mathematics, physics and intellectual breadth courses common to all programs. A second-term student who has selected a degree program should be meeting with that program advisor for third-term elections.

Students who have not selected a degree program should consult the Engineering Advising Center for their course selections.

## LSA Honors-Level Courses

Some math and science courses in LSA are considered honors level equivalents of the core math and science requirements. A student whose record indicates qualifications to perform at an advanced level should discuss this option with an advisor in the Engineering Advising Center.

## Minimum Common Requirements

Each of the degree programs offered by the College includes credit hours that are common to all programs, subject to appropriate adjustment for equivalent alter-

natives. See individual sample schedules for required programs in each program section of this Bulletin. Some programs may have a higher minimum grade requirement for some courses.

## Engineering 100: Introduction to Engineering

Engineering 100 introduces students to the professional skills required of engineers and provides them with an overview of engineering at the beginning of their program. An important component of the course is the real-world engineering project. Important engineering skills developed in Engineering 100 include:

- Preparation of written technical reports and oral presentations to communicate ideas to a broad audience
- Technical problem solving and the creative engineering design process
- Teamwork and team management
- Professional responsibility
- The influence of engineers on society
- Sustainable engineering
- Decision-making skills

Numerous sections are offered both Fall and Winter semesters, featuring a variety of design projects. Students are strongly encouraged to select a section that aligns with their interests. Details on each of the sections can be found at the Engineering 100 website:

<http://eng100.engin.umich.edu>

**Important Note:** You must receive a grade of C- or better in Engineering 100 to fulfill the requirement, however earning a grade lower than C may negatively impact a student's eligibility to declare a program and may require repeating the course. Note: A grade of "C" is required for EECS Programs. Transfer students must complete English composition or a course equivalent to ENGR 100 as a prerequisite for transfer admission. Be sure to consult with the Office of Recruitment and Admissions if you have questions.

## Advanced Placement English Credit

Advanced Placement (AP) English Literature credit is assessed as English departmental credit and can be used towards the Liberal Arts Courses (LACs) of the Intellectual Breadth Requirement. You will not receive credit for Sweetland Writing Center courses.

## Engineering 101: Introduction to Computers and Programming

The objective of Engineering 101 is to introduce students in engineering to the algorithmic method that drives the information age. Algorithms are an organized means to construct the solution of a problem, structured as a well-defined set of steps that can be carried out by a mechanism such as a computer.

Engineering 101 focuses on the development of algorithms to solve problems of relevance in engineering practice and on the implementation of these algorithms using high-level computer languages. It is centered on quantitative and numerical problems that are suited to computational solutions. These often arise as part of larger, more complex problems in engineering practice.

Engineering 101 also ties itself to the introductory physics and math courses, and provides concrete examples of some of the concepts being covered in those classes. Sample problem types might include:

- Finding area and volume
- Simulating statistical processes
- Data analysis
- Physical simulation
- Simulating complex systems with simple rules
- Minimization and optimization
- Computer graphics
- Logic Puzzles

In addition to the problem-solving component, students who take Engineering 101 will learn aspects of the C++ programming languages and be exposed to the MATLAB programming language. C++ and MATLAB are used today in many fields of engineering. MATLAB is also popular and has powerful capa-

bilities for handling computation involving matrices and for visualizing data using 2-D and 3-D graphics. It is important to note that MATLAB will be useful in future math and engineering courses.

Students entering Engineering 101 are not expected to know how to program; this skill will be taught as part of the class. Visit the Engineering 101 website for detailed information on specific sections of the class.

## Engineering 151: Accelerated Introduction to Computers and Programming

Engineering 151 provides an accelerated alternative to Engineering 101 for students either with previous programming experience or with strong motivation and natural intuition for algorithms. It introduces students to the algorithm development, procedural programming concepts and languages covered in Engineering 101 but at a faster pace. It also introduces object-oriented programming, engineering analysis methods and additional topics such as parallel computing or embedded systems. Visit the Engineering 151 website for more detailed information.

**Important notes** (1) You must receive a grade of "C-" or better in Engineering 101 or Engineering 151 to fulfill the requirement, however earning a grade lower than C may negatively impact a student's eligibility to declare a program and may require repeating the course.

## Mathematics

The mathematics courses of 115 (4 credits), 116 (4 credits), 215 (4 credits), and 216 (4 credits) provide an integrated 16-credit-hour sequence in college mathematics that includes analytic geometry, calculus, elementary linear algebra and elementary differential equations.

All students with strong preparation and interest in mathematics are encouraged to consider one of the honors-level math sequences. Qualified and interested students should consult their engineering advisor about these options. It is not necessary to be in an honors pro-

gram to enroll in these courses.

Earning a grade lower than C may negatively impact a students' eligibility to declare a program and may require repeating the course. Experience indicates that students earning a grade of C- or below in a math class may have an insufficient foundation for further study in the quantitative field of engineering.

## Chemistry

Chem 130 (3 credits) with laboratory Chem 125/126 (2 credits) is required by most degree programs. Students will normally elect these courses during the freshman year. The following degree programs require additional chemistry: Biomedical Engineering, Chemical Engineering and Materials Science and Engineering. Students expecting to enter one of these degree programs would normally elect Chem 130 (3 credits), and Chem 210 (4 credits) with laboratory, Chem 211 (1) during the freshman year depending on UM placement exam results.

**Important Notes:** (1) If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution you will have met the Chemistry Core Requirement for CoE. (2) Students who place into Chem 210/211 will not be given credit for Chem 130. (3) Earning a grade lower than C may negatively impact a students' eligibility to declare a program and may require repeating the course.

## Physics

The usual first year schedule includes Physics 140 (4 credits) with laboratory, Physics 141 (1 credit). This course requires completion of Calculus I. A second course, Physics 240 (4 credits) with laboratory, 241 (1 credit), is required by all programs and is normally scheduled in the third term.

**Important Notes:** (1) If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit for Physics 140/141 and 240/241 from another institution you will have met the Physics Core Requirement for CoE. (2) All students with strong preparation

and interest in physics are encouraged to consider the honors-level physics sequence. (3) Earning a grade lower than C may negatively impact a students' eligibility to declare a program and may require repeating the course.

## Transfer credits for Core Math and Science

Students who through use of transfer credit or credit-by-test have fewer than 31 credits total in: math covering the introductory sequence (equivalent to Math 115 – 214/216); introductory physics (Phys 140, 141, 240, 241); and introductory chemistry (Chem 130, 125/126); but have learned the required content as assessed by the math, physics or chemistry department must nevertheless make up the difference in credit hours. This can be done using any number of elective courses in math or science, or, at the discretion of the program advisor, using engineering courses with a mathematical or science focus (e.g. engineering statistics, solid state or nuclear physics, etc.), to make up the total of 31 credits.

Note: ABET Criterion 5 requires all students to have a minimum of 32 credits of college level math and basic sciences, some with an experimental experience. They must also have 48 credits of engineering topics (engineering science and design). All of our programs provide at least one additional credit of math or science within departmental curricula, and in applying this policy for missing math and science credits “basic science” and “engineering science” will be appropriately distinguished.

## Intellectual Breadth

Note: For students matriculated into the College of Engineering before September 2011, the Humanities and Social Science Requirements apply. You can also refer to the previous edition of the Bulletin as appropriate to your year of matriculation.

For students matriculated for Fall term 2011 and after the following requirements apply:

It is important that our students learn about modes of

thought and areas of human accomplishment beyond the purely technical. This breadth can be designed by students to provide context to their engineering work by learning about human modes of thought, the structure and history of the human societies that they serve as engineers, how humans behave and interact, and how humans express their aspirations in the arts, literature and music. This breadth will help students to understand the impact of engineering solutions in a global, economic, environmental and societal context. This breadth makes our students more flexible, creative and better able to work with diverse groups.

We cannot precisely define all of these possibilities for every student so we strive to create a broad intellectual opportunity for students to pursue their interests both beyond and within engineering. Students are encouraged to use these credits in a coherent way to build a foundation of understanding in both the liberal arts and other disciplines that might contribute to their development of creativity or professional foundation.

The College of Engineering requires all students to complete 16 credits of intellectual breadth courses, and between 9 and 16 credits of general electives (depending on engineering major). Each student selects 16 credits of intellectual breadth courses - subject to these rules:

- **Humanities:** At least 3 credits of Humanities classes marked HU in the LSA course guide; credit by test cannot be used to meet this requirement.
- **Professional & Creative Development Courses (PCDC):** no more than 4 credits of PCDC (defined below).
- **Liberal Arts Courses (LACs):** The remainder of the 16 credits are drawn from any of the LACs (defined below).
- At least 3 credits in the Humanities or LACs must be at the 300 level or higher.

The currently approved numbers of general elective hours for each degree program are:

<b>Degree Program</b>	<b>Credits of General Electives</b>
Aerospace Engineering	9
Biomedical Engineering	11
Chemical Engineering	12
Civil and Environmental Engineering	12
Climate and Meteorology (pending final stage of approval)	11
Computer Engineering	13-16
Computer Science	15
Data Science	15
Earth System Science and Engineering	11
Electrical Engineering	11
Engineering Physics	12
Environmental Engineering	12
Industrial and Operations Engineering	9-12
Materials Science Engineering	12
Mechanical Engineering	9
Naval Architecture and Marine Engineering	9
Nuclear Engineering and Radiological Sciences	10
Space Science and Engineering (pending final stage of approval)	10

## Definition of Liberal Arts Courses

Liberal Arts Courses (LACs) are intended to give students the broader education in qualitative critical thinking and human society that can give context to their engineering practice and to their contributions as citizens. For the sake of the College of Engineering's intellectual breadth requirements, Liberal Arts Courses (LACs) are meant to exclude mathematics and science courses, as well as some courses that are considered preparatory to the CoE experience. Student's elections of LACs are expected to be in this spirit. The precise operational definition of a LAC is:

- Any course offered by any UM-Ann Arbor unit marked as HU or SS in the LSA course guide is considered a LAC.
- For a course not marked as HU or SS but offered under one of the LSA subjects listed below, it is considered a LAC if it is not marked BS, NS, QR/1 or QR/2 in the LSA course guide.
- In addition, if a course is not marked HU or SS in the LSA course guide, but is marked EXPERIENTIAL or INDEPENDENT, then explicit permission of a CoE program advisor is needed to use it for a LAC course.
- Study Abroad Courses (STDABRD) might be counted as LACs, but only by explicit permission of a CoE program advisor. This is not meant to discourage study abroad, but reflects the broad nature of the STDABRD designation, which otherwise defies classification. As described below, transfer credit from US and foreign institutions may also be accepted as LACs credit.
- Please note that not all courses listed under the departments or divisions in the table are HU. Students must be sure that the courses they choose have the HU marked in the LSA Course Guide and be 300 and above.

Note: Chemical Engineering, Civil & Environmental Engineering, Mechanical Engineering and

Arabic, Armenian, Persian, Turkish & Islamic Studies (AAPTIS)	Ancient Civilizations & Biblical Studies (ACABS)	American Culture (AMCULT)
Anthropological Archaeology (ANTHRARC)	Cultural Anthropology (ANTHRCUL)	Armenian Studies (ARMENIAN)
Asian Studies (ASIAN)	Asian Languages (ASIANLAN)	Bosnian, Croatian, & Serbian (BCS)
Afroamerican & African Studies (CAAS)	Classical Archaeology (CLARCH)	Classical Civilization (CLCIV)
Classical Linguistics (CLLING)	Complex Systems (CMLXSYS)	Communication Studies (COMM)
Comparative Literature (COMPLIT)	Comprehensive Studies Program (CSP)	Czech (CZECH)
Dutch (DUTCH)	Economics (ECON)	English (ENGLISH)
Environment (ENVIRON)	French (FRENCH)	Geography (GEOG)
German (GERMAN)	Greek (GREEK)	Great Books (GTBOOKS)
History of Art (HISTART)	History (HISTORY)	Hebrew & Jewish Cultural Studies (HJCS)
College Honors (HONORS)	International and Comparative Studies (CICS)	Italian (ITALIAN)
Judiac Studies (JUDIAC)	Latin American & Caribbean Studies (LACS)	Latin (LATIN)
Lloyd Hall Scholars (LHSP)	Linguistics (LING)	Medieval & Early Modern Studies (MEMS)
Middle Eastern & North African Studies (MENAS)	Modern Greek (MODGREEK)	Museum Studies (MUSEUMS)
Organizational Studies (ORGSTUDY)	Philosophy (PHIL)	Polish (POLISH)
Political Science (POLSCI)	Portuguese (PORTUG)	Psychology (PSYCH)
Russian, East European & Eurasian Studies (REEES)	Religion (RELIGION)	Romance Languages & Literatures (ROMLANG)
Romance Linguistics (ROMLING)	Russian (RUSSIAN)	Screen Arts & Culture (SAC)
South Asian Studies (SAS)	Scandinavian (SCAND)	Slavic Linguistics, Literary Theory, Film & Surveys (SLAVIC)
Sociology (SOC)	Spanish (SPANISH)	Southeast Asian Studies (SEAS)
Ukrainian (UKRAINE)	Women's Studies (WOMENSTD)	Yiddish (YIDDISH)

Materials Science & Engineering each requires one course in economics. This economics requirement can overlap with the LAC requirement.

## Professional or Creative Development Courses (PCDC)

Professional and creative development courses offer a student the opportunity to build on non-engineering and non-technical courses to develop their creativity and professional capabilities as engineers. PCDC courses include any one course (no more than 4 credits) from the following subjects in the indicated units, provided they are not marked BS or NS in the LSA course guide:

- Taubman College of Architecture and Urban Planning: Architecture (ARCH), Urban Design (UD), Urban Planning (UP).
- School of Art & Design (ARTDES, UARTS)
- Ross School of Business: Accounting (ACC), Business Administration (BA), Business Economics and Public Policy (BE), Entrepreneurial Studies (ES), Law History & Communication (LHC), Marketing (MKT), Management and Organization (MO), Strategy (STRATEGY)
- School of Music, Theatre & Dance: Music Composition (COMP), Musicology (MUSICOL), Music Theory (THEORY), Theater & Drama (THREMU)
- School of Natural Resources and Environment (NRE)
- Ford School of Public Policy (PUBPOL)
- School of Public Health: Health Behavior & Health Education (HBEHED), Health Management & Policy (HMP).

## Transfer Credit and Credit by Test

College course credit transferred as any course meeting these requirements will be accepted as an HU, LAC or PCDC. Courses transferred as departmental credit can be accepted at the discretion of a CoE program advisor. Courses evaluated for transfer credit may also be marked HU or SS, in which case they are considered humanities or liberal arts courses, as described above.

In addition, courses transferred as English Composition (ENGCMPTC) also count as an LAC. Credit by test (e.g. Advanced Placement, A-Level and International Baccalaureate) can be used to satisfy any of these requirements except for the 3 credit humanities requirement. Foreign language credit by test at the 200-level or higher can count toward the LAC requirement but not the 3-credit humanities requirement. Foreign language credit by test at the 100-level can be used for General Electives only. In addition, language credit by test is limited to 8 credits.

## Credit for Foreign Language

The CoE will grant credit for students passing a language placement test offered by the College of LSA provided the student has previously studied that language in a course in their secondary education. This will be verified using their high school or college transcripts. AP language credit will also be granted.

"Study of a language in a course" means a student took coursework designed to teach them the fundamental vocabulary, grammar, pronunciation, and writing system of that language as a foreign language, as opposed to a class in literature, argumentative or essay writing or creative writing in a language whose fundamentals they already knew.

The CoE values the study of language, so even when credit might not be granted, students are encouraged to take any language placement test for which they may be qualified, so that they can be properly placed in a more advanced language course.

## General Electives

General electives are intended to allow students to explore any dimension of intellectual endeavor that they elect, in both technical (including engineering) and non-technical fields. This requirement can be met by any course offered by the UM Ann Arbor, subject to the following restrictions, or by transfer credit subject to the same restrictions in spirit.

Restrictions: Courses that require tutoring of other students enrolled in courses are limited to a maximum of 3 credits, with the exception of Physics 333 & Physics 334 which are both allowed for a maximum of 6 credits.

All undergraduate degree programs in the College of Engineering will accept credits earned in 200-, 300- and 400-level courses in military, naval or air science.

Tutorial courses are not acceptable for credit of grade points but will be included on the student's official record.

## Degree Options

### Undergraduate Engineering Degrees

The College of Engineering offers 15 undergraduate programs of study, all of which lead to a Bachelor of Science in Engineering (B.S.E.) degree. Twelve of these programs have specialized accreditation by ABET.

The available undergraduate degree programs and the major department responsible for each are:

**EAC:** These programs are accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>.

**CAC:** This program is accredited by the Computing Accreditation Commission of ABET, <http://www.abet.org>.

Each of the undergraduate degree programs has core requirements that are common to all Programs. These common requirements include 16 credits of math (calculus, differential equations and linear algebra), 15 credits of science (physics and chemistry), 16 credits of Intellectual Breadth and 8 credits of first year engineering courses. In addition, each program has between 9 and 15 credits of general electives. The remaining credit hours are specific to

Degree Program	Major Department	ABET Accreditation
B.S.E. in Aerospace Engineering	Aerospace Engineering (AERO)	EAC
B.S.E. in Biomedical Engineering	Biomedical Engineering (BME)	EAC
B.S.E. in Chemical Engineering	Chemical Engineering (ChE)	EAC
B.S.E. in Civil Engineering	Civil and Environmental Engineering (CEE)	EAC
B.S.E. in Climate and Meteorology	Climate and Space Sciences and Engineering (CLASP)	No
B.S.E. in Computer Engineering	Electrical Engineering & Computer Science (EECS)	EAC
B.S.E. in Computer Science	Electrical Engineering & Computer Science (EECS)	CAC
B.S.E. in Data Science	Electrical Engineering & Computer Science (EECS)	No
B.S.E. in Electrical Engineering	Electrical Engineering & Computer Science (EECS)	EAC
B.S.E. in Engineering Physics	Nuclear Engineering and Radiological Sciences (NERS)	No
B.S.E. in Environmental Engineering	Civil and Environmental Engineering (CEE)	EAC
B.S.E. in Industrial and Operations Engineering	Industrial and Operations Engineering (IOE)	EAC
B.S.E. in Materials Science and Engineering	Materials Science and Engineering (MSE)	EAC
B.S.E. in Mechanical Engineering	Mechanical Engineering (ME)	EAC
B.S.E. in Naval Architecture and Marine Engineering	Naval Architecture and Marine Engineering (NAME)	EAC
B.S.E. in Nuclear Engineering and Radiological Sciences	Nuclear Engineering and Radiological Sciences (NERS)	EAC
B.S.E. in Space Sciences and Engineering	Climate and Space Sciences and Engineering (CLASP)	No

the B.S.E. degree program that the student elects to pursue.

Many of the courses required for one program may be used to meet the requirements of another. This opportunity to obtain additional undergraduate engineering degrees must be discussed with the pertinent program advisor. See "Requirements for an Additional Bachelor's Degree."

## Declaring One of the Degree Programs

To give students the opportunity to explore the numerous engineering degrees offered by the College, first year undergraduate engineering students not transferring from another institution of higher education enter the College without declaring a specific engineering major. None of the majors require any 100-level courses to be taken by a student other than those in the common engineering, math and science core. Students are urged to declare a specific engineering major by the start of their 3rd term of enrollment. Undeclared students cannot register for a 4th term in the College unless they have met with their advisor and developed a plan to select and declare a major within a reasonable time. This plan can be developed in coordination among the EAC advisors and departmental program advisors.

Criteria to declare a degree program are described in the Rules section of the bulletin: <http://engin.umich.edu/college/academics/bulletin/rules/registration>

## Dual Baccalaureate Degree Opportunities

Students with interest in more than one program offered by the College may work for an additional bachelor's degree concurrently if they plan their course elections carefully. Students will find that it is possible to satisfy the subject requirements of both programs in a minimum amount of time by conferring early with the respective program advisors. Approval by involved departments is required. See the Rules section of the

Bulletin: <http://engin.umich.edu/college/academics/bulletin/rules/graduation>. The College generally recommends that students consider pursuing some of the many co- and extra-curricular activities offered as an alternative to a second CoE degree.

Opportunities to obtain an additional bachelor's degree in the College of Literature, Science, and the Arts, the School of Business Administration, the School of Music and other academic units are also available under Multiple Dependent Degree Program options and are described below. These programs may take 11 to 12 terms to complete because of the differences in degree requirements between the degrees offered in different colleges.

## Multiple Dependent Degree Programs (MDDP)

### College of Engineering and the College of Literature, Science, and the Arts

Students enrolled for a bachelor's degree in the College of Engineering or the College of Literature, Science, and the Arts (LS&A) may obtain the degrees in both colleges simultaneously by enrolling in the MDDP Program that has been established by the two colleges, and by fulfilling the requirements as outlined below. This program has been developed to make it convenient for students to obtain a broader education than would normally be possible by enrolling in only one college. It is particularly advantageous for students who wish to develop some depth of understanding in both the technically oriented studies offered in the College of Engineering and the physical, natural, or social sciences and humanities available in LS&A. Such a combination can provide a truly liberal education for the 21st century and should be excellent preparation for meeting the challenges of modern society, which involve, to an ever-increasing extent, both technical and sociological issues.

## Program Requirements

Candidates for a Bachelor of Science in Engineering (B.S.E.) in the College of Engineering combined with a Bachelor of Arts (B.A.) in LS&A must:

- satisfy the requirements of one of the degree programs in the College of Engineering;
- take a minimum of 90 credit hours of work in LS&A, satisfy the distribution requirements of LS&A, and fulfill the concentration requirements for one of the LS&A programs; and
- have a cumulative grade point average of 2.00 or higher.

Candidates for a Bachelor of Science in Engineering (B.S.E.) in the College of Engineering, combined with a Bachelor of General Studies (B.G.S.) in LS&A must:

- satisfy the requirements of one of the degree programs in the College of Engineering;
- take a minimum of 90 credit hours of work in LS&A of which 40 credit hours must be for courses numbered 300 or higher and are passed with a grade of "C" or higher, with no more than 15 of these 40 credit hours to consist of courses in any one department; and
- have a cumulative grade point average of 2.00 or higher.

Students transferring to the University of Michigan with advanced standing and entering a MDDP Program must complete a minimum of 60 credit hours of work in LS&A in residence.

All students should consult the program advisors in their field of specialization in every college each term to develop an optimum set of courses for the particular combination of fields of specialization of interest to them.

In general, advisors working with students in the MDDP Program will, whenever possible, attempt to minimize the total number of courses required by recommending those that will contribute toward fulfilling requirements in both colleges. Thus, many of the courses needed to fulfill the requirements in mathematics,

chemistry and physics in the College of Engineering will contribute toward fulfilling natural science distribution requirements and prerequisites for concentration in fields such as astronomy, chemistry, geology-mineralogy, mathematics and physics in LS&A.

Likewise, requirements in humanities and liberal arts courses for the College of Engineering can be selected from courses taken to fulfill distribution requirements in LS&A. In this way, it is usually possible for students carrying average loads of 16 credit hours per term to complete the requirements of the MDDP Program in 10 or 11 terms.

In order to ensure that the courses selected apply effectively and efficiently to both degrees, students must assume responsibility for maintaining contact between their two advisors. They should become thoroughly familiar with the general regulations and procedures of both colleges and with the academic requirements and course offerings in both fields of specialization as set forth in the Bulletin of each college. If unusual difficulties or special problems arise, students should consult the MDDP Program advisors who will work with the students and their faculty advisors in attempting to find a solution.

## Regulations

The following regulations for enrollment will apply:

1. Students initially enrolled in either the College of Engineering or LS&A may enter the MDDP Program.
2. To be qualified for admission, students normally should have completed 30 credit hours of the appropriate course work. LS&A students must have an overall grade point average equal to, or higher than, the current minimum grade point average for cross-campus transfer for the particular engineering degree sought. Engineering students must have an overall grade point average of at least 2.7.
3. Students considering this program must obtain the signature of the College of Engineering Registrar to apply for admission and to establish advising procedures as soon as their interests are firmly established, preferably by the end of the first year. Upon

applying for admission, students must choose a field of specialization in each college. Application for admission must then be approved by the Associate Dean's Office of each college and by the academic advisor in each of these fields of specialization.

4. After being admitted to this program, students will continue to register in the college in which they first enrolled, and that college will be responsible for maintenance of their primary academic records.
5. Students participating in this program should consult with the program advisor for their field of specialization in each college prior to registration each term, to obtain approval of course elections. To be permitted to continue in the MDDP Program, students must satisfy the requirements of both colleges with regard to good scholastic standing.
6. Students in good scholastic standing who wish to withdraw from the MDDP Program may continue to enroll for a single degree in their original college. If they wish to transfer, they may do so provided their record is acceptable to the other college. For instructions regarding transfers, students should consult the appropriate officials of the college in which they are registered. Students not in good scholastic standing will normally remain in the college in which they initially enrolled and be subject to the rules of that college.
7. Upon satisfying the program requirements of both colleges, students will receive both degrees on the same date. At the beginning of the term in which they expect to graduate, they must apply for graduation through Student Business in Wolverine Access in each college.

### **College of Engineering and the Ross School of Business**

Students originally enrolled in an undergraduate degree program in the College of Engineering who are admitted to the Ross School of Business may obtain degrees in both simultaneously by enrolling in the MDDP Program that has been established between the two. This program is designed to allow students to develop a course of study that offers broader academic opportunities than would normally be possible by enrolling in

only one college. These combined degrees are open to students initially enrolled in Engineering who are accepted into the Ross School of Business BBA program.

In order to ensure that the courses selected apply efficiently to both degrees, students must maintain coordination between their College of Engineering and Business School advisors. The students must consult the program advisors in their degree disciplines for specific requirements for the appropriate degrees.

Degree requirements must be met for both colleges simultaneously to be eligible to receive the appropriate undergraduate degrees. Upon satisfying the program requirements of both colleges, students will receive both degrees on the same date. At the beginning of the term in which they expect to graduate, students must apply for graduation through Student Business in Wolverine Access in each college/school and must ask their program advisor in each unit to submit an appropriate notification of their eligibility for graduation to the appropriate office in the College or School.

Students who are admitted to the BBA program and wish to pursue the MDDP must make this clear to both colleges. Unless this is done, admission to the BBA program can result in the student being disenrolled from the College of Engineering. Like most other dual degree programs, this program will generally require 11 to 12 terms to complete both degrees.

### **College of Engineering and the School of Music, Theatre and Dance**

This program is designed to allow students to develop a course of study that offers broader academic opportunities than those offered by the College of Engineering or the School of Music, Theatre and Dance individually.

The program is intended for students who seek the technical studies associated with the College of Engineering in combination with the professional training in applied or academic studies associated with the School of Music, Theatre and Dance. These dual degrees are open to students enrolled in the College of Engineering or the School of Music, Theatre and Dance. They lead to concurrent bachelor's degrees from both units, and

are intended for students who were admitted as first-year students to both units.

Each student should consult faculty advisors in both engineering and music to develop the best plan of study. Primary responsibility for planning the academic program and continued contact with academic advisors in the two fields rests with the student, who is also responsible for becoming familiar with the academic policies and procedures of both units and the academic requirements in both fields as described in the Bulletins of both the College of Engineering and of the School of Music, Theatre and Dance. The student is responsible for maintaining contact with the appropriate engineering department (or, if undeclared, the Engineering Advising Center) in order to receive proper advising for course selection, etc.

Candidates for the combined Bachelor of Science in Engineering (B.S.E.) in the College of Engineering and appropriate degree (B. Mus., B.M.A., or B.F.A.) in the School of Music, Theatre and Dance must:

- complete one of the degree programs in the College of Engineering;
- complete one of the degree programs in the School of Music, Theater and Dance (usually 90 credits); and
- maintain a minimum cumulative grade point average of 2.00 and good scholastic standing in both the College of Engineering and the School of Music, Theatre and Dance.

It is usually possible for students electing 16-17 credits per term to meet all requirements in 11 or 12 terms.

Students interested in this program will be admitted as first-year students into both the College of Engineering and the School of Music, Theatre and Dance.

Students who are dually enrolled and decide not to pursue a degree from the School of Music, Theatre and Dance do not have to reapply for admission to the College of Engineering.

## College of Engineering and the Stamps School of Art and Design

Students enrolled in an undergraduate degree in the College of Engineering (CoE) or School of Art & Design (A&D) may obtain degrees from both simultaneously by enrolling in the MDDP Program that has been established between the two. This program is designed to allow students to develop a course of study that offers broader academic opportunities than would normally be possible by enrolling in only one unit or the other.

Students are required to meet regularly with advisors in both A&D and CoE to review specific course requirements and to develop a plan of study. It is the student's responsibility to develop a strategy for completing the degree requirements for both undergraduate degrees, as well as learn the academic policies for both units as described in the A&D Undergraduate Student Handbook and the CoE Bulletin. In order to remain in good academic standing in both A&D and CoE, MDDP students must maintain a minimum cumulative grade point average of 2.0, and must follow additional academic policies of both academic units.

Degree requirements must be met for both programs simultaneously to be eligible to receive the appropriate undergraduate degrees. Candidates must complete a Bachelor of Science in Engineering (B.S.E.) in the College of Engineering, and a Bachelor of Fine Art (B.F.A.) in the School of Art & Design. Upon completion of the requirements of both academic units, MDDP students are granted concurrent degrees. If a requirement for either degree is lacking, neither degree will be conferred. The student must submit a separate Diploma Application through Wolverine Access to each unit along with any additional required documents.

## Combined Bachelor's/Master's Programs

In many fields, the Master's degree provides substantial benefits for engineering graduates seeking employment. The College of Engineering therefore offers two

different options for those students who wish to obtain a combined Bachelor's and Master's degree. Both of these options are academically demanding and require recommendation from the student's undergraduate program advisor. The combined programs in the College of Engineering include the Sequential Undergraduate/Graduate Studies Program (SUGS) and the Engineering Global Leadership Honors Program (EGL).

## Sequential Undergraduate/ Graduate Study (SUGS)

The five-year Sequential Undergraduate/Graduate Study (SUGS) Program permits students who enter the program in the first term of their senior year to receive the B.S.E. and M.S.E. degrees (or the B.S.E. and M.Eng. degrees) upon completion of a minimum of 149 credit hours (depending on program). The baccalaureate may be awarded upon completion of the undergraduate requirements or concurrently with the Master's degree. Students apply to the SUGS program at the end of their junior year or early in the first semester of their senior year. Consult with the appropriate graduate departmental coordinator for specific deadlines. Recommendation from the appropriate Undergraduate Program Advisor is required, and the standard department graduate admission process is used. SUGS admissions requirements will vary and each program will have a minimum GPA for admission; interested students should contact the department in which they would like to pursue graduate study. For a list of SUGS programs by department, please refer to the degree program listings under the B.S.E. home department.

## Honors Program

The College of Engineering Honors Program identifies highly talented students who demonstrate extraordinary academic ability, intellectual curiosity and clear potential to make a difference as a leader in their field. Honors Program students pursue challenging coursework and enrich their academics through significant engagement beyond the classroom. The program is intended to inspire and enable highly motivated students to reach

beyond the traditional curriculum in both breadth and depth.

Students must choose a capstone experience area, such as research, entrepreneurship, design, global business/operations or public service, and are required to develop academic breadth and leadership experience:

## Core Academic Requirements

- Maintain a cumulative GPA of 3.6.
- Complete 9 credits of advanced electives in an identified **focus area**, selected in consultation with the capstone supervisor and honors program faculty advisor. These credits cannot be required by the minor or specifically required by the major. They can include technical elective credit.
- Complete an **honors capstone experience** (e.g. a project, research experience, thesis, etc.).

This capstone can draw on the major design experience, but must extend beyond that experience to demonstrate the student's individual scholarly or professional work. Each student will identify a capstone supervisor to oversee this experience. See below for more details.

## Academic Breadth and Leadership Requirements

- Participate in an honors seminar each year. The honors seminar will center on leadership development, community building and discussion related to the student's focus area. Portions of the seminar will be required for all honors students, while other topics offered will be specific to a student's focus area. Existing seminars and colloquia will also be leveraged.
- Develop academic breadth through the completion of a UM minor.

## Additional Rules

- Courses counting toward the Honors Program cannot be elected as pass/fail.
- Students must be admitted to the program at least a year and a half before they plan to graduate, so that they can participate in leadership seminars and community building experiences.
- The honors program faculty advisor may approve specialized curriculum plans in both the core and breadth components of the Honors Program.

## Admission criteria and process

In order to be admitted, students must,

- Have completed two full-time terms at UM (or, for transfer students, one term).
- Have declared a major within the College of Engineering.
- Maintain a 3.6 minimum GPA.
- Submit an Honors Program application, including essays, an academic plan, two recommendation forms, and a resume.
- Be interviewed and recommended for admission by an admission committee (comprised of the honors program faculty advisor, a representative of the Faculty Advisory Board, a staff advisor and a student representative).

## Honors capstone process and completion

Each student will identify a capstone supervisor (typically a CoE faculty member) to oversee the honors capstone experience. Honors capstone proposals must be approved by the student's capstone supervisor, and the honors program faculty advisor; these parties will ensure that sufficient rigor is present in the proposed project. Students should meet regularly with their capstone supervisor to assess progress and establish goals throughout the duration of the project. The project will be considered complete once it has been publicly presented and the capstone supervisor and honors program

faculty advisor have certified its completion. The Faculty Advisory Board will work with the honors program faculty advisor to establish criteria for ensuring the quality of capstone projects. Students must display their capstone project at a public forum, typically CoE Design Expo, and the project must be published online in the Honors Capstone Library.

## Program completion

Students who complete the program will graduate "with honors" and will receive a notation on their transcript and diploma.

## Engineering Global Leadership Honors Program

The Engineering Global Leadership (EGL) Honors Program is a specialization of the Honors Program. Employers tell us that the inability of many professionals to communicate across cultures and across the engineering and business boundary is one of the greatest barriers to global competitiveness. The EGL Honors Program prepares students to bridge these gaps. The business coursework offers a focus in operations management, along with the basics of marketing, accounting and finance. Completion of the International Minor for Engineers exposes students to the language, history and customs of another part of the world. The success of EGL graduates confirms that this preparation is in high demand. Students admitted to the CoE Honors Program who choose a global business/operations focus are eligible to apply to EGL.

The EGL Honors Program requires the completion of the following:

- All requirements of the College of Engineering Honors Program
- The International Minor for Engineers (simultaneously fulfills CoE Honors required minor)
- 9 credits of Technology and Operations coursework in the Ross School of Business, as required by the Tauber Institute for Global Operations (simultaneously fulfills CoE Honors required focus

area)

- The Tauber Institute for Global Operations Team Project (simultaneously fulfills CoE Honors Capstone Experience)
- A UM College of Engineering Master's degree
- 6 credits of elective coursework in the Ross School of Business (typically completed during the Master's program)

### College of Engineering Honors Program

Email: [coehonors@umich.edu](mailto:coehonors@umich.edu)

Website: [honors.engin.umich.edu](http://honors.engin.umich.edu)

## Cooperative Education

The Cooperative (co-op) Education Program assists students in pursuing an optional program of work while studying in the College of Engineering. Students can find co-op positions independently or by using ECRC resources such as ENGenius.Jobs, a web-based recruiting system. A co-op search is just as any other job search—students apply to organizations and then may be invited to interview. Students must work a minimum of thirty hours per week for a minimum of six weeks while on a co-op work assignment.

Full-time students are eligible to participate in the Cooperative Education Program. A student can be enrolled in the Cooperative Education Program for a single semester or multiple semesters. Co-op students participating in the program for multiple semesters may tailor their work assignments for consecutive terms, for example May to December, January to August or alternate work and school semesters.

### Finding a Position through the ECRC

The ECRC displays co-op positions on its web-based recruiting system, ENGenius.Jobs. Employers provide the ECRC with a job description and requirements for the co-op position. Students should submit their resumés via instructions on ENGenius.Jobs. The employer will review the resumes and select students to interview on campus, at the employer location, or by telephone.

Final selection of a student for co-op work assignment

is a mutual agreement entered into by the employer and the student, and the student becomes an employee of that company. Note that the ECRC does not guarantee a co-op position for every applicant; however, every effort is made to assist students finding appropriate positions.

### Work Assignment

While working a co-op assignment, students are subject to the rules and regulations of the employer. Work assignments must be at least 30 hours per week for a minimum of six weeks. The employer will evaluate the student's performance at the end of the co-op work term and forward the evaluation to the Engineering Career Resource Center. Co-op students are also required to complete and return an evaluation report of their learning experience to the ECRC.

### Getting Started

Students interested in the co-op programs should contact or visit the ECRC to pick up a co-op packet and discuss the rules and regulations of the Cooperative Education Program with the co-op coordinator. Co-op students are registered in ENGR 400 while on a co-op work assignment; registration is by permission only and must be completed through the ECRC.

### Engineering Career Resource Center

230 Chrysler Center

Ann Arbor, Michigan 48109-2192

Phone: (734) 647-7160

[career.engin.umich.edu](http://career.engin.umich.edu)

## Education Abroad

The International Programs in Engineering (IPE) office provides support for a variety of education abroad opportunities for CoE students. International experiences for CoE students can take many forms from traditional study abroad for academic credit to work/internship abroad, research, volunteer and co-curricular international projects in conjunction with CoE student organizations.

### College of Engineering Study Abroad

IPE sponsors full-year, semester and summer study abroad programs for academic credit. CoE students

may choose from programs taught in English or foreign languages, depending on their skill levels and prior experience. IPE staff members advise students about program options and provide assistance with applications and course approvals. Undergraduate students in good academic standing are eligible to participate in College of Engineering study abroad programs. Additional requirements may apply; please see the IPE website, <http://www.ipe.engin.umich.edu> for program specific admission guidelines.

Most forms of student financial aid can be applied to College of Engineering study abroad programs. IPE offers walk-in advising Monday-Friday from 1:00pm to 4:30pm, no appointment needed.

### **International Programs in Engineering**

245 Chrysler Center  
Ann Arbor, MI, 48109-2092  
Phone: (734) 647-7192  
Email: [ipe-office@umich.edu](mailto:ipe-office@umich.edu)

### **Campus-Wide Study Abroad Programs**

CoE students may also participate in study abroad programs sponsored by other UM Schools and Colleges. The LS&A Center for Global & Intercultural Study (CGIS) offers a broad range of study abroad programs that are open to CoE students. Students considering a CGIS study abroad program must consult the International Programs in Engineering office to determine applicability of credit to engineering degree requirements. For CoE students, grades for STDABRD credit programs will generally not be calculated into the cumulative GPA, but for STDABRD courses taught by UM faculty, students may petition for an exception to this rule. Campus-wide study abroad programs can be found in M-Compass, <https://mcompass.umich.edu>.

### **Non-UM Study Abroad Programs**

Students studying abroad on a program that is not sponsored by a UM office may earn transfer credit if the program sponsor is a fully accredited institution of higher learning, an official transcript is furnished by that institution, and the course is evaluated for transfer credit. Students considering non-UM study abroad must register their plans in the CoE travel registry prior to departure and consult with the IPE Office about

course approvals and transfer credit. CoE Registry, <http://www.ipe.engin.umich.edu/registry>

### **Work/Internship Abroad**

IPE in partnership with the Engineering Career Resource Center (ECRC) assist students pursuing a work or internship position abroad. Overseas work experience can enhance your future job prospects, provide exposure to foreign business environments and help you understand global trends in the engineering profession. Whether it's an internship with a multinational corporation or a research position in a foreign laboratory, overseas employment presents unique opportunities for professional development.

Students should meet with a Career Counselor from ECRC or an International Programs Advisor from IPE to discuss work abroad and internship search strategies. The ECRC can also critique resumes and provide resources to help adapt application documents for a non-U.S. audience. More information can be found online at <http://workabroad.engin.umich.edu>.

### **International Travel with CoE Student Organizations**

IPE in partnership with the CoE Office of Student Affairs provides support and assistance for student organizations that travel internationally. Beyond traditional study and work abroad opportunities, the College encourages student organizations to consider developing international experiences for their members. International travel can be a great way to maximize an organization's impact and to build leadership skills for their members. Check M-Compass, <https://mcompass.umich.edu>, to see where CoE student organizations are currently engaged globally. There are many resources available to student organizations who want to travel internationally, please visit [http://studentorgs.engin.umich.edu/students\\_leadership\\_international-experiences-travel](http://studentorgs.engin.umich.edu/students_leadership_international-experiences-travel) for more details.

## Undergraduate Research Opportunity Program (UROP)

The UROP program enables students to work one-on-one or as part of a small group of students on research projects conducted by faculty and research scientists all across campus. Students will choose research projects by looking through a catalog of over 1000 research projects and will then interview for the positions with the faculty researcher. Students spend an average of nine to ten hours per week working on their research projects. Students can participate in the program for academic credit through ENGR 280 if working on an engineering project or UC 280 for projects outside of the College of Engineering. Students receive one credit per three hours of work per week. Most students register for three credits, which is a nine-hour commitment per week. Students with work-study awards in their financial aid package can also participate for work-study support. All students participating in the program are also required to attend a biweekly research peer seminar, meeting monthly with a peer advisor, read research-related articles (e.g., research ethics, research in specific disciplines, research methods) and complete short journal assignments.

For more information and to access the online application, please visit the UROP website at <http://www.lsa.umich.edu/urop>.

## CoE Minors and Supplemental Studies

### Climate and Space Sciences and Engineering Minor

The primary goal of the Climate and Space Sciences and Engineering (Climate & Space) Minor is to provide exposure to research opportunities in atmospheric, climate and space science and engineering for those students who wish to work in the geoscience or space industry but are not majoring in Climate and Space Sciences and Engineering. The secondary goal is to in-

crease awareness of the Climate and Space Sciences and Engineering and the educational and research opportunities within Climate & Space within the College of Engineering as a whole. This program is for undergraduate students in the College of Engineering.

Students must have:

- Registered no later than the last day to add courses for the semester in which they complete the last courses for the minor,
- Submitted his or her program of study for the minor to the Climate & Space undergraduate advisor.
- Attained a minimum GPA of 2.0 in the designated courses
- Completed the Climate & Space Minor as part of a degree program

### Requirements

#### A. Prerequisite coursework:

Math (8 Credits)

MATH 115 ,and

MATH 116;

Physics: (10 Credits)

PHYSICS 140, 141, and

PHYSICS 240, 241;

#### B. Required Coursework (9 credits)

One course from SPACE 101 (Introduction to Rocket Science – 3 credits),

CLIMATE 102 (Extreme Weather – 3 credits), SPACE 103 (Introduction to

Space Weather – 3 credits) or CLI

MATE 105 (Our Changing Climate – 3 credits)

CLIMATE 320/SPACE 320 (Earth and Space System Evolution, 3 credits)

CLIMATE 321/SPACE 321 (Earth and Space System Dynamics, 3 credits)

#### C. Core Focus Courses (minimum 6 credits)

At least two courses from one of the following tracks:

- Meteorology
- Climate Science and Impacts Engi-

neering

- Space Sciences
- Space Engineering

For additional information go to:

<http://aoss.engin.umich.edu>

Effective 9/1/15, <http://clasp.engin.umich.edu>

## International Minor for Engineers

The global business environment demands engineers who are able to combine technical expertise with international understanding. Today's graduates work in multinational teams, create products for a global marketplace and solve problems that cross national borders and cultures. The International Minor for Engineers addresses a core set of skills and experiences that will prepare CoE graduates for the challenges of the global engineering profession.

- **Foreign Language Requirement (6-10 credits)**  
In total, four semesters of the same college-level language are required (cannot be English or dead/extinct language). May be satisfied by UM courses, transfer credit, or intensive language program abroad. Non-native English speakers may use their native language, but they must be able to demonstrate proficiency on their UM transcript.
- **International Courses (9-15 credits)**  
These requirements include at least two-courses on non-U.S. cultures or societies plus a comparative perspectives course. At least one of these courses must be listed at the 300-level or above.
- **ENGR 260: Engineering Across Cultures (1 credit)**  
This course explores the role of local culture in identifying and solving engineering problems. Lectures, guest speakers and group discussions focus on intercultural knowledge and case studies of engineering projects in a global context. The final course project is a culture-specific needs assessment of a technical project outside the United States.
- **Required International Experience**  
Students may satisfy this requirement through study, work, research or organized volunteer work abroad, spanning a minimum of six contiguous weeks within the same country outside the U.S. All

international experiences must be approved by the International Programs Faculty Advisor. International students may not satisfy this requirement through programs in their home countries.

In total, the minor requires 16-20 credits to complete. This assumes that students meet a two-semester (or equivalent) foreign language pre-requisite before declaring the minor. More information can be found at <http://intlminor.engin.umich.edu>.

## Minor in Electrical Engineering (EE)

A Minor in Electrical Engineering (EE), offered through the EECS Department, is open to undergraduate students. LSA requirements are described in the LSA Bulletin and interested students should consult with both LSA and CoE Electrical Engineering Advisors. CoE students may declare the EE minor provided they have met the following eligibility requirements:

1. Students must have an average of 2.0 or higher at time of declaring the EE minor
2. Students must have completed all Math and Physics prerequisites with a grade of C or better
3. Students pursuing a major in Electrical Engineering (EE), Computer Engineering (CE) and Computer Science (CS -- including LSA/CS) are not eligible for the EE minor

The EE minor is completed in 15 credit hours; at least one elective must be at the 400-level. All courses for the EE minor must be completed with a grade of C or better.

- EECS 215 (Note: BIOMEDE 211 may be used in place of EECS 215 if an additional EECS course is taken from the following approved course lists)
- One of the following program core courses: 216, 230, 270, 320
- Two electives from among the following courses: 216, 230, 270, 320, 311, 312, 330, 334, 351, 370, 373, 411, 413, 414, 420, 421, 423, 425, 427, 429, 430, 434, 452, 455, 460, 461, 470, 530

## Suggested Program Options

1. Systems: Communications, Control, Signal Processing
2. Electromagnetics and Optics
3. Circuits and Solid State

### Sample Paths:

Path Options	Required Core	Path Preparation Core	Elective 1	Elective 2
Systems	215	216	351, 455, 460	451, 452, 455, 460, 461 (no duplicates)
Electromagnetics and Optics	215	230	330, 334	411, 430, 434, 438, 530
Circuits & Solid State	215	216	311, 312, 320	411, 413, 414, 420, 421, 423, 425, 427, 429

## Minor in Environmental Engineering

Administered through the Department of Civil and Environmental Engineering, the minor in Environmental Engineering provides students with a basic background in the tools environmental engineers use to assess environmental impacts, model contaminant fate, and perform sustainable engineering decision-making. CoE students may declare the minor provided they meet the following eligibility requirements:

- Students must have a grade point average of 2.0 or higher at the time of declaration
- Students must have completed the prerequisite coursework for the "core" minor courses with a C or better
- Students pursuing a major in Civil or Environmental

Engineering are not eligible for the minor

A minimum of 16 credit hours, three core courses and two electives, is required to complete the Environmental Engineering minor. All courses for the minor must be completed with a grade of C or better as follows:

Required core courses (10-11 credits):

- CEE 265
- CEE 325 or equivalent from: MECHENG 320, CHE 342, NERS 344, NAVARCH 320, AEROSP 225, BIOMEDE 331, MATSCIE 335
- CEE 365

Two electives (6 credits) from the following courses:

- CEE 482, 460, 465, 481, 482, 563

For additional information, please visit the Civil and Environmental Department website at <http://cee.umich.edu/minor-environmental-engineering>.

## Minor in Naval Engineering

The primary goal of the Naval Engineering Minor is to provide a coherent path to employment in the marine industry and an exposure to research opportunities in the marine industry for those students not majoring in naval architecture and marine engineering. The secondary goal is to increase awareness of the marine industry and its needs within the College of Engineering as a whole.

The marine industry includes naval architecture firms, the shipping and offshore industries, and the United States Navy and Coast Guard as major entities. In addition to naval architects and marine engineers, this industry requires engineers from a wide range of disciplines, including mechanical, electrical, and civil engineers, computer and material scientists, and industrial operations researchers. The scale and harshness of the marine environment poses particular challenges not found in other realms of engineering practice, and graduates with knowledge of these marine-related disciplines will be better prepared to meet them.

This program is for undergraduate students in the Col-

lege of Engineering and undergraduate Military Officer Education Students, including the Army, Air Force, and Navy/Marine programs who may be enrolled in other University of Michigan Colleges. More information on the Naval Engineering Minor website.

## Multidisciplinary Design Minor

The Multidisciplinary Design Minor offers multi-term, on-campus, immersive design team experiences for academic credit. This minor is not built on a list of required courses, rather it is earned through a set of four experiences that can be tailored to a student's interests. Note: This minor is also open to students from outside the College of Engineering.

The MD minor is comprised of 15 total credits across four experiences:

1. Introductory "Design, Build, Test" Experience
2. Multi-Term Design Project
3. Connections Course
4. ENGR 456: Peer Mentorship/Leadership Course

### Introductory "Design, Build, Test" Experience (at least 2 credits)

Must include a team-based, complete Design/Build/Test process. For engineering students this is most often fulfilled through ENGR 100. For non-engineering students, other design-based courses or an introductory/extra semester on the design project team may also be allowed to fulfill this requirement.

### Multi-Term Design Project (at least 7 upper-level design credits over at least 2 semesters)

The Multidisciplinary Design Program offers various team-based, multidisciplinary engineering design project options, including:

1. MDP-organized\* externally-sponsored: industry/government/non-profit
2. MDP-organized\* faculty-based research teams: also called Vertically Integrated Projects/"VIP"

3. Significant work on student organization project teams (Solar Car, Steel Bridge, Woven Wind, etc.) with permission from the team's faculty advisor and MDP
4. Students may also propose their own, unique multi-term design project. To propose a project, please contact the MDP Office.

The Multi-term Design Project can be curricularized utilizing the ENGR x55 course sequence, departmental design courses and/or independent study courses. The project must span a minimum of two consecutive semesters of in-depth work: the credits cannot all be earned in the same semester.

\*Recruitment for MDP-organized projects occurs annually each October

### Connections Course (at least 3 credits)

A connections course is required to support the Multi-Term Design Project: providing additional breadth or depth in specific skills relevant to the project, but outside of the student's major coursework. This requirement can be met with any course outside of a student's required classes for their major. This course is taken prior to or during the final semester of project work.

### ENGR 456: Peer Mentorship/Leadership Course (2 credits)

Students study models of leadership and mentorship while participating in reflective and integrative learning exercises based on previous design team experience. Simultaneously, students take on mentorship/leadership roles within a design team to offer technical, professional, and interpersonal guidance. Students must have significant previous multidisciplinary design project experience to enroll.

Completing the minimum credit hours for the above list adds up to 14 credit hours; therefore the student needs at least one extra credit hour in any one of the first three components to meet the minimum of 15 required credits. The following rules apply to the Multidisciplinary Design Minor:

1. Transfer credit may not be used to fulfill requirements of this minor.
2. Only the 2-credit mentorship and leadership requirement (ENGR 456) can be taken Pass/Fail.
3. The Academic Advisor of the Multidisciplinary Design Minor Program is responsible for approving any variance in course requirements for the minor.

For more information, please visit <http://mdp.engin.umich.edu>.

## Program in Sustainable Engineering (PISE)

Administered through the Department of Civil and Environmental Engineering, the Program in Sustainable Engineering (PISE) provides students an opportunity to develop their understanding of the challenges associated with sustainable design of technology systems, exploring economic, environmental and social challenges of sustainable development across disciplines. Upon completing the program, students should be able to:

- Quantify the environmental and economic impacts of design decisions
- Understand the difference between life cycle design and environmentally sustainable design
- List key sustainability considerations in the design of an engineering system
- Identify trade-offs among social, economic and environmental drivers in engineering decision making
- Identify more sustainable choices among engineering options

The program consists of the following requirements:

- 3-credit foundation course Sustainable Engineering Principles (CEE 265) of Sustainable Engineering and Design (ME 499)
- 3-credits of coursework from a selection of courses identified within the College of Engineering that feature significant content in sustainable engineering.
- 3-credits of coursework from a selection of courses identified outside the College of Engineering that

feature significant content in sustainability, specifically considering non-engineering issues at the intersection of technology and society.

If planned well in advance of the senior year, the program should not add to the 128 credits required for a B.S.E. For complete information, visit the Program in Sustainable Engineering website at <http://pise.engin.umich.edu>.

## Program in Global Health Design (PGHD)

The Specialized Study Program in Global Health Design (PGHD) allows students to focus their elective and upper-level design coursework around the theme of global health design. Students who complete the program will have a holistic understanding of best practices in design for global health as well as a growing knowledge of strategies and trends in the field of global health at large.

The Program in Global Health Design allows students to choose courses informed by their past curricula, academic interests, and future goals that will best strengthen their specific design skillsets and projects.

The program includes three requirements:

1. **Design foundations course** that includes a global health project. Such a course is at the 300 level or higher and exposes students to problem definition, concept generation, analysis, prototyping, and evaluation. Examples include: ME 450, BME 450, and ARTDES 342.1. Additional courses meeting the criteria can be petitioned.
2. **Global health foundations course** that broadens the student's knowledge of global health outside of a design context. Students propose this course as part of their declaration to the program and can change it later by petition.
3. **Depth course** that deepens the student's understanding of the thematic area of their design project and/or to strengthen their global health design skill-

set.

For more information contact [globalhealthdesign@umich.edu](mailto:globalhealthdesign@umich.edu).

## Program in Socially Engaged Design (PSED)

The Program in Socially Engaged Design is an academic program that allows students to focus their elective courses around the aim of gaining proficiency in skills important to socially engaged design. The program will support and guide students in their exposure to key design practices as well as traditionally non-engineering skills, both essential to the effective design of products, processes, systems, and services, within high-resource and low-resource settings.

The program includes four requirements:

1. **Required foundations course:** Front-End Design (ME 499)
2. **Depth Course** that deepens a student's understanding of socially engaged design. This course is proposed by the student or selected from a list.
3. **Breadth Course** that broadens that student's education outside of the College of Engineering and compliments their socially engaged design work. This course is proposed by the student or selected from a list.
4. **Learning Blocks** offered by the Center for Socially Engaged Design's Socially Engaged Design Academy. These learning blocks round out the student's socially engaged design knowledge and skillset by providing instruction and assessment on topics that are not currently covered or covered in a limited manner at a curricular level within the CoE (For more information see [insitu.engin.umich.edu/academy](http://insitu.engin.umich.edu/academy)). The student proposes to execute blocks that will supplement the student's interest in socially engaged design.

For more information contact [sociallyengageddesign@umich.edu](mailto:sociallyengageddesign@umich.edu).

## Other Approved Academic Minors

Engineering students have considerable flexibility in electing courses from other colleges through their Intellectual Breadth courses and general electives. In the interest of helping students make coherent choices in selecting these courses, we allow and encourage our students to pursue minors offered in LSA, Art & Design, Ross School of Business and the School of Social Work.

Minors also serve as recognition, via a transcript notation, of the completion of these more in-depth course sequences. Electing to earn an academic minor is optional and there is no limit on the number of academic minors a student may elect.

In practice, a student will meet with an advisor in the minor discipline and together map out the minor courses. The certification that the appropriate courses have been completed will be communicated from the offering department to a student's undergraduate program advisor in CoE as well as the College of Engineering Student Records Office. The student will be responsible for making sure this paperwork arrives at the appropriate offices.

## Minors Approved by the College of Engineering

The list below shows the minors approved for students in the College of Engineering..

### Minors Offered Through LSA (list subject to change):

- Afroamerican and African Studies
- American Culture
- Anthropology
- Applied Statistics
- Arab and Muslim American Studies
- Asian Languages and Cultures
- Asian Studies

- 
- Asian/Pacific Islander American Studies
  - Astronomy and Astrophysics
  - Biochemistry
  - Biological Anthropology
  - Biology
  - Biophysics
  - Bosnian/Croatian/Serbian Literature and Culture
  - Central Eurasian Studies
  - Chemical Measurement Science
  - Chemical Physics
  - Chemistry
  - Classical Archaeology
  - Classical Civilization
  - Complex Systems
  - Computer Science
  - Creative Writing
  - Crime and Justice
  - Czech Language, Literature, and Culture
  - Digital Studies
  - Drama: Text to Performance
  - Early Christian Studies
  - Earth Sciences
  - East European Studies
  - Eastern Europe, Cultures and Literatures
  - Ecology and Evolutionary Biology
  - Economics
  - Energy and Science Policy
  - Entrepreneurship
  - Environment
  - Environmental Geology
  - Epistemology and Philosophy of Science
  - Food and the Environment
  - French and Francophone Studies
  - Gender and Health
  - Gender, Race, and Nation
  - General Philosophy
  - Geology
  - German Studies
  - Global History
  - Global Media Studies
  - Greek (Ancient) Language and Literature
  - Greek (Modern) Language and Literature
  - History
  - History of Art
  - History of Law and Policy
  - History of Medicine and Health
  - History of Philosophy
  - Interdisciplinary Astronomy
  - Intergroup Relations Education
  - International Studies
  - Islamic Studies
  - Italian
  - Judaic Studies
  - Latin American and Caribbean Studies
  - Latin Language and Literature
  - Latina/o Studies
  - Law, Justice and Social Change
  - Lesbian, Gay, Bisexual, Transgender, Queer (LGBTQ) and Sexuality Studies
  - Linguistics
  - Mathematics
  - Medical Anthropology
  - Medieval and Early Modern Studies
  - Mind and Meaning
  - Modern European Studies
  - Modern Middle Eastern and North African Studies
  - Moral and Political Philosophy
  - Museum Studies
  - Native American Studies
  - Near Eastern Languages and Cultures
  - Oceanography
  - Paleontology
  - Peace and Social Justice
  - Physics
  - Plant Biology
  - Polish Language, Literature, and Culture
  - Political Science
  - Polymer Chemistry
  - Portuguese
  - Religion
  - Russian Language, Literature, and Culture
  - Russian Studies
  - Scandinavian Studies
  - Science, Technology, and Society
  - Spanish Language, Literature, and Culture
  - Statistics
  - Sustainability
  - Translation Studies
  - Ukrainian Language, Literature and Culture
  - Urban Studies
  - Water and the Environment
  - Writing
  - Yiddish Studies

## Policies and Procedures for Declaring and Completing LSA Academic Minors

The following describes the policies and procedures to be followed for declaring and completing LSA minors:

1. Each B.S.E. student who wishes to complete an approved academic minor must develop a plan for the minor in consultation with the designated LSA advisor, who must also approve it. The faculty and staff advisors in the LSA units will advise Engineering students on course selection and complete the minor declaration form and confirm completion of the minor. No prior approval is required from an Engineering advisor.
2. Students may not elect two academic minors offered by the same department or program.
3. The minor declaration form must be received by the College of Engineering Student Records Office. Upon receipt of the declaration form, the staff member will enter the minor in the M-Pathways database. The form will be available through all Engineering academic departments, the Engineering Advising Center and all relevant LSA departments.
4. Student Transcripts:
  - The unofficial transcript for an Engineering student who has declared a minor will show the minor in the program action history section.
  - The official transcript issued by the Registrar's Office will show the minor at the beginning of the transcript when the student has completed the degree.
5. Minors cannot be completed and added to the transcript after a student has graduated.

More information on LSA minors can be found in the LSA Bulletin.

## Minor in Computer Science

A Minor in Computer Science (CS), offered through LSA and administered by the EECS Department, is open to undergraduate students. Students wishing to pursue this minor should meet with a faculty advisor for the LSA Computer Science major.

Students must satisfy two prerequisites before declaring the minor:

MATH 115, and one of the following programming courses: EECS 183 or ENGR 101, or their equivalent. Students must also be currently enrolled in and pursuing one of the minor Core Courses to be eligible to declare.

Requirements for the Minor (16 credits total):

- A. Three Core Courses (4 credits each; must complete all three):
  - EECS 203: Discrete Mathematics
  - EECS 280: Programming and Introductory Data Structures
  - EECS 281: Data Structures and Algorithms
- B. Elective Course: One 4-credit elective selected from EECS 388, 482, 483, 484, 485, 487, 490, 492, or 493.

Note: EECS 281 has both EECS 203 and 280 as prerequisites. All of the electives have EECS 281 as a prerequisite. Thus, completing the minor requires a minimum of three academic terms.

Grades of C or better must be achieved in all courses taken to satisfy Computer Science requirements.

## Minor in Art & Design

Undergraduate engineering students can complete an academic Minor in Art & Design in consultation with an advisor in the School of Art & Design. Appointments may be scheduled by visiting or calling the Smucker-Wagstaff Academic Programs Center, Art & Architecture Building, room 2038, or (734) 764-0397. The requirements for the Minor are maintained by the School.

Students must secure written approval from their home school/college to pursue an A&D minor and must develop a plan for the minor in consultation with an A&D advisor.

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## Minors in Other Schools/Colleges

- Minor in Business (Ross School of Business)  
**<https://www2.bus.umich.edu/MyiMpack/academics/businessminor>**
- Minor in Community Action and Social Change (School of Social Work) **<http://ssw.umich.edu/offices/casc-undergraduate-minor>**
- Minor in Design and Production (School of Music, Theatre & Dance) **<http://www.music.umich.edu/departments/theatre/programs/minor-design-production.htm>**
- Minor in Global Theatre and Ethnic Studies (School of Music, Theatre & Dance) **[http://www.music.umich.edu/departments/theatre/programs/minor\\_af\\_amer.htm](http://www.music.umich.edu/departments/theatre/programs/minor_af_amer.htm)**
- Minor in Music (School of Music, Theatre & Dance) **[http://www.music.umich.edu/current\\_students/student\\_resources/AcademicMinors.htm](http://www.music.umich.edu/current_students/student_resources/AcademicMinors.htm)**
- Minor in Performing Arts Management (School of Music, Theatre & Dance) **[http://www.music.umich.edu/current\\_students/student\\_resources/AcademicMinors.htm](http://www.music.umich.edu/current_students/student_resources/AcademicMinors.htm)**

# Graduate Education

## Mission Statement

- Provide support, improve communication, and start new initiatives for graduate students, departments, and interdisciplinary programs.
- Provide a positive graduate student experience and increase the retention of graduate students through various programs and activities.
- Utilize a variety of recruitment programs to attract a high-quality and diverse graduate student body.

## Admissions

<http://www.engin.umich.edu/college/admissions/graduate>

## Application Information

Depending on which degree you seek, choose one of the following applications:

### M.S., M.S.E., Ph.D. (Horace H. Rackham School of Graduate Studies)

Rackham administers the admission process for more than 14 engineering departments and programs that offer graduate and graduate/professional degrees. Departments recommend admission to Rackham. Rackham monitors requirements and procedures and certifies the admission recommendation as appropriate. Rackham highly encourages applications via the web; however if there are extenuating circumstances, it is possible to submit a paper application. Please be advised that paper applications take considerably longer to process and may delay official admission decisions.

- Web Application <http://www.rackham.umich.edu/prospective-students/admissions/applying/submit-your-application/start/apply-annarbor> (For Ann Arbor campus only)
- Inquiry Form, <http://goo.gl/forms/khNLdjT3bH>

Applicants may be required to send supplemental mate-

rials to either the Rackham Graduate School and/or their College of Engineering department of interest. If you are confused about where to send your application materials, please contact the appropriate official departmental admission contact.

### M.Eng., D.Eng. (College of Engineering)

The following form is for students interested in the Master of Engineering degree with majors in the following fields of study: Applied Climate, Automotive Engineering, Construction Engineering & Management, Energy Systems Engineering, Global Automotive and Manufacturing Engineering, Manufacturing, Space Engineering, Structural Engineering, Systems Engineering + Design, and the Doctor of Engineering in Manufacturing degree. To request materials, please visit:

- Inquiry Form, <https://www.applyweb.com/public/inquiry?s=umenginq>
- Web Application, <https://www.applyweb.com/umengin/>

## Application Status

Some departments or programs review applications on a rolling basis as applications are received; others review applications on a scheduled basis. Before contacting the department or program please allow at least eight weeks for processing.

## Admissions Criteria

Contact individual departments or programs for specific admissions criteria:

<http://adge.engin.umich.edu/graduate-education/gradprogcontacts>.

Admission is usually determined by an evaluation of the following:

- Transcript of your academic record.
- Recommendations from two or three faculty members who have supervised your course work or research.
- While the GRE general test is required of all applicants, including the University of Michigan gradu-

ates who apply to CoE Ph.D. programs, our focus is on the student's academic and research potential. Since GRE scores have been shown to have little or no correlation with student excellence in research at the University of Michigan, we will no longer require a minimum score for the combined Verbal and Quantitative tests or for the Analytical Writing test.

- Statement of Purpose for your graduate study objectives.
- Personal statement that explains any extenuating circumstances (optional).
- Test of English as a Foreign Language (TOEFL), or the Michigan English Language Assessment Battery (MELAB), for applicants who studied at an institution where the language of instruction is not English or for whom English is not their native language. <http://www.rackham.umich.edu/admissions/tests>
- Although departments may adjust their GPA requirements to reflect their own applicant needs, the average GPA of the Fall 2013 entering class of Ph.D. students is 3.7. The average GPA for master's students is 3.6.

## Degree Options

<http://grad.engin.umich.edu/home>

### Dual Master's

Graduate students in the College of Engineering can pursue dual master's degrees within the College or across units of the University of Michigan campus.

## Engineering Degrees

Master of Engineering (M.Eng.)

Doctor of Engineering in Manufacturing (D.Eng.)

Information on these programs can be requested on the following website: <https://www.applyweb.com/public/inquiry?s=umenginq>

## Rackham Graduate School

<http://www.rackham.umich.edu/prospective-students>

## Master of Science/Master of Science in Engineering

The Master of Science and Master of Science in Engineering degrees represent mastery of a particular discipline in the College of Engineering. They require 30 credits of course work, taken predominantly from the area of study. Some programs involve theses or internships. Others require only coursework.

## Doctor of Philosophy (Ph.D.)

The doctoral degree is conferred in recognition of marked ability and scholarship in a chosen field of knowledge. There is no general course or credit requirement for the doctorate. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in related subject areas outside the department, called cognate subjects. In most areas, a student must pass a comprehensive examination in a major field of specialization and be recommended for candidacy for the doctorate. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the results of the investigation in the form of a dissertation. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

A student can apply directly for admission to the doctoral program after graduating with a B.S. degree from a relevant field. The student becomes a pre-candidate for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in the field of specialization. Candidacy is achieved when the student demonstrates competence in his/her broad field of knowledge through completion of a prescribed set of courses and passing a comprehensive exam.

Requirements regarding foreign language and non-technical courses are left to individual departments or programs, and to the Rackham Graduate School. A prospective doctoral student should consult the program advisor for specific details.

## Funding and Fellowships for Graduate Students

<http://grad.engin.umich.edu/funding>

### Funding for Ph.D. Students

The College of Engineering at the University of Michigan operates under a fully-funded model for all Ph.D. students. Students receive a guarantee of full funding at the point of admission and throughout the duration of their four- or five-year program. This funding commitment is guaranteed provided the student meets all necessary milestones, and fulfills program requirements as stipulated by their individual faculty advisor and/or department/graduate program. This comprehensive package includes tuition, fees, University health insurance and a monthly stipend. The funding package can come from a variety of sources including University of Michigan, College of Engineering or Rackham Graduate School fellowships, Graduate Student Research Assistant (GSRA) appointments or Graduate Student Instructor (GSI) positions. Some students also receive funding from documented external fellowships or any combination of the aforementioned. The typical guarantee of funding for a Ph.D. student admitted directly from a bachelor's degree program is five years while those admitted directly from a master's degree program is four years. Exact funding amounts will vary between engineering departments.

### Funding for Master's Students

The College of Engineering, in partnership with Rackham Graduate School offers some fellowships for new full-time master's students who are U.S. citizens and permanent residents. This Bridge to the Doctorate Program offers two terms of funding for the first academic year (i.e. tuition, living stipend, health insurance and fees). Admitted master's students are automatically considered for this award based on the information in their official admission applications. Overall funding for Master's students is limited, in that there is no guaranteed funding package. Departments may have some special fellowships or awards designated for master's students. In some cases, individual departments may

have Graduate Student Instructor (GSI) positions or Graduate Student Research Assistant (GSRA) appointments available that master's students can apply for. Master's students who have interest in a Ph.D. program can reapply at the appropriate application deadline to receive consideration for admission and full funding to a Ph.D. program.

For additional funding resources and opportunities for new and continuing Master's and Ph.D. students visit: <http://grad.engin.umich.edu/funding>. Using the Funding Sources and Fellowships website, graduate students will find resources from across the Michigan campus, tips on applying for fellowships, as well as a number of external funding opportunities.

# Sample Schedules and Course Descriptions

## How to Read a Course Description

Courses and course descriptions are listed under each degree program. Course titles and numbers, prerequisites, other notes, credit hours and descriptions approved by the College of Engineering Curriculum Committee are included in this Bulletin. Course descriptions for CoE courses also are available on the College's Web site at: <http://courses.engin.umich.edu/>. They may be downloaded or printed.

Schedules of classes are issued separately by the office of the Registrar, giving hours and room assignments for the courses and sections offered each term. The schedule of classes can be found at: <http://www.umich.edu/~regoff/schedule/>

## What the Course Number Indicates

The number of each course is designated to indicate the general level of maturity and prior training expected.

100	First-year-level course
200	Sophomore-level course
300	Junior-level courses
400*	Senior-level course
500	Predominantly Graduate-level
600	Graduate-level courses and above

Unless a phrase such as "junior standing," "senior standing," or "graduate standing" is part of the list of

prerequisites for a course, a student may elect an advanced-level course relative to his/her current status if the other prerequisites are satisfied. If the difference in standing level is greater than one academic year, it is usually not wise to elect an advanced-level course without first consulting the department or the instructor offering the course.

In general, the prerequisites listed for a course designate specific subject materials and/or skills the student is expected to have mastered before electing the course (or, in some cases, concurrently with it).

*\*A 400-level course listed in the Bulletin of the Horace H. Rackham School of Graduate Studies may be elected for graduate credit when this is approved by the student's graduate program advisor.*

## Course Equivalence

Unless otherwise stated, the phrase "or equivalent" may be considered an implicit part of the prerequisite for any course. When a student has satisfactorily completed a course that is not listed but is believed to be substantially equivalent to one specified as a prerequisite for a course that the student wants to elect, the individual may consult the program advisor and upon determining if equivalency has been satisfied, election may be approved.

## Permission of Instructor

The phrase "or permission of instructor (or department)" may be considered an implicit part of the statement of prerequisites for any course. When permission is a stated requirement, or when a student does not have the stated prerequisite for a course but can give evidence of background, training, maturity or high academic record, the student should present to the program advisor a note of approval from the instructor or department concerned.

## Representative Sample Schedules

The information in this Bulletin for a number of the

degree programs includes a schedule that is an example of one leading to graduation in eight terms. This sample schedule is for informational purposes only and should not be construed to mean that students are required to follow the schedule exactly.

A transfer student attending a community or liberal arts college and pursuing a pre-engineering degree program may not be able to follow a similar schedule because of a lack of certain offerings. Departmental program advisors should always be consulted when planning course selections.

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

# Aerospace Engineering

## Overview

Aerospace technology has grown out of the problems of design, construction and operation of vehicles that move above the Earth's surface, vehicles ranging from airplanes and helicopters to rockets and spacecraft. Design of such vehicles has always been challenging, not only because of the high premium placed on light-weight vehicles performing efficiently and with high reliability, but also because they must sometimes operate in hostile environments. These same requirements exist not only for future spacecraft and high-performance transport aircraft, but also for the next generation of ground transportation, such as high-speed trains, over-water transportation and automated motor vehicles. In addition to working on vehicle-oriented design problems, aerospace engineering graduates are often involved in systems management in the broadest sense. Because of the anticipated life mission of the aerospace student, the undergraduate curriculum at the University of Michigan is designed to convey a clear understanding of the fundamental aspects of the fields most pertinent to aerospace engineering. Real-life problems in aerospace and related areas are emphasized in the applications of theory. In their senior year, students select a design course in which they are given an appreciation of the interrelation of the various areas of study in the design of a whole system.

## Department Administration

### Department Chair

Dan Inman, Clarence "Kelly" Johnson Professor of Aerospace Engineering, 3064 FXB.

### Contacts

Aerospace Engineering Department  
3000 Francois-Xavier Bagnoud Building (FXB)  
1320 Beal Ave  
Ann Arbor, MI 48109-2140  
Phone: (734) 764-3310  
Website: <http://aerospace.engin.umich.edu/>

## Mission

To provide internationally recognized leadership in aerospace engineering education, through a continuously improving educational program that graduates students with strong engineering science fundamentals while incorporating applied engineering aspects.

## Goals

- Educate students who are widely known for exceptional strength in technical fundamentals across all aerospace disciplines, who are cognizant of modern aerospace technologies and who are sought after by top graduate schools and by aerospace and related industries worldwide.
- Support vibrant and highly recognized research programs that serve the educational goals of the undergraduate and graduate degree programs, that make major contributions to the knowledge base in aerospace sciences and technology and that are turned to by industry and government for solutions.
- Create an environment of intellectual challenge and excitement that at the same time is collegial and conducive to higher learning.
- Take full advantage of knowledge, technology, facilities and resources at the University of Michigan.

## Objectives

The Undergraduate Program Educational Objectives are that, within 3-5 years after graduation:

- Alumni of the program will use their breadth and depth of knowledge and skills in the fundamental disciplines of aerospace engineering to pursue successful professional careers
- Alumni will feel that they received outstanding preparation for the next step in their careers, whether it be graduate school or work in industry, government or academia
- Alumni of the program will be emerging leaders in engineering, science, academia, business and public service
- Alumni of the program will be productive citizens

with high professional and ethical standards.

The above program educational objectives are accomplished by a rigorous curriculum that emphasizes fundamentals in basic sciences, mathematics and the humanities and integrates classroom and laboratory experiences in the fundamental disciplines of Aerospace Engineering. More specifically our curricular goals are to:

- Educate students in the following fundamental disciplines of Aerospace Engineering: aerodynamics, materials, structures, propulsion, flight mechanics, orbital mechanics, software, dynamics and control
- Educate students in the methodology and tools of design and the synthesis of fundamental aerospace disciplines necessary to carry out the design of an aerospace vehicle or system
- Educate students in the basics of instrumentation and measurement, laboratory techniques and how to design and conduct experiments
- Develop students' ability to function on multi-disciplinary teams and provide them with teamwork experiences throughout their curriculum
- Develop students ability to communicate effectively
- Expose students to environmental, ethical and contemporary issues in Aerospace Engineering
- Expose students to other disciplines of engineering beyond the aerospace field.

## Outcomes

Program Student Outcomes are that UM Aerospace Engineering graduates demonstrate:

- An ability to apply knowledge of mathematics, science and engineering;
- An ability to design and conduct experiments as well as to analyze and interpret data;
- An ability to design a system, component or process to meet desired needs;
- An ability to function on multi-disciplinary teams;
- An ability to identify, formulate and solve engineering problems;
- An understanding of professional and ethical re-

sponsibility;

- An ability to communicate effectively;
- The broad education necessary to understand the impact of engineering solutions in a global and societal context;
- A recognition of the need for, and an ability to engage in life-long learning;
- A knowledge of contemporary issues;
- An ability to use the techniques, skills and modern engineering tools necessary for engineering practice;
- A knowledge of aerodynamics, aerospace materials, structures, propulsion, flight mechanics, orbital mechanics, software, dynamics and control; and
- Competence in the integration of aerospace science and engineering topics and their application in aerospace vehicle design.

## Undergraduate

### Degree Program

The degree program gives the student a broad education in engineering by requiring basic courses in aerodynamics and propulsion (collectively referred to as "gas dynamics"), structural mechanics and flight dynamics and control systems. These courses cover fundamentals and their application to the analysis, design and construction of aircraft, spacecraft and other vehicular systems and subsystems. Courses in gas dynamics treat fluid and gas flow around bodies and through turbojet engines and rocket nozzles. In courses on structural mechanics, lightweight structures are studied from their strength, elastic, stiffness, stability and dynamic behavior. Flight dynamics and control systems courses deal with the dynamical behavior of vehicles and systems as a whole, their stability and controllability both by human pilots and as autonomous systems. Integration of all these subjects takes place in the capstone aircraft design course or space system design course that is chosen by students. The aerospace engineering program offers considerable flexibility through technical and general electives, in which students have an opportunity to study in greater depth any of the areas mentioned above. In addition, other technical elective areas are available to aerospace engineering students,

including aerophysical sciences, environmental studies, computers, person-machine systems and transportation. Elective courses in each technical elective area include courses taught both inside and outside the aerospace engineering department.

## Sample Schedule

### B.S.E. in Aerospace Engineering

The Aerospace Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <http://aerospace.engin.umich.edu/AcademicPrograms/undergrad/sampleplan.html>.

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, 215, and 216	16	4	4	4	4	-	-	-	-
ENGR 100, Introduction to Engineering	4	4	-	-	-	-	-	-	-
ENGR 101, Introduction to Computers	4	-	4	-	-	-	-	-	-
CHEM 125/126, 130 or 210, 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141 <sup>2</sup>	5	-	5	-	-	-	-	-	-
Physics 240 with Lab 241 <sup>2</sup>	5	-	-	5	-	-	-	-	-
Intellectual Breadth	16	4	4	-	-	-	-	4	4
<b>Related Technical Core Subjects (12 hours)</b>									
MECHENG 240, Intro to Dynamics and Vibrations	4	-	-	-	4	-	-	-	-
MATSCIE 220, Intro to Materials	4	-	-	-	-	-	-	4	-
EECS 314, Circuit Analysis and Electronics	4	-	-	-	-	4	-	-	-
<b>Aerospace Science Subjects (29 hours)</b>									
AEROSP 201, Introduction to Aerospace Engineering	3	-	-	3	-	-	-	-	-
AEROSP 215, Introduction to Solid Mechanics and Aerospace Structures	4	-	-	-	4	-	-	-	-
AEROSP 225, Introduction to Gas Dynamics	4	-	-	-	4	-	-	-	-
AEROSP 315, Aircraft and Spacecraft Structures	4	-	-	-	-	4	-	-	-
AEROSP 325, Aerodynamics	4	-	-	-	-	-	4	-	-
AEROSP 335, Aircraft and Spacecraft Propulsion	4	-	-	-	-	4	-	-	-
AEROSP 347, Space Flight Mechanics	3	-	-	-	-	3	-	-	-
AEROSP 348, Aircraft Dynamics and Control	3	-	-	-	-	-	3	-	-
<b>Aerospace Engineering Subjects (16 hours)</b>									
AEROSP 205, Intro Aerospace Engineering Systems	3	-	-	3	-	-	-	-	-
AEROSP 285, Aero Engineering Seminar	1	-	-	1	-	-	-	-	-
AEROSP 305, Aerospace Engineering Lab I	4	-	-	-	-	-	4	-	-
AEROSP 405, Aerospace Engineering Lab II	4	-	-	-	-	-	-	4	-
AEROSP 481, Aircraft Design or AEROSP 483, Space System Design	4	-	-	-	-	-	-	-	4
<b>Electives (16 Hours)</b>									
Technical Electives <sup>3</sup>	7	-	-	-	-	-	-	4	3
General Electives	9	-	-	-	-	-	5	-	4
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>15</b>	<b>16</b>	<b>16</b>	<b>15</b>

Candidates for the Bachelor of Science degree in Engineering (Aerospace Engineering) - B.S.E. (Aerospace E.) - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for the College of Engineering

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for the College of Engineering

<sup>3</sup> Technical electives must total at least 7 credits of approved upper division courses (that is, 300 level or above). At least 3 credits must be approved mathematics or science courses, a maximum of 3 credits is allowed for directed study and a maximum of 2 credits is allowed for seminar courses. Recommended courses that satisfy the mathematics or science technical electives are described in a document that can be obtained from the Department or on the Department website.

## Focus of Study

The Aerospace Engineering department offers a variety of areas of focus for students to consider. Specific information about the requirements can be found on the department advising website.

- Propulsion, Aerodynamics and Combustion
  - Air-Breathing Propulsion and Combustion Science
  - Space Propulsion
  - Aerodynamics and Turbulence
  - Computational Fluid Dynamics of Transonic and Hypersonic Vehicles
- Structural Mechanics
  - Advanced Materials for Airframe Applications
  - Adaptive Materials and Constitutive
  - Modeling for Aerospace Structures
  - Aeroelasticity, Structural Dynamics, Optimal Design of Structures
- Flight Dynamics and Control
  - Dynamics and Control of Aircraft
  - Dynamics and Control of Spacecraft
  - Astrodynamics
- Aerospace Vehicles

## Sequential Undergraduate/Graduate Study (SUGS)

The five-year Sequential Undergraduate/Graduate Study (SUGS) Program permits students who enter the program in the first term of their senior year to receive the B.S.E. and M.S.E. degrees (or the B.S.E. and M.Eng. degrees) upon completion of a minimum of 149 credit hours. Students should speak with the department advising office to learn more about the SUGS application process and procedures. SUGS admissions requirements will vary. <http://www.engin.umich.edu/college/academics/bulletin/ug-ed/combined>

- B.S.E. in Aerospace Engineering/M.S.E. in Aerospace Engineering
- B.S.E. in Aerospace Engineering/M.Eng. in Space Engineering

## Graduate

### Graduate Degrees

- Master of Science in Engineering (M.S.E.) in Aerospace Engineering
- Master of Engineering (M.Eng.) in Space Engineering
- Doctor of Philosophy (Ph.D.) in Aerospace Engineering

### M.S.E. in Aerospace Engineering

This degree is designed for students who desire a curriculum that is focused on the scientific aspects of Aerospace Engineering. A total of 30 credit hours is required (typically 10 classes). Of these, 15 credit hours must be 500-level classes in Aerospace Engineering with a B grade or better (excluding AEROSP 590 and AEROSP 585), and 6 credits must be from approved courses in mathematics. The remaining credits can be fulfilled with any Rackham-approved AEROSP courses, where up to six credit hours of directed study (AEROSP 590) and three credit hours of aerospace engineering seminar series (AEROSP 585) may be elected. Students are encouraged to take advantage of directed study and become involved in research as part of their M.S.E. experience. The M.S.E. program does not include an option for a thesis per se; however, through AEROSP 590, students can perform research work in close supervision of a faculty member and investigate a problem of common interest.

Admission requirements include a strong performance in an undergraduate program in engineering or science and submission of acceptable Graduate Record Exam (GRE) scores.

Students are strongly encouraged to consult with faculty in their intended areas of specialization to discuss the composition of their program.

### M.Eng. in Space Engineering

The M.Eng. in Space Engineering provides a compre-

hensive set of courses and training in space-related science and engineering, and the systems approach to design and manage complex space systems. The M.Eng. in Space Engineering requires 30 credits of course work, of which 18 must be at the 500-level or higher and 24 must be graded (not P/F).

Course elections must include:

- Depth in a main area (9 credits). For example, a student could select dynamics and control, structures or propulsion.
- Breadth by crossing engineering/science boundaries (9 credits)
- Systems engineering (6 credits)
- Team design experience (6 credits)

## Doctor of Philosophy (Ph.D.) in Aerospace Engineering

Study towards the Ph.D. degree requires a strong background in an area of specialization and an ability to carry out independent research. Students must complete, in order:

### Precandidacy Status

A student must apply for and be admitted to precandidacy status before taking the Preliminary Exam. Once admitted, the student is a pre-candidate. Students admitted directly to the doctoral program may also earn a Master degree by fulfilling the Master degree requirements concurrently with the Doctoral degree. The embedded Aero M.S.E. degree is awarded at the end of the Ph.D. studies.

### Research Involvement

The student must initiate research activity with his/her advisor in the first year of graduate study.

### Preliminary Exam

The Ph.D. degree requires a sound background in aerospace engineering combined with strong knowledge of applied mathematics and computational sciences. The Ph.D. dissertation requires that the student demonstrate ability to pursue and solve an original research problem, which implies the ability to carry out independent

research. Each student must apply, with the endorsement of her/his research advisor, to the Graduate Student Services Coordinator to take a Preliminary Examination. The student must be registered in the Department of Aerospace Engineering during the term in which the preliminary examination is taken. For the May exam, this refers to the preceding Winter semester. The student must formally indicate the three core courses and the two additional courses selected from a list given on the departmental website. To qualify for the preliminary examination, a student must achieve a G.P.A. of at least 3.5/4.0 in the five chosen courses. The student must also specify her/his doctoral research area as approved by her/his Aerospace faculty advisor and should submit to the Graduate Coordinator a research portfolio consisting of material related to his/her research activity.

### Advancing to Candidacy

Candidacy can occur once the student passes the preliminary examination, completes the Rackham cognate requirement, attends all Responsible Conduct of Research and Scholarship (RCRS) workshops, and accumulates at least 18 credit hours of course work.

### The Dissertation

The student must perform original research, present a written dissertation and defend the dissertation at a final oral presentation. The research is done under the supervision of a faculty adviser in the Aerospace Engineering department and a dissertation committee. Students are expected to begin research in their first year of graduate study.

### Ph.D. Degree

The Ph.D. degree is awarded upon successful completion of a Ph.D. dissertation, a Ph.D. defense, and other academic credit requirements. See the Rackham Graduate School Academic Policies for details. Students should have taken a minimum of 16 graduate courses beyond the bachelor's degree. There is no foreign language requirement, and there are no specific course requirements.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **AEROSP 201. Introduction to Aerospace Engineering**

*Prerequisite: Preceded by ENGR 100, ENGR 101, PHYS 140/141 and MATH 116 (3 credits)*

Introduction to Aerospace Engineering. Flight vehicles in the atmosphere and in space. Flight technologies, including structures, materials, propulsion, aerodynamics, vehicle dynamics, flight control, flight information systems and systems integration. An overview of aeronautics. Steady aircraft flight and performance. An overview of astronautics.

### **AEROSP 205. Introduction to Aerospace Engineering Systems**

*Prerequisites: PHYS 140, 141, MATH 116, ENGR 100, ENGR 101 or 151. (3 credits)*

A Systems Engineering Experience: Introduces engineering processes by means of design, build, test and operation of flight vehicles. Exposure to technologies including: computer aided design, manufacturing, simulation, composites, mechanisms, instrumentation and basic electronics. Embedded software development for data acquisition and processing, control and communications. Individual and team projects.

### **AEROSP 215. Introduction to Solid Mechanics and Aerospace Structures**

*Prerequisite: Preceded or accompanied by MATH 216 and AEROSP 201. (4 credits)*

An introduction to the fundamental phenomena of solid and structural mechanics in Aerospace systems. Includes analysis and numerical methods of solutions used for design of thin-walled Aerospace structures. Emphasis is placed on understanding behavior particular to thin-walled structures.

### **AEROSP 225. Introduction to Gas Dynamics**

*Prerequisite: MATH 215, CHEM 125/130, Physics 140/141. (4 credits)*

This course covers fundamental concepts in thermodynamics and fluid dynamics. Topics include molecular

and continuum concepts for fluids, first and second laws of thermodynamics, conservation laws for moving fluids, one-dimensional compressible flows, shocks and expansion waves, flows in nozzles, and two- and three-dimensional compressible flows.

### **AEROSP 285. Aerospace Engineering Seminar**

*Prerequisite: Preceded or accompanied by AEROSP 201. (1 credit)*

Seminars by noted speakers, designed to acquaint undergraduates with contemporary technologies and broader issues in the global aerospace enterprise. Technical communications based upon the seminars.

### **AEROSP 290. Directed Study**

*Prerequisite: Permission of instructor (1-3 credits)*

Study aspects of aerospace engineering that are not suitable for technical elective credit. May be used for student team projects, pilot ground school, UROP or other academic studies that are directed by an Aerospace Engineering faculty member.

### **AEROSP 305. Aerospace Engineering Laboratory I**

*Prerequisite: Preceded or accompanied by EECS 206 or 215 or EECS 314. Preceded by AEROSP 205, AEROSP 225 and AEROSP 215. (4 credits)*

First course of a two-semester sequence covering fundamentals of instrumentation and measurement and their application in engineering testing and experimentation. Includes principles of analog and digital data acquisition, analysis of discrete measurement data, statistical assessment of hypotheses, design of experiments and similarity scaling of data. Emphasized development of skills for written communication and for working effectively in a team environment.

### **AEROSP 315. Aircraft and Spacecraft Structures**

*Prerequisite: Preceded by AEROSP 215 and MATH 216. (4 credits)*

Concepts of displacement, strain, stress, compatibility, equilibrium and constitutive equations as used in solid mechanics. Emphasis is on boundary-value problem formulation via simple examples, followed by the use of the finite-element method for solving problems in vehicle design.

**AEROSP 325. Aerodynamics**

*Prerequisite: Preceded by MATH 216 and AEROSP 225. (4 credits)*

Fundamental concepts in aerodynamics. Students learn how airfoils produce lift and how the pressure distribution about an airfoil can be calculated. Introduces the boundary-layer concept, how boundary layers lead to drag and what makes them prone to instability and turbulence or separation. Effects of the wing planform shape on lift and drag. Introduction to airfoil design, high-lift devices and high-speed aerodynamics.

**AEROSP 335. Aircraft and Spacecraft Propulsion**

*Prerequisite: Preceded by AEROSP 225 and MATH 216. (4 credits)*

Airbreathing propulsion, rocket propulsion and an introduction to modern advanced propulsion concepts. Includes thermodynamic cycles as related to propulsion and the chemistry and thermodynamics of combustion. Students analyze turbojets, turbofans and other air-breathing propulsion systems. Introduces liquid- and solid-propellant rockets and advanced propulsion concepts such as Hall thrusters and pulsed plasma thrusters. Students also learn about the environmental impact of propulsion systems and work in teams to design a jet engine.

**AEROSP 347. Space Flight Mechanics**

*Prerequisite: Preceded by ME 240, Math 216, and AE 201 (3 credits)*

Introduction to space flight mechanics. The two-body problem. Orbital transfers, maneuvers and orbital analysis. Ground tracks and relative motion in orbit. Gravity assist trajectories. Spacecraft attitude and rotational dynamics. Euler's and Poisson's equations. Stability analysis. Open loop attitude control momentum management using thrusters and reaction wheels.

**AEROSP 348. Aircraft Dynamics and Control**

*Prerequisite: Preceded by AE 347 (3 credits)*

Introduction to the dynamics and control of atmospheric flight vehicles. Nonlinear equations of motion. Stability derivatives and linearized equations for longitudinal and lateral flight dynamics. Concepts from linear systems: state equations, transfer functions, stability, time response, frequency response. Fundamentals of feedback control, including root locus and Nyquist

analysis applied to flight control.

**AEROSP 384. Introduction to Solid Modeling and CAD**

*Prerequisite: Preceded or accompanied by AEROSP 201 and AEROSP 215. (3 credits)*

Design process including specifications, configurations, trades and design drivers. Introduction to solid visualization and modeling through an integrated CAD/CAE/CAM/PDM software package in the context of the design process. The role of CAD in analysis, manufacturing and product management. Flight vehicle related projects.

**AEROSP 390. Directed Study**

*Prerequisite: Permission of instructor (1-3 credits)*

Study specialized aspects of aerospace engineering. May be used for student team projects, pilot certification or other academic studies that are directed by an Aerospace Engineering faculty member. The student will submit a final report.

**AEROSP 405. Aerospace Laboratory II**

*Prerequisite: Preceded by AEROSP 305. Preceded or accompanied by AEROSP 315 and AEROSP 325. (4 credits)*

Second course of a two-semester sequence covering fundamentals of instrumentation and measurement and their application in engineering testing and experimentation. Focuses primarily on application of the fundamental principles learned in Aero 305 to more advanced test and measurement applications. Involves instructor-designed experiments and one major project conceived, designed, conducted, analyzed and reported by student teams. Emphasizes development of skills for written communication and for working effectively in a team environment.

**AEROSP 416 (NAVARCH 416). Theory of Plates and Shells**

*Prerequisite: AEROSP 315. (3 credits)*

Linear elastic plates. Membrane and bending theory of axisymmetric and non-axisymmetric shells. Variational formulation of governing equations boundary conditions. Finite element techniques for plate and shell problems.

**AEROSP 421. Engineering Aerodynamics***Prerequisite: AEROSP 325. (3 credits)*

This course teaches contemporary aerodynamic analysis and design of aerospace vehicles and other systems. Topics include: review of theoretical concepts and methods, computer-based CFD tools, experimental methods and wind tunnel testing. Case studies are discussed to illustrate the combined use of advanced aerodynamic design methods. A team project is required.

**AEROSP 423. Computational Methods for Aerospace Engineering***Prerequisite: ENGR 101 or ENGR 151 and MATH 216 w/ minimum grade of C-. (3 credits)*

This course covers computational methods used in Aerospace engineering, including time integration techniques for ordinary differential equations, finite differences, finite volumes, finite elements, and probabilistic methods. Emphasis is placed on analysis and implementation of the underlying numerical methods. Computer programming in Matlab or a similar language is required.

**AEROSP 445. Flight Dynamics of Aerospace Vehicles***Prerequisite: AEROSP 348. (3 credits)*

Flight-oriented models of aerospace vehicles. Analytical modeling principles for analysis and control. Computer-based simulation, performance evaluation and model validation. Flight properties of various aerospace vehicles, such as fixed-wing aircraft, rotorcraft, launch and reentry vehicles, orbiters and interplanetary vehicles.

**AEROSP 447. Flight Testing***Prerequisite: AEROSP 305 and AEROSP 348. (3 credits)*

Theory and practice of obtaining flight-test data on performance and stability of airplanes from actual flight tests. Modern electronic flight test instrumentation, collection of flight test data, calibration procedures for air data sensors, estimation of stability derivatives from flight test data.

**AEROSP 450. Flight Software Systems***Prerequisite: ENGR 101 and AEROSP 201, or graduate standing. (3 credits)*

Theory and practice of embedded flight software systems. Computational theory topics include discrete mathematics, finite automata, computational complexity and model checking. Software development concepts include object oriented programming, networks, multi-threaded software, real-time scheduling and sensor/actuator interface protocols. Emphasis placed on C/C++ development in Linux with guidance, navigational control applications.

**AEROSP 464 (AOSS 464) (ENSCEN 464). The Space Environment***Prerequisite: Senior or graduate standing in a physical science or engineering. (3 credits)*

An introduction to physical and aeronomical processes in the space environment. Discussion of theoretical tools, the Sun, solar spectrum, solar wind, interplanetary magnetic field, planetary magnetosphere, ionospheres and upper atmospheres. Atmospheric processes, densities, temperatures and wind.

**AEROSP 481. Aircraft Design***Prerequisite: Preceded by AEROSP 325. Preceded or accompanied by AEROSP 315, AEROSP 335 and AEROSP 348. (4 credits)*

Multidisciplinary integration of aerodynamics, performance, stability and control, propulsion, structures and aeroelasticity in a systems approach aimed at designing an aircraft for a set of specifications. Includes weight estimates, configuration and power plant selection, tail-sizing, maneuver and gust diagrams, wing loading, structural and aeroelastic analysis. Students work in teams on the design project.

**AEROSP 483. Space System Design***Prerequisite: Preceded by AEROSP 347. Preceded or accompanied by AEROSP 315, 325, and 335. (4 credits)*

Introduction to the engineering design process for space systems. Includes a lecture phase that covers mission planning, launch vehicle integration, propulsion, power systems, communications, budgeting and reliability. Subsequently, students experience the latest practices in space-systems engineering by forming into mission-component teams and collectively designing a space mission. Effective team and communication skills are emphasized. Report writing and presentations

are required throughout, culminating in the final report and public presentation.

#### **AEROSP 484. Computer Aided Design**

*Prerequisite: Preceded by AEROSP 315, AEROSP 325, AEROSP 335, and AEROSP 345. (4 credits)*

Advanced computer-aided design. Students learn about computer generation of geometric models, calculation of design parameters, trade-off diagrams and finite-element modeling and analysis. Each student carries out a structural component design using industry-standard software. The course includes individual and team assignments.

#### **AEROSP 490. Directed Study**

*Prerequisite: Permission of instructor (1-3 credits)*

Study of advanced aspects of aerospace engineering directed by an Aerospace faculty member. The student will submit a final report.

#### **AEROSP 495. Special Topics in Aerospace Engineering**

*Prerequisite: Permission of instructor. (1-4 credits)*

Specific aerospace engineering topics that are not treated in the regular Aerospace Engineering undergraduate curriculum.

#### **AEROSP 510. Finite Elements in Mechanical and Structural Analysis I**

*Prerequisite: AEROSP 315. (3 credits)*

Introductory level. Finite element solutions for structural dynamics and nonlinear problems. Normal modes, forced vibrations, Euler buckling (bifurcations), large deflections, nonlinear elasticity, transient heat conduction. Computer laboratory based on a general purpose finite element code.

#### **AEROSP 511. Finite Elements in Mechanical and Structural Analysis II**

*Prerequisite: AEROSP 510 or MECHENG 505. (3 credits)*

Introduction to fundamental principles and latest developments in aerosol science. The dependence of aerosol composition and size distributions on the underlying atmospheric thermodynamics, dynamics, chemistry, and physics will be presented. Recent observations and theoretical treatments are used to illustrate aspects of

aerosol science that are poorly quantified at present.

#### **AEROSP 512. Experimental Solid Mechanics**

*Prerequisite: AEROSP 305, AEROSP 315 or equivalents. (3 credits)*

Lectures and experiments that demonstrate historical and contemporary methods of measurement in solid mechanics. A review of classical experiments that substantiate many typical assumptions (e.g., material linearity or Hooke's Law) concerning the response of solids. An introduction to contemporary techniques of process measurement involving piezoresistivity.

#### **AEROSP 513. Foundations of Solid and Structural Mechanics I**

*Prerequisite: AEROSP 315, MECHENG 311 or equivalent. (3 credits)*

Introduction to linear continuum and structural mechanics. Three-dimensional analysis of stress and infinitesimal strain, including transformation of tensors, equations of motion, and kinematic compatibility. Boundary value problem formation. Constitutive relations for isotropic and anisotropic linear elastic materials. Introduction to variational calculus and energy methods. Applications to thin-walled and slender aerospace structures.

#### **AEROSP 514. Foundations of Solid and Structural Mechanics II**

*Prerequisite: AEROSP 315 or equivalent. (3 credits)*

Introduction to nonlinear continuum and structural mechanics. Elements of tensor calculus, basic kinematics, conservation laws (mass, linear and angular momentum, energy, etc.), constitutive equations in continual applications in hyperelastic solids, numerical (f.e.m.) methods for the corresponding nonlinear boundary value problems, derivation of nonlinear shell theories from 3-D considerations.

#### **AEROSP 515. Mechanics of Composite and Microstructured Media**

*Prerequisite: AEROSP 514 or equivalent. (3 credits)*

An introduction to the mechanics of composite (more than one phase) solids with an emphasis on the derivation of macroscopical constitutive laws based on the microstructure. Eshelby transformation theory, self consistent methods, homogenization theory for periodic

media, bounding properties for effective moduli of composites. Applications of aerospace interest.

### **AEROSP 516. Mechanics of Fibrous Composites**

*Prerequisite: AEROSP 315 or MECHENG 412. (3 credits)*

Effective stiffness properties of composites. Constitutive description of laminated plates. Laminated plate theory. Edge effects in laminates. Nonlinear theory of generally laminated plates. Governing equations in the Von Karman sense. Laminated plates with moderately large deflections. Post-buckling and nonlinear vibration of laminated plates. Failure theories and experimental results for laminates.

### **AEROSP 518. Theory of Elastic Stability I**

*Prerequisite: AEROSP 315 or MECHENG 412 or the equivalent. (3 credits)*

Concepts of stability and bifurcation. Simple examples to illustrate buckling and instability mechanisms in structures. Both equilibrium and time dependent problems discussed. General theory for stability in continuum, conservative elastic solids. Applications to bars, rings, plates and shells.

### **AEROSP 520. Compressible Flow I**

*Prerequisite: AEROSP 325. (3 credits)*

Elements of inviscid compressible-flow theory: review of thermodynamics; equations of frictionless flow; analysis of unsteady one-dimensional and steady supersonic two-dimensional flows; including the method of characteristics; small-disturbance theory with applications to supersonic thin-airfoil theory.

### **AEROSP 521. Experimental Methods in Fluid Mechanics**

*Prerequisite: AEROSP 405 or Grad standing. (3 credits)*

Fundamentals principles and practice of non-intrusive measurement techniques for compressible and incompressible flows. Review of geometric and Gaussian beam optics; Laser Doppler Velocimetry; quantitative flow field measurement techniques including interferometry, Laser Induced Fluorescence and Particle Image Velocimetry. Advanced data processing techniques for turbulent flow. Error estimation.

### **AEROSP 522. Viscous Flow**

*Prerequisite: AEROSP 325. (3 credits)*

The Navier-Stokes equations, including elementary discussion of tensors, exact solutions. Laminar boundary-layer theory; three-dimensional and compressible boundary layers. Laminar-flow instability theory; transition. Introduction to the mechanics of turbulence; turbulent free shear flows and boundary layers.

### **AEROSP 523 (MECHENG 523). Computational Fluid Dynamics I**

*Prerequisite: AEROSP 325 or preceded or accompanied by MECHENG 520. (3 credits)*

Physical and mathematical foundations of computational fluid mechanics with emphasis on applications. Solution methods for model equations and the Euler and the Navier-Stokes equations. The finite volume formulation of the equations. Classification of partial differential equations and solution techniques. Truncation errors, stability, conservation, and monotonicity.

### **AEROSP 524. Aerodynamics II**

*Prerequisite: AEROSP 325. (3 credits)*

Two- and three-dimensional potential flow about wings and bodies; complex-variable methods; singularity distributions; numerical solution using panel methods. Unsteady aerodynamics; slender-body theory. Viscous effects: airfoil stall, high-lift systems, boundary-layer control. Wings and bodies at transonic and supersonic speeds; numerical methods.

### **AEROSP 525. Introduction to Turbulent Flows**

*Prerequisite: AEROSP 522. (3 credits)*

Mathematical description of turbulent flow phenomena. Flow equations, vorticity dynamics, Reynolds-averaged equations, engineering turbulence models. Theory of homogeneous turbulence, spectral dynamics. Shear flow turbulence, mean and fluctuating structure of free and wall-bounded turbulent flows.

### **AEROSP 526. Hypersonic Aerothermodynamics**

*Prerequisite: Graduate standing or AEROSP 225 and AEROSP 325. (3 credits)*

Hypersonic vehicles offer rapid air transportation and access to space. This course provides an introduction to the aerothermodynamics of hypersonic vehicles. Topics covered include: vehicle types (missiles, space planes,

air-breathers); flight dynamics (trajectory, range, stability); aerothermodynamics (fluid dynamics, thermodynamics, aerodynamics, heating); and propulsion systems (scramjets, combined cycles).

### **AEROSP 527. Unsteady Aerodynamics and Aeroacoustics**

*Prerequisite: AEROSP 325 or equivalent or permission of instructor. (3 credits)*

Theoretical and numerical aspects of unsteady aerodynamics and aerodynamically-generated noise. Topics include vortex dynamics, steady and unsteady airfoil theory, indicial methods, unsteady compressible flow, basics of physical acoustics, sound generation by moving bodies and turbulence, combustion noise.

### **AEROSP 530. Gas-Turbine Propulsion**

*Prerequisite: AEROSP 335. (3 credits)*

Advanced analysis of turbojet engines: effect of altitude parameters on engine performance; off-design equilibrium running of a turbojet engine; dynamics of engine considered as a quasi-static system; fluid mechanics of a rotating axial blade row; centrifugal compressors; transonic flow problems.

### **AEROSP 532. Molecular Gas Dynamics**

*Prerequisite: Permission of instructor. (3 credits)*

Analysis of basic gas properties at the molecular level. Kinetic theory: molecular collisions, the Boltzmann equation. Maxwellian distribution function. Quantum mechanics: the Schrodinger equation, quantum energy states for translation, rotation, vibration, and electronic models of atoms and molecules. Statistical mechanics: the Boltzmann relation, the Boltzmann energy distribution, partition functions. These ideas are combined for the analysis of a chemically reacting gas at the molecular level.

### **AEROSP 533 (ENSCEN 533). Combustion Processes**

*Prerequisite: AEROSP 225. (3 credits)*

This course covers the fundamentals of combustion systems and fire and explosion phenomena. Topics covered include thermochemistry, chemical kinetics, laminar flame propagation, detonations and explosions, flammability and ignition, spray combustion and the use of computer techniques in combustion problems.

### **AEROSP 535. Rocket Propulsion**

*Prerequisite: AEROSP 335. (3 credits)*

Analysis of liquid and solid propellant rocket power plants; propellant thermochemistry, heat transfer, system considerations. Low-thrust rockets, multi-stage rockets, trajectories in powered flight, electric propulsion.

### **AEROSP 536. Electric Propulsion**

*Prerequisite: AEROSP 335, senior standing. (3 credits)*

Introduction to electric propulsion with an overview of electricity and magnetism, atomic physics, non-equilibrium flows and electrothermal, electromagnetic and electrostatic electric propulsion systems.

### **AEROSP 540 (MECHENG 540). Intermediate Dynamics**

*Prerequisite: MECHENG 240. (3 credits)*

Newton/Euler and Lagrangian formulations for three dimensional motion of particles and rigid bodies. Principles of dynamics applied to various rigid-body and multi-body dynamics problems that arise in aerospace and mechanical engineering.

### **AEROSP 543. Structural Dynamics**

*Prerequisite: AEROSP 315 or AEROSP 540. (3 credits)*

A Natural frequencies and mode shapes of elastic bodies. Nonconservative elastic systems. Structural and viscous damping. Influence coefficient methods for typical flight structures. Response of structures to random and shock loads.

### **AEROSP 544. Aeroelasticity**

*Prerequisite: AEROSP 315 or AEROSP 540. (3 credits)*

Vibration and flutter of elastic bodies exposed to fluid flow. Static divergence and flutter of airplane wings. Flutter of flat plates and thin walled cylinders at supersonic speeds. Oscillations of structures due to vortex shedding.

### **AEROSP 545. Aeromechanics of Rotary Wing Vehicles**

*Prerequisite: Preceded by AERO 315 and AERO 325. (3 credits)*

This course deals with fundamental aspects of helicopter aerodynamics, performance, dynamics, stability and control, aeroelastic stability in flap-pitch, flap-lag and coupled flap-lag-torsion. Aeroelastic response in forward flight or the vibration problem is also considered.

#### **AEROSP 548. Astrodynamics**

*Prerequisite: AEROSP 347 or graduate standing. (3 credits)*

Review of two-body problem for spacecraft: orbital trajectories, transfers, targeting and time of flight. Orbit perturbation formulations and analysis. Restricted 3-body problem and applications.

#### **AEROSP 549. Orbital Analysis and Determination**

*Prerequisite: Either AEROSP 548, AEROSP 540, or AEROSP 573 - Permission of Instructor. (3 credits)*

The analysis, characterization and determination of space trajectories from a dynamical systems viewpoint. The general formulation and solution of the spacecraft trajectory design and navigation problems. Computation of periodic orbits and their stability. Estimation of model parameters from spacecraft tracking data (e.g., gravity field estimation). Elements of precision modeling and precision orbit determination.

#### **AEROSP 550 (CEE 571) (EECS 560) (MECHENG 564). Linear Systems Theory**

*Prerequisite: Graduate standing. (4 credits)*

Linear spaces and linear operators. Bases, subspaces, eigenvalues and eigenvectors, canonical forms. Linear differential and difference equations. Mathematical representations: state equations, transfer functions, impulse response, matrix fraction and polynomial descriptions. System-theoretic concepts: causality, controllability, observability, realizations, canonical decomposition, stability.

#### **AEROSP 551 (EECS 562). Nonlinear Systems and Control**

*Prerequisite: Graduate standing. (3 credits)*

Introduction to the analysis and design of nonlinear systems and nonlinear control systems. Stability analysis using Liapunov, input-output and asymptotic methods. Design of stabilizing controllers using a variety of methods: linearization, absolute stability theory, vibrational control, sliding modes and feedback lineariza-

tion.

#### **AEROSP 552. Aerospace Information Systems**

*Prerequisite: ENGR 101 and MATH 216 or graduate standing. (3 credits)*

Information systems for Aerospace applications. Data abstraction, elementary data structures. Graphs, automata theory. Life cycle models, validation & verification. Deterministic search algorithms. Decision making under uncertainty; review of probability theory, introduction to information theory, Bayesian Networks, Markov chains, Markov Decision Processes. Substantial code development in a traditional programming language.

#### **AEROSP 566. Data Analysis and System Identification**

*Prerequisite: Graduate standing (3 credits)*

Methods of data analysis and empirical modeling. Sensors and measurement concepts. Time and frequency data analysis; statistical and spectral concepts. Linear regression and identification of time-series models. Parameter estimation using optimization. Basis-function expansions and nonlinear time series identification. Eigensystem realization and subspace identification. Nonlinear state space identification.

#### **AEROSP 573. Dynamics and Control of Spacecraft**

*Prerequisite: AEROSP 347 or graduate standing. (3 credits)*

Introduction to spacecraft dynamics and control. Spacecraft orbit and attitude representations, kinematics, dynamics. Perturbation equations for near circular orbits. Spacecraft maneuvers formulated and solved as control problems.

#### **AEROSP 574 (AOSS 574). Introduction to Space Physics**

*Prerequisite: Senior or graduate standing. (4 credits)*

A graduate level introduction to physical and aeronomical processes in the space environment. Discussion of theoretical tools, the Sun, solar wind, heliosphere, magnetosphere, ionosphere and the upper atmosphere. Spacecraft interaction with radiation, spacecraft-plasma interactions.

#### **AEROSP 575. Flight and Trajectory Optimization**

*Prerequisite: AEROSP 348 or graduate standing. (3*

*credits)*

Formulation and solution of optimization problems for atmospheric flight vehicles and space flight vehicles. Optimality criteria, constraints, vehicle dynamics. Flight and trajectory optimization as problems of non-linear programming, calculus of variations and optimal control. Algorithms and software for solution of flight and trajectory optimization problems.

#### **AEROSP 579. Control of Structures and Fluids**

*Prerequisite: AEROSP 348 or graduate standing. (3 credits)*

Stabilization and vibration suppression for structures and fluids. Control-oriented modeling of structural and acoustic dynamics. Fixed-gain and adaptive control methods. Control-oriented fluid dynamics for compressible and incompressible fluids. Feedback stabilization of laminar flow, rotating surge and stall.

#### **AEROSP 580 (EECS 565). Linear Feedback Control Systems**

*Prerequisite: EECS 460 or AEROSP 345 or MECHENG 461 and AEROSP 550 (EECS 560). (3 credits)*

Control design concepts for linear multivariable systems. Review of single variable systems and extensions to multivariable systems. Purpose of feedback. Sensitivity, robustness, and design trade-offs. Design formulations using both frequency domain and state space descriptions. Pole placement/observer design. Linear quadratic Gaussian based design methods. Design problems unique to multivariable systems.

#### **AEROSP 581 (AOSS 581). Space System Management**

*Prerequisite: Graduate standing. (3 credits)*

The first part of the course will provide detailed information on how space policy is developed in the United States and the international space community, and how these policies result in specific missions. The second part will provide detailed information on modern management techniques and processes. Project managers from NASA centers and industry will lecture on the detailed management techniques and processes.

#### **AEROSP 582 (AOSS 582). Spacecraft Technology**

*Prerequisite: Graduate standing. (4 credits)*

Systematic and comprehensive review of spacecraft and space mission design and key technologies for space missions. Discussions on project management and the economic and political factors that affect space missions. Specific space mission designs are developed in teams. Students of AERO 483/583 choose their projects based on these designs.

#### **AEROSP 583. Management of Space Systems Design**

*Prerequisite: Preceded by AEROSP 582. (4 credits)*

Meets with Aero. Eng. 483 (Space System Design), or other senior design course when appropriate topic is chosen. Students in this course lead teams in high level project design of a space system. Modern methods of concurrent engineering manufacturing, marketing and finance, etc., are incorporated.

#### **AEROSP 584. Avionics, Navigation and Guidance of Aerospace Vehicles**

*Prerequisite: AEROSP 348 or graduate standing. (3 credits)*

Principles of aerospace navigation and guidance. Deterministic and stochastic linear perturbation theory. Position fixing and celestial navigation with redundant measurements. Recursive navigation and Kalman filtering. Pursuit guidance, proportional navigation, ballistic guidance and velocity-to-be-gained guidance.

#### **AEROSP 585. Aerospace Engineering Seminar**

*Prerequisite: AEROSP 285 or senior standing. (1 credit)*

A series of seminars by noted speakers designed to acquaint graduate and undergraduate students with contemporary research and technological issues in the aerospace industry. Involves a short term paper pertinent to one of the seminar topics.

#### **AEROSP 588. Multidisciplinary Design Optimization**

*Prerequisite: MATH 419 or equivalent, MATH 371 or equivalent, graduate standing. (3 credits)*

Introduction to numerical optimization and its application to the design of aerospace systems, including: mathematical formulation of multidisciplinary design problems, overview of gradient-based and gradient-free algorithms, optimality conditions (unconstrained and

constrained, Pareto optimality), sensitivity analysis and multidisciplinary problem decomposition. No background in aerospace is required.

### **AEROSP 590. Directed Study**

*Prerequisite: Graduate standing and permission of instructor. (1-6 credits)*

Study of advanced aspects of aerospace engineering directed by an Aerospace faculty member. Primarily for graduates. The student will submit a final report.

### **AEROSP 597 (AOSS 597). Fundamentals of Space Plasma Physics**

*Prerequisite: Senior-level statistical physics course. (3 credits)*

Basic plasma concepts, Boltzmann equation, higher order moments equations, MHD equations, double adiabatic theory. Plasma expansion to vacuum, transonic flows, solar wind, polar wind. Collisionless shocks, propagating and planetary shocks. Fokker-Planck equation, quasilinear theory, velocity diffusion, cosmic ray transport, shock acceleration. Spacecraft charging, mass loading.

### **AEROSP 611. Advanced Topics in Finite Element Structural Analysis**

*Prerequisite: AEROSP 511 or MECHENG 605. (3 credits)*

Cyclic symmetry, design sensitivities and optimization. Applications to stress analysis, vibration, heat conduction, centrifugal effects, buckling. Introduction to high-level matrix-oriented programming languages (e.g., Direct Matrix Abstraction Program). Use of a large, general purpose finite element code as a research tool.

### **AEROSP 614. Advanced Theory of Plates and Shells**

*Prerequisite: AEROSP 416. (3 credits)*

Differential geometry of surfaces. Linear and nonlinear plate and shell theories in curvilinear coordinates. Anisotropic and laminated shells. Stability and post-buckling behavior. Finite element techniques, including special considerations for collapse analysis.

### **AEROSP 615 (CEE 617) (MECHENG 649). Random Vibrations**

*Prerequisite: MATH 425 or equivalent, CEE 513 or*

*MECHENG 541 or AEROSP 543 or equivalent. (3 credits)*

Introduction to concepts of random vibration with applications in civil, mechanical and aerospace engineering. Topics include: characterization of random processes and random fields, calculus of random processes, applications of random vibrations to linear dynamical systems, brief discussion on applications to nonlinear dynamical systems.

### **AEROSP 618. Theory of Elastic Stability II**

*Prerequisite: AEROSP 518 or equivalent and graduate standing. (3 credits)*

Koiter's theory for buckling, post-buckling, mode interaction and imperfection sensitivity behavior in nonlinear solids. Applications to thin-walled beams, cylindrical and spherical shells as well as to 3-D hyperelastic solids. Loss of ellipticity in finitely strained solids. Hill's theory on bifurcation, uniqueness and post-bifurcation analysis in elastic-plastic solids with applications.

### **AEROSP 623. Computational Fluid Dynamics II**

*Prerequisite: AEROSP 523 or equivalent, substantial computer programming experience, and AEROSP 520. (3 credits)*

Advanced mathematical and physical concepts in computational fluid dynamics, with applications to one- and two-dimensional compressible flow. Euler and Navier-Stokes equations, numerical flux functions, boundary conditions, monotonicity, marching in time, marching to a steady state, grid generation.

### **AEROSP 625. Advanced Topics in Turbulent Flow**

*Prerequisite: AEROSP 525. (3 credits)*

Fundamentals of turbulent shear flows, with emphasis on dimensional reasoning and similarity scaling. Development of laminar shear flows, instability and transition to turbulent flow, kinetic and scalar energy transport mechanisms in turbulent shear flows, critical examination of numerical methods for turbulent flows, comparisons with experiments.

### **AEROSP 627. Advanced Gas Dynamics**

*Prerequisite: AEROSP 520, AEROSP 522. (3 credits)*

Linear and nonlinear surface waves. Flow instabilities; nonlinear stability analysis. Vorticity dynamics: vortex motions, instabilities and breakdown. Boundary layers:

steady and unsteady interactions; nonlinear instability.

**AEROSP 633. Advanced Combustion**

*Prerequisite: AEROSP 533. (3 credits)*

Thermodynamics of gas mixtures, chemical kinetics, conservation equations for multi-component reacting gas mixtures, deflagration and detonation waves. Nozzle flows and boundary layers with reaction and diffusion.

**AEROSP 714. Special Topics in Structural Mechanics**

*Prerequisite: Permission of instructor. Term offered depends on special topic (to be arranged)*

**AEROSP 729. Special Topics in Gas Dynamics**

*Prerequisite: Permission of instructor (to be arranged)*

Advanced topics of current interest.

**AEROSP 740. Special Topics in Flight Dynamics and Control Systems**

*(to be arranged)*

**AEROSP 800. Seminar****AEROSP 810. Seminar in Structures**

*(to be arranged)*

**AEROSP 820. Seminar in Aerodynamics**

*(to be arranged)*

**AEROSP 830. Seminar in Propulsion**

*(to be arranged)*

**AEROSP 840. Dynamics and Control Systems**

*(to be arranged)*

**AEROSP 990. Dissertation/Pre-Candidate**

*(2-8 credits); (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**AEROSP 995. Dissertation/Candidate**

*Prerequisite: Graduate School authorization for admission as a doctoral candidate. (8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Biomedical Engineering

## Overview

Students who enjoy math, physics and chemistry, but who also have a keen interest in biology and medicine, should consider a career in Biomedical Engineering (BiomedE). Synthetic heart valves, the fMRI scanner and automatic bio-sensors for rapid gene sequencing are each examples of BiomedE. BiomedE is the newest engineering discipline, integrating the basic principles of biology with the tools of engineering.

With the rapid advances in biomedical research, and the severe economic pressures to reduce the cost of health care, BiomedE plays an important role in the medical environment of the 21st century. Over the last decade, BiomedE has evolved into a separate discipline bringing the quantitative concepts of design and optimization to problems in biomedicine.

The opportunities for biomedical engineers are wide ranging. The medical-device and pharmaceutical industries are increasingly investing in biomedical engineers. As gene therapies become more sophisticated, biomedical engineers will have a key role in bringing these ideas into real clinical practice. Finally, as technology plays an ever-increasing role in medicine, there will be a larger need for physicians with a solid engineering background. From biotechnology to tissue engineering, from medical imaging to microelectronic prosthesis, from biopolymers to rehabilitation engineering, biomedical engineers are in demand.

## Department Administration

### Department Chair

Lonnie Shea, William and Valerie Hall Department  
Chair of Biomedical Engineering  
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## Mission

The mission of the Department of Biomedical Engineering is to provide leadership in education, training and cutting-edge research by translating science and engineering to solve important challenges in medicine and life sciences to the benefit of humanity.

## Goals

To provide students with the education needed for a rewarding career.

## Objectives

The Accreditation Board for Engineering and Technology (ABET) defines the Program Educational Objectives as accomplishments that are expected of our graduates within a few years after graduation. In recognition of the fact that BiomedE graduates may pursue a broad range of careers, the BiomedE Program Objectives are phrased to reflect the preparation provided by the program for these career options. The Program Educational Objectives for the Department of BiomedE are that our students are:

1. Prepared for professional practice in entry-level BiomedE positions or to pursue graduate study in engineering, medicine and other professional degree programs through rigorous instruction in the engineering sciences and biology, including laboratory and design experience;
2. Prepared for a variety of careers resulting from the opportunity to deepen their technical understanding in a particular subject via a program of related technical electives and from the development of team-

work, communication and other non-technical skills.

## Outcomes

- An ability to apply knowledge of mathematics, science and engineering to biomedical engineering problems. (ABET 3a)
- An ability to design and conduct experiments, as well as to analyze and interpret data. (ABET 3b)
- An ability to design a system; component, or process to meet desired needs. (ABET 3c)
- An ability to function on multi-disciplinary teams. (ABET 3d)
- An ability to identify, formulate and solve engineering problems. (ABET 3e)
- An understanding of professional and ethical responsibility. (ABET 3f)
- An ability to communicate effectively orally and in writing. (ABET 3g)
- The broad education necessary to understand the impact of engineering solutions in a global and societal context. (ABET 3h)
- A recognition of the need for, and an ability to engage in life-long learning. (ABET 3i)
- A knowledge of contemporary issues. (ABET 3j)
- An ability to use the techniques, skills and modern engineering and computing tools necessary for engineering practice. (ABET 3k)
- A knowledge of biology and physiology. (Program)
- The capability to apply advanced mathematics (including differential equations and statistics), science and engineering to solve the problems at the interface of engineering and biology. (Program)
- An ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living materials and systems. (Program)

## Undergraduate

### Degree Program

BiomedE offers a four year undergraduate degree along with a recommended one year masters degree in a Sequential Undergraduate/Graduate Studies (SUGS) program. Qualified undergraduates may pursue a combined undergraduate/graduate program in one of three concentrations: biochemical, bioelectrics, or biomechanics, leading to a Bachelor of Science in Engineering degree (B.S.E. in Biomedical Engineering). Six graduate concentrations: bioelectrics, biomaterials, biomechanics, biotechnology, biomedical imaging, and medical product development, leading to a Master of Science in Engineering degree (M.S. in Biomedical Engineering).

# Sample Schedule

## B.S.E. in Biomedical Engineering

The Biomedical Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website: <http://www.bme.umich.edu/programs/undergrad/current.php>.

	Total Credit Hours	Term:									
		1	2	3	4	5	6	7	8	9	10
<b>Subjects Required by all Programs (53 hours)</b>											
Mathematics 115, 116, 215, 216	16	4	4	4	4	-	-	-	-	-	-
Engineering 100, Introduction to Engineering	4	4	-	-	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	-	4	-	-	-	-	-	-	-	-
Chemistry 130 <sup>1</sup>	3	3	-	-	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	5	5	-	-	-	-	-	-	-	-
Intellectual Breadth	16	-	4	4	4	4	-	-	-	-	-
<b>Advanced Science and Math (12 hours)</b>											
Biology 172 or 174, Introduction to Biology (If using AP Bio credit(195), then Bio 173 (2) is required.)	4	-	-	-	4	-	-	-	-	-	-
Chemistry 210/211, Structure and Reactivity I and Lab	5	-	-	5	-	-	-	-	-	-	-
MCDB 310, Introduction to Biological Chemistry or BIOCHEM 415, Introduction to Biological Chemistry or Chemistry 351, Fundamentals of Biochemistry	3	-	-	-	-	-	3	-	-	-	-
<b>Required Program Subjects (36 hours)</b>											
BIOMEDE 211, Circuits & Systems for Biomedical Engineers	4	-	-	-	-	4	-	-	-	-	-
BIOMEDE 221, Biophysical Chemistry & Thermodynamics	4	-	-	-	-	4	-	-	-	-	-
BIOMEDE 231, Introduction to Biomechanics	4	-	-	-	4	-	-	-	-	-	-
BIOMEDE 241, Biomedical Undergraduate Lab	4	-	-	-	-	4	-	-	-	-	-
BIOMEDE 350, Introduction to Biomedical Design	3	-	-	-	-	-	3	-	-	-	-
BIOMEDE 418, Quantitative Cell Biology	3	-	-	-	-	-	3	-	-	-	-
BIOMEDE 419, Quantitative Physiology	4	-	-	-	-	-	-	4	-	-	-
BIOMEDE 450, Biomedical Design or	4	-	-	-	-	-	-	-	4	-	-
BIOMEDE 451, Biomedical Design, Part I and	2	-	-	-	-	-	-	2	-	-	-
BIOMEDE 452, Biomedical Design, Part II	3	-	-	-	-	-	-	-	3	-	-
BIOMEDE 458, Biomedical Instrumentation & Design	4	-	-	-	-	-	-	4	-	-	-
MATSCIE 250, Principles of Engineering Materials	4	-	-	4	-	-	-	-	-	-	-
<b>Concentration Requirements and Electives<sup>3</sup> (14 hours)</b>											
General Electives (11 hours)	11	-	-	-	-	-	4	4	3	-	-
<b>Total</b>	<b>128</b>	<b>16</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>17</b>	<b>16-18</b>	<b>12-13</b>	<b>-</b>	<b>-</b>
<b>M.S. Biomedical Engineering</b>											
<b>Required Program Subjects M.S. (14-15 hours)</b>											
Advanced Math	3	-	-	-	-	-	-	-	-	3	-
Advanced Statistics	3	-	-	-	-	-	-	-	-	-	3
BIOMEDE 500, Seminar	1	-	-	-	-	-	-	-	-	-	1
BIOMEDE 550, Ethics & Enterprise	1	-	-	-	-	-	-	-	-	1	-
BIOMEDE 590, Directed Research (2-3) or BIOMEDE 599, Graduate Design, Part I (3) and BIOMEDE 599, Graduate Design, Part II (4)	2-7	-	-	-	-	-	-	-	-	1-3	1-4
Life Science	3	-	-	-	-	-	-	-	-	3	-
M.S. Concentration Requirements <sup>3</sup> (8 hours)	8	-	-	-	-	-	-	-	-	4	4
<b>M.S. Total Hours</b>	<b>21-26</b>	<b>-</b>	<b>-</b>	<b>12-14</b>	<b>9-12</b>						

Candidates for the Bachelor of Science in Engineering in Biomedical Engineering - B.S.E. in Biomed E. - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

### Notes:

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> Concentration requirements and electives: A list of approved courses is available on the department website and in 1111 Gerstacker.

## Concentrations

The undergraduate program is divided into three concentrations: the biochemical, bioelectrical and biomechanical. Organization of the undergraduate curriculum into concentrations allows students to gain deeper preparation in a chosen subarea of BiomedE. The concentrations are structured similarly, and each concentration consists of a set of required concentration courses as well as a list of concentration electives from which students must fulfill their credit requirements.

### Biochemical concentration

Advances in cellular and molecular biology have changed and expanded the ways that therapeutic devices and drugs are designed. Modern biotechnology depends on scientists and engineers who study the fundamental properties of cell, molecular and tissue biology and apply this to engineer chemicals and materials to interact with living systems. Goals include production of improved biomaterials for medical implants and prosthetics, tissues engineered for specific functionality and new therapeutic drugs. The biochemical curriculum emphasizes critical areas of chemistry, molecular biology, and cell biology, but also exposes students to a broad range of engineering approaches necessary for this interdisciplinary field. Graduates of this concentration are well prepared for jobs in the pharmaceutical or medical device industries, to attend professional schools, or study for a Ph.D. in BiomedE.

### Bioelectrical concentration

The bioelectrical area has a long history as a part of BiomedE program. This concentration allows students to study electrical and systems engineering in an integrated fashion. A goal of this concentration is to produce students who can see the interdependence of different engineering disciplines in the development of modern medical devices and analysis systems. Individuals completing this program will be able to work as engineers in the rapidly expanding medical diagnostic, therapeutic and systems industry. Students are prepared to pursue Ph.D. programs in Electrical Engineering, Systems Science or other BiomedE fields, and this concentration also provides the foundation for advanced degrees in medicine or basic medical science.

### Biomechanical concentration

Biomechanics permeates a wide range of fields that affect our everyday lives. Examples include designing work tasks to reduce physical stresses, designing surgical devices to withstand loads and developing advanced prostheses and surgical procedures to ensure proper physiological function. Biomechanics is a hybrid discipline requiring a thorough understanding of classic engineering mechanics, physiology and cell biology, as well as the interfaces between these fields. The goal of the biomechanical concentration is to provide students with a rigorous background in the mechanics and dynamics of solids and fluids, as well as physiology, cell biology, and molecular biology. Graduates are prepared for a wide range of professions including the medical device industry, automotive safety and biotechnology industries concerned with mechanically functional tissue. Students graduating from this concentration also have excellent preparation to attend medical school or pursue a Ph.D. in BiomedE or related fields.

## Sequential Undergraduate/ Graduate Study (SUGS)

The five-year Sequential Undergraduate/Graduate Study (SUGS) program permits students who enter the program in the first term of their senior year to receive the B.S.E. and M.S.E. degrees (or the B.S.E. and M.S. degrees) upon completion of a minimum of 149 credit hours. Students should speak with the department advising staff to learn more about the SUGS application process and procedures. SUGS admissions requirements will vary.

<http://www.engin.umich.edu/college/academics/bulletin/ug-ed/combined>

Available programs include:

- B.S.E. in Biomedical Engineering/M.S.E. in Biomedical Engineering
- B.S. in Cell and Molecular Biology/M.S. in Biomedical Engineering
- B.S.E. in Chemical Engineering/M.S.E. in Biomedical Engineering

- B.S.E. in Electrical Engineering and Computer Science/M.S.E. in Biomedical Engineering
- B.S.E. in Industrial and Operations Engineering/M.S.E. in Biomedical Engineering
- B.S.E. in Material Science Engineering/M.S.E. in Biomedical Engineering
- B.S.E. in Mechanical Engineering/M.S.E. in Biomedical Engineering

## Graduate

### Graduate Degrees

- Master of Science (M.S.) in Biomedical Engineering
- Doctor of Philosophy (Ph.D.) in Biomedical Engineering

### M.S. in Biomedical Engineering

The Department of Biomedical Engineering's graduate program at the University of Michigan is in the Rackham School of Graduate Studies granting the M.S. and Ph.D. degrees in Biomedical Engineering.

The department is interdisciplinary. A student may plan a widely diversified educational program to advance the student's personal goals. Research opportunities are as diversified as the range of activities conducted by the University units supporting the department.

### Entrance Requirements for the Department of Biomedical Engineering

Those students with a Bachelor of Science in Engineering or Physics degree should present a minimum background of:

- Biology Course with Lab or Physiology Course with Lab
- Biological Science
- Physics (2 terms)
- Mathematics (through ordinary differential equations)
- Minimum of 4 Engineering Courses

Each applicant's background and preparation is evaluated during the admission process. Our Graduate Admissions Committee frequently recommends applicants for admission who have not completed all prerequisites as undergraduates. These applicants must complete these courses as graduate students, usually in their first year of coursework.

### Degree Requirements

In order to obtain the master's degree in Biomedical Engineering, students must satisfactorily complete (B or better) a minimum of 30 credit hours of graduate study beyond the bachelor's degree. Within this requirement, a group of core courses or their equivalents in the biological sciences, and several graduate level engineering and physical science courses must be completed. Directed research work is required to familiarize the student with the unique problems associated with biological systems research. The core course requirements or their equivalent total 12-23 credit hours for each sub-group of the curriculum. There are six (6) curriculum options available:

- Bioelectrical
- Biomaterials
- Biomechanics
- Biotechnology
- Biomedical Imaging
- Medical Product Development

Please see the department web site for further details. A grade of "B" or better must be attained in each course used toward the master's degree.

### Ph.D. in Biomedical Engineering

The Ph.D. degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in her/his broad field of knowledge through completion of a prescribed set of courses and passing a comprehensive examination.

All Ph.D. students must satisfactorily complete (B or better) a minimum of nine (9) credit hours of letter graded course work (any electives with Rackham credit and approved by the student's research advisor) beyond those which are required for a master's degree. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

Requirements regarding foreign language and non-technical courses are left to individual departments or programs, and to the Graduate School. A prospective doctoral student should consult the program advisor regarding specific details.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **BIOMEDE 211. Circuits and Systems for Biomedical Engineering.**

*Prerequisite: MATH 214 or MATH 216, and Physics 240. (4 credits)*

Students learn circuits and linear systems concepts necessary for analysis and design of biomedical systems. Theory is motivated by examples from biomedical engineering. Topics covered include electrical circuit fundamentals, operational amplifiers, frequency response, electrical transients, impulse response, transfer functions and convolution, all motivated by circuit and biomedical examples. Elements of continuous time domain-frequency domain analytical techniques are developed.

### **BIOMEDE 221. Biophysical Chemistry and Thermodynamics**

*Prerequisite: CHEM 210 and MATH 116. Recommend MCDB 310 or Biol Chem 415 or CHEM 351 be taken concurrently. (4 credits)*

This course covers the physio-chemical concepts and processes relevant to life. The emphasis lies on the molecular level. Topics: Biomimetics; Energy and Driving Forces; Biochemical Equilibria; Aqueous Solutions; Molecular Self-Assembly; Bio-Electrochemistry; Biopolymers; Molecular Recognition and Binding Equilibria in Biology.

### **BIOMEDE 231. Introduction to Biomechanics**

*Prerequisite: MATH 116. (4 credits)*

This course will provide students with an introduction to topics in biomechanics, including statics, dynamics, and deformable body mechanics, as they apply to biological tissues and systems.

### **BIOMEDE 241. Biomedical Undergraduate Laboratory**

*Prerequisite: BIOMEDE 211, 221, and 231. (4 credits)*

This course provides an introduction to experimentation in circuits, systems, physical chemistry, thermodynamics, and mechanics with emphasis on biological applications. Lectures and laboratories on lab safety, measurement and analysis of physiological systems; operational amplifiers; rate of reaction; heat of reaction; whole body, tissue, and cellular mechanics; probability and statistical analysis.

### **BIOMEDE 280. Undergraduate Research**

*Prerequisite: Permission of instructor. (1-4 credits)*

This course offers research experience to first- and second-year Engineering students in an area of mutual interest to the student and to a faculty member within the College of Engineering. For each hour of credit, it is expected that the student will work a minimum of three hours per week. The grade for the course will be based on a final project/report evaluated by the faculty sponsor and participation in other required UROP activities, including bimonthly research group meetings and submission of a journal chronicling the research experience.

### **BIOMEDE 295. Biomedical Engineering Seminar**

*Prerequisite: None. (1 credit)*

Current research will be presented by faculty in the

BME department. The goal is to help students decide if they want to pursue a B.S. in BME or choose a different undergraduate major department as part of the SUGS program leading to an M.S. in BME.

### **BIOMEDE 311. Biomedical Signals and Systems**

*Prerequisite: BIOMEDE 211, EECS 215, or EECS 314. (4 credits)*

Theory and practice of signals and systems in both continuous and discrete time domains with examples from biomedical signal processing and control. Continuous-time linear systems convolution, steady-state responses, Fourier and Laplace transforms, transfer functions, poles and zeros, stability, sampling, feedback. Discrete-time linear systems: Z transform, filters, Fourier transform, signal processing.

### **BIOMEDE 321. Bioreaction Engineering and Design**

*Prerequisite: BIOMEDE 221, MCDB 310 or Biol Chem 415 or CHEM 351 (MCDB 310 or Biol Chem 415 or CHEM 351 may be concurrent). (3 credits)*

This course introduces topics in enzyme kinetics, enzyme inhibition, biochemical pathway engineering, mass and energy balance, cell growth and differentiation, cell engineering, bioreactor design, and analysis of the human body, organs, tissues, and cells as bioreactors. The application of bioreaction/bioreactor principles to tissue engineering is also discussed.

### **BIOMEDE 331. Introduction to Biofluid Mechanics**

*Prerequisite: Preceded by BIOMEDE 231 and MATH 215, 216 with a min. grade of C." (4 credits)*

This course introduces the fundamentals of biofluid dynamics and continuum mechanics, and covers the application of these principles to variety of biological flows. Fluid flow in physiology and biotechnology is investigated at a variety of scales, ranging from subcellular to whole body.

### **BIOMEDE 332. Introduction to Biosolid Mechanics**

*Prerequisite: Preceded by BIOMEDE 231 and Math 215, 216 with a min grade of C." (4 credits)*

This course covers the fundamentals of continuum mechanics and constitutive modeling relevant for biological tissues. Constitutive models covered include linear elasticity, nonlinear elasticity, viscoelasticity and poro-

elasticity. Structure-function relationships which link tissue morphology and physiology to tissue constitutive models will be covered for skeletal, cardiovascular, pulmonary, abdominal, skin, eye and nervous tissues.

### **BIOMEDE 350. Introduction to Biomedical Engineering Design**

*Prerequisite: Advised BIOMEDE 211, 221, 231; co-requisite BIOMEDE 241. (3 credits)*

This course uses problem-based learning to introduce students to biomedical engineering design concepts, tools and methodologies. Students will work in small groups and use virtual design and computational tools to propose and validate feasible solutions to real-world biomedical engineering problems with industrial and/or clinical relevance.

### **BIOMEDE 410 (MATSCIE 410). Design and Applications of Biomaterials**

*Prerequisite: MATSCIE 220 or 250 or permission of instructor. (3 credits)*

Biomaterials and their physiological interactions. Materials used in medicine/dentistry: metals, ceramics, polymers, composites, resorbable, smart, natural materials. Material response/degradation: mechanical breakdown, corrosion, dissolution, leaching, chemical degradation, wear. Host responses: foreign body reactions, inflammation, wound healing, carcinogenicity, immunogenicity, cytotoxicity, infection, local/systemic effects.

### **BIOMEDE 417. Electrical Biophysics**

*Prerequisite: BIOMEDE 211, or EECS 215 or EECS 314. (4 credits)*

Electrical biophysics of nerve and muscle; electrical conduction in excitable tissue; quantitative models for nerve and muscle including the Hodgkin Huxley equations; biopotential mapping, cardiac electrophysiology and functional electrical stimulation; group projects. Lecture and recitation.

### **BIOMEDE 418. Quantitative Cell Biology**

*Prerequisite: MCDB 310, BIOLCHEM 415, 515, or CHEM 351, and Physics 240, Math 216. (3 credits)*

This course introduces the fundamentals of cell structure and functioning. The goal is to provide a general background in cell biology, with emphasis placed on physical aspects that are of particular interest to engi-

neers.

### **BIOMEDE 419. Quantitative Physiology**

*Prerequisite: MCBD 310 or BIOLCHEM 415, 451, 515 or CHEM 351. (4 credits)*

Quantitative Physiology provides learning opportunities for senior undergraduate and graduate students to understand and develop competencies in a quantitative, research oriented, systems approach to physiology. Systems examined include cellular; musculoskeletal; cardiovascular; respiratory; endocrine; gastrointestinal; and renal. Mathematical models and engineering analyses are used to describe system performance where applicable.

### **BIOMEDE 424. (MECHENG 424) Engineering Acoustics**

*Prerequisite: MATH 216 and Physics 240. (3 credits)*

Vibrating systems; acoustic wave equation; plane and spherical waves in fluid media; reflection and transmission at interfaces; propagation in lossy media; radiation and reception of acoustic waves; pipes, cavities and waveguides; resonators and filters; noise; selected topics in physiological, environmental and architectural acoustics.

### **BIOMEDE 430. Rehabilitation Engineering and Assistive Technology**

*Prerequisite: Previous or simultaneous registration in IOE 333 or instructor approval. (3 credits)*

This is a lecture course which surveys the design and application of rehabilitation engineering and assistive technologies in a wide range of areas, including wheeled mobility, seating and positioning, environmental control, computer access, augmentative communication, sensory aids, as well as emerging technologies.

### **BIOMEDE 450. Biomedical Engineering Design**

*Prerequisite: BIOMEDE 458 and senior standing. (4 credits)*

Interdisciplinary designed groups carry out biomedical instrumentation design projects. Projects are sponsored by Medical School and College of Engineering research labs and local industry. Students are exposed to the entire design process: design problem definition, generation of a design specification, documentation, design review process, prototype fabrication, testing

and calibration.

### **BIOMEDE 451. Biomedical Engineering Design, Part I**

*Prerequisite: BIOMEDE 458 and senior standing. (2 credits)*

Two semester course - Interdisciplinary groups design-build-test biomedical instrumentation projects. Projects are sponsored by Medical School and Engineering research labs, and local industry. Students are exposed to the entire design process: Design problem definition, generation of a design specification, documentation, design review process, prototype fabrication, testing, and calibration.

### **BIOMEDE 452. Biomedical Engineering Design, Part II**

*Prerequisite: BIOMEDE 451, 458, and senior standing. (3 credits)*

Two semester course -- Interdisciplinary groups design-build-test biomedical instrumentation projects. Projects are sponsored by Medical School and Engineering research labs, and local industry. Students are exposed to the entire design process: design Problem definition, generation of a design specification, documentation, design review process, prototype fabrication, testing, and calibration.

### **BIOMEDE 456 (MECHENG 456). Modeling in Biosolid Mechanics**

*Prerequisite: BIOMEDE 332. (3 credits)*

Definition of biological tissue and orthopaedic device mechanics including elastic, viscoelastic and non-linear elastic behavior. Emphasis on structure function relationships. Overview of tissue adaptation and the interaction between tissue mechanics and physiology.

### **BIOMEDE 458 (EECS 458). Biomedical Instrumentation and Design**

*Prerequisite: (BIOMEDE 211 and BIOMEDE 241) or (EECS 215 or EECS 314) or graduate standing. (4 credits)*

Students design and construct functioning biomedical instruments. Hardware includes instrumentation amplifiers and active filters constructed using operational amplifiers. Signal acquisition, processing analysis and display are performed. Project modules include meas-

urement of respiratory volume and flow rates, biopotentials (electrocardiogram), and optical analysis of arterial blood oxygen saturation (pulse-oximetry).

**BIOMEDE 464 (MATH 464). Inverse Problems**

*Prerequisite: MATH 217, MATH 417, or MATH 419; and MATH 216, MATH 256, MATH 286, or MATH 316. (3 credits)*

Mathematical concepts used in the solution of inverse problems and analysis of related forward operators is discussed. Topics include ill-posedness, singular-value decomposition, generalized inverses, and regularization. Inverse problems considered (e.g., tomography, inverse scattering, image restoration, inverse heat conduction) are problems in biomedical engineering with analogs throughout science and engineering.

**BIOMEDE 474. Introduction to Tissue Engineering**

*Prerequisite: BME 410, senior standing or permission of instructor. (3 credits)*

This course focuses on understanding the principles of tissue engineering and regenerative medicine. Emphasis is on the components and design criteria of tissue engineering constructs. The course will cover multiple examples of engineering soft and hard tissue and application of new technologies in regenerative medicine.

**BIOMEDE 476 (MECHENG 476). Biofluid Mechanics**

*Prerequisite: BIOMEDE 331 or MECHENG 320. (4 credits)*

This is an intermediate level fluid mechanics course which uses examples from biotechnology processes and physiologic applications, including the cardiovascular, respiratory, ocular, renal, musculo-skeletal and gastrointestinal systems.

**BIOMEDE 479. Biotransport**

*Prerequisite: MATH 216, BIOMEDE 331 or MECHENG 330, or permission of instructor. (4 credits)*

Fundamentals of mass transport as it relates to biomedical systems. Convection, diffusion, osmosis and conservation of momentum, mass and energy will be applied to cellular and organ level transport. Examples of diffusion combined with reaction will also be examined.

**BIOMEDE 481 (NERS 481). Engineering Principles of Radiation Imaging**

*Prerequisite: None. (2 credits)*

Analytic description of radiation production, transport and detection in radiation imaging systems. Measurements methods for image quality and statistical performance of observers. Systems for radiographic and radioisotope imaging, including film/screen, storage phosphor, and electronic radiography, fluoroscopy, computed tomography, Anger camera and PET systems. Emphasis on impact of random process on observer detection.

**BIOMEDE 484 (NERS 484) (ENSCEN 484). Radiological Health Engineering Fundamentals**

*Prerequisite: NERS 312 or equivalent or permission of instructor. (4 credits)*

Fundamental physics behind radiological health engineering and topics in quantitative radiation protection. Radiation quantities and measurement, regulations and enforcement, external and internal dose estimation, radiation biology, radioactive waste issues, radon gas, emergencies and wide variety of radiation sources from health physics perspective.

**BIOMEDE 490. Directed Research**

*(1-4 credits)*

Provides an opportunity for undergraduate students to perform directed research devoted to BiomedE.

**BIOMEDE 495. Introduction to Bioengineering**

*Prerequisite: Permission of instructor; mandatory pass/fail. (1 credit)*

Definition of scope, challenge, and requirements of the bioengineering field. Faculty members review engineering-life sciences interdisciplinary activities as currently pursued in the College of Engineering and Medical School.

**BIOMEDE 499. Special Topics**

*(1-4 credits)*

Topics of special interest selected by faculty. Lecture, seminar or laboratory.

**BIOMEDE 500 (UC 500). Biomedical Engineering Seminar**

*Mandatory, satisfactory/unsatisfactory. (1 credit)*

This seminar will feature various bioengineering-related speakers.

### **BIOMEDE 503. Statistical Methods for Biomedical Engineering**

*Prerequisite: Graduate standing or permission of instructor. (3 credits)*

This course will cover descriptive statistics, probability theory, distributions for discrete and continuous variables, hypothesis testing and analysis of variance, as well as more advanced topics. We will make connections with real problems from engineering, biology and medicine, and computational tools will be used for examples and assignments.

### **BIOMEDE 504 (Microbiology 504). Cellular Biotechnology**

*Prerequisite: Graduate student standing or consent of the instructor. (3 credits)*

Biotechnology is a rapidly evolving, multi-disciplinary field that impacts nearly every aspect of our daily lives from the food we eat to the medicine we take. This course covers basic scientific and engineering principles behind this growing field, along with entrepreneurial aspects of translating innovative biotechnological solutions into new products.

### **BIOMEDE 506 (MECHENG 506). Computational Modeling of Biological Tissues**

*Prerequisite: None. (3 credits)*

Biological tissues have multiple scales and can adapt to their physical environment. This course focuses on visualization and modeling of tissue physics and adaptation. Examples include electrical conductivity of heart muscle and mechanics of hard and soft tissues. Homogenization theory is used for multiple scale modeling.

### **BIOMEDE 510. Medical Imaging Laboratory**

*Prerequisite: BIOMEDE 516 or permission of instructor. (3 credits)*

This course provides the student practical, hands-on experience with research grade, medical imaging systems including x-ray, magnetic resonance, nuclear medicine and ultrasound. Participants rotate through each of the respective areas and learn about and perform experiments to support previous theoretical instruction.

### **BIOMEDE 517. Neural Engineering**

*Advised prerequisites: BME 211 or EECS 215 or EECS 314, EECS 216, Math 216, ENGR 101 or EECS 183. (3 credits)*

This course focuses on techniques for understanding and interacting with the nervous system. Students first implement quantitative models of neurons followed by models of recording and stimulation. Next, students apply machine learning techniques to extract information from large neural data sets.

### **BIOMEDE 516 (EECS 516). Medical Imaging Systems**

*Prerequisite: EECS 451. (3 credits)*

Principles of modern medical imaging systems. For each modality the basic physics is described, leading to a systems model of the imager. Fundamental similarities between the imaging equations of different modalities will be stressed. Modalities covered include radiography, x-ray computed tomography (CT), NMR imaging (MRI) and real-time ultrasound.

### **BIOMEDE 519 (Physiol 519). Bioengineering Physiology**

*Prerequisite: MCDB 310 or Biol Chem 415, 451, 515 or CHEM 351 or permission of instructor. (4 credits)*

Quantitative description of the structure and function of mammalian systems, including the neuromuscular, cardiovascular, respiratory, renal and endocrine systems. Mathematical models are used to describe system performance where applicable. Lectures, laboratories and problem sessions.

### **BIOMEDE 522. Biomembranes: Transport, Signaling and Disease**

*Prerequisite: MCDB 310 or Biol Chem 415, 451, 515, or CHEM 351 and BIOMEDE 221 and CHEM 210 or permission of instructor. (3 credits)*

This course focuses on the biochemistry and biophysics of transport and signaling processes through biomembranes and on the relevance of these processes for disease and therapy. The course discusses topics including composition of biomembranes; fluidity and self-assembly of lipids; membrane proteins; membrane potential; signal transduction.

### **BIOMEDE 523. Business of Biology: The New**

**Frontiers of Genomic Medicine**

*Prerequisite: Graduate Standing. (3 credits)*

Advances in life science research have enhanced our understanding of the human genome, human genetic variation, and the role that genes play in our everyday health, response to treatment and susceptibility to disease. This new frontier in genomic medicine ushers in both opportunity and peril for individuals, companies and societies. The objective in this interdisciplinary graduate course is to explore the intersections between science, technology, commerce and social policy as they come together to advance (and in some cases retard) progress toward more-personalized health care. The course is intended for graduate students in medicine, biomedical and health-related science, public health, law, engineering, and business interested in the future of health care. Due to variation in student backgrounds coming into the course, efforts are made to establish a shared vocabulary and knowledge base across the disciplines. Interdisciplinary student teams are assigned to a group research project which is presented at the end of the course.

**BIOMEDE 525 (Microb 525). Cellular and Molecular Networks**

*Prerequisite: BIOL 105 or BIOL 112 and MATH 215. (3 credits)*

This course is designed to equip the student with appropriate concepts and techniques for the quantitative analysis of the integrated behavior of complex biochemical systems. A general approach is developed from the basic postulates of enzyme catalysis and is illustrated with numerous specific examples, primarily from the microbial cell.

**BIOMEDE 530. Rehabilitation Engineering and Technology Lab I**

*Prerequisite: Previous or simultaneous registration in BIOMEDE 430. (1 credit)*

This is a lab course which provides hands-on experience in the use of assistive technologies and in-depth consideration of rehabilitation engineering research and design of assistive technologies for a wide range of areas, including environmental control, computer access, augmentative communication, wheeled mobility, sensory aids and seating and positioning.

**BIOMEDE 533 (KINE 530). Neuromechanics**

*Prerequisite: Graduate standing. (3 credits)*

This course focuses on interactions of the nervous and musculoskeletal systems during human and animal movement with a focus on basic biological and engineering principles. Topics will include neuromechanical control of movement, neurorehabilitation, biorobotics, and computer simulations of neuromechanical systems.

**BIOMEDE 534 (IOE 534) (MFG 534). Occupational Biomechanics**

*Prerequisite: IOE 333 or IOE 334. (3 credits)*

Anatomical and physiological concepts are introduced to understand and predict human motor capabilities, with particular emphasis on the evaluation and design of manual activities in various occupations. Quantitative models are developed to explain: (1) muscle strength performance; (2) cumulative and acute musculoskeletal injury; (3) physical fatigue; and (4) human motion control.

**BIOMEDE 550. Ethics and Enterprise**

*Prerequisite: None. (1 credit)*

Ethics, technology transfer and technology protection pertaining to BiomedE are studied. Ethics issues range from the proper research conduct to identifying and managing conflicts of interest. Technology transfer studies the process and its influences on relationships between academia and industry.

**BIOMEDE 551 (BIOINF 551) (CHEM 551) (BiolChem 551). Proteome Informatics**

*Prerequisite: Bio Chem and calculus. (3 credits)*

Introduction to proteomics, mass spectrometry, peptide identification and protein inference, statistical methods and computational algorithms, post-translational modifications, genome annotation and alternative splicing, quantitative proteomics and differential protein expression analysis, protein-protein interaction networks and protein complexes, data mining and analysis of large-scale data sets, clinical applications, related technologies such as metabolomics and protein arrays, data integration and systems biology.

**BIOMEDE 552. Biomedical Optics**

*Prerequisite: MATH 216. (3 credits)*

This course provides students with an understanding of current research in biomedical optics. Topics include: fundamental theoretical principles of tissue optics; computational approaches to light transport in tissues; optical instrumentation; an overview of applications in clinical optical diagnostics and laser-based therapy; an introduction to biomedical microscopy and applications in biophotonic technology.

### **BIOMEDE 556. Molecular and Cellular Biomechanics**

*Prerequisite: Senior standing. (3 credits)*

This course will focus on how biomechanical and biophysical properties of subcellular structures can be determined and interpreted to reveal the workings of biological nano-machines.

### **BIOMEDE 561. Biological Micro-and Nanotechnology**

*Prerequisite: Biol 172 or 174, Intro Physics and Chemistry, graduate standing, or permission of instructor. (3 credits)*

Many life processes occur at small size-scales. This course covers scaling laws, biological solutions to coping with or taking advantage of small size, micro- and nanofabrication techniques, biochemistry and biomedical applications (genomics, proteomics, cell biology, diagnostics, etc.). There is an emphasis on micro fluidics, surface science and non-traditional fabrication techniques.

### **BIOMEDE 563. (CHE 563) (MATSCIE 563) Biomolecular Engineering of Interfaces**

*Prerequisite: Senior or graduate standing. (3 credits)*

This class focuses on biomolecular engineering of surfaces and interfaces in contact with biological systems. Recent advances in the interfacial design of materials as well as methods that enable studying such systems will be highlighted.

### **BIOMEDE 574. Cells in Their Environment**

*Prerequisite: Graduate standing or permission of instructor. (3 credits)*

This course focuses on how mammalian cells interact with the complex 3D environment that surrounds them in tissues. The goal is to provide students with a thorough understanding of how cell function is controlled

and how this knowledge can be applied to the prevention and treatment of disease.

### **BIOMEDE 580 (NERS 580). Computation Projects in Radiation Imaging**

*Prerequisite: Preceded or accompanied by NERS 481. (1 credit)*

Computational projects illustrate principles of radiation imaging from NERS 481 (BIOMEDE 481). Students will model the performance of radiation systems as a function of design variables. Results will be in the form of computer displayed images. Students will evaluate results using observer experiments. Series of weekly projects are integrated to describe the performance of imaging systems.

### **BIOMEDE 582 (NERS 582). Medical Radiological Health Engineering**

*Prerequisite: NERS 484 (BIOMEDE 484) or graduate status. (3 credits)*

This course covers the fundamental approaches to radiation protection in radiology, nuclear medicine, radiotherapy and research environments at medical facilities. Topics presented include health effects, radiation dosimetry and dose estimation, quality control of imaging equipment, regulations, licensing and health physics program design.

### **BIOMEDE 584 (CHE 584) (Biomaterials 584). Advances in Tissue Engineering**

*Prerequisite: MCDB 310 or Biol Chem 415, 451, 515 or CHEM 351, CHE 517, or equivalent biology course; senior standing. (3 credits)*

Fundamental engineering and biological principles underlying field of tissue engineering are studied, along with specific examples and strategies to engineer specific tissues for clinical use (e.g., skin). Student design teams propose new approaches to tissue engineering challenges.

### **BIOMEDE 590. Directed Research**

*Prerequisite: None. Mandatory satisfactory/unsatisfactory. (to be arranged)*

Provides opportunity for bioengineering students to participate in the work of laboratories devoted to living systems studies.

**BIOMEDE 591. Thesis**

*Prerequisite: 2 hrs of BiomedE 590; mandatory satisfactory/unsatisfactory. (credit to be arranged)*

To be elected by bioengineering students pursuing the master's thesis option. May be taken more than once up to a total of 6 credit hours. Graded on a satisfactory/unsatisfactory basis only.

**BIOMEDE 594. Recent Advances in Polymer Therapeutics**

*Prerequisite: BIOMEDE 410, senior standing, or permission of instructor. (3 credits)*

The course will review the basic principles of polymer science and controlled drug delivery. The course will discuss specific examples of biopolymer applications in protein, peptide, nucleic acids, vaccine delivery and the formulation of nanostructured devices and their application in targeted delivery of therapeutic and imaging agents.

**BIOMEDE 596 (ChE 596) (Pharm 596). Health Science and Engineering Seminar**

*Prerequisite: Graduate standing, I, II (1 credit)*

This seminar will feature invited speakers from pharmaceutical, biomedical and other life sciences-related industries and academic institutions.

**BIOMEDE 598 (ChE 598). Global Quality Systems and Regulatory Innovation**

*Prerequisite: Senior or graduate students enrolled in the CoE and health related professional schools (2 credits)*

This course is for scientists, engineers, and clinicians to understand and interpret various relevant global and regional quality systems for traditional and cutting edge global health technologies, solutions and their implementation. Speakers from academia, the FDA, and biomedical related industries will be invited to participate in teaching this course.

**BIOMEDE 599. Special Topics I, II**

*(1-6 credits)*

Topics of current interest selected by the faculty. Lecture, seminar or laboratory.

**BIOMEDE 616 (ChE 616). Analysis of Chemical Signaling**

*Prerequisite: MATH 216, Biol Chem 415, 451, 515. (3 credits)*

Quantitative analysis of chemical signaling systems, including receptor/ligand binding and trafficking, signal transduction and second messenger production and cellular responses such as adhesion and migration.

**BIOMEDE 635 (IOE 635). Laboratory in Biomechanics and Physiology of Work**

*Prerequisite: IOE 534 (BIOMEDE 534). (2 credits)*

This laboratory is offered in conjunction with the Occupational Biomechanics lecture course (IOE 534) to enable students to examine experimentally: (1) musculoskeletal reactions to volitional acts; (2) the use of electromyography (EMG's) to evaluate muscle function and fatigue; (3) biomechanical models; (4) motion analysis systems; and (5) musculoskeletal reactions to vibrations.

**BIOMEDE 646 (MECHENG 646). Mechanics of Human Movement**

*Prerequisite: MECHENG 540 (AEROSP 540) or MECHENG 543 or equivalent. (3 credits)*

Dynamics of muscle and tendon, models of muscle contraction. Kinematics and dynamics of the human body, methods for generating equations of motion. Mechanics of proprioceptors and other sensors. Analysis of human movement, including gait, running and balance. Computer simulations and discussion of experimental measurement techniques.

**BIOMEDE 990. Dissertation/Pre-Candidate**

*(1-8 credits); (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**BIOMEDE 995. Dissertation/Candidate**

*Prerequisite: Graduate School authorization for admission as a doctoral candidate. (8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Chemical Engineering

## Overview

The degree program in chemical engineering was established in 1898 at the University of Michigan, one of four schools to introduce the profession in the United States. The University of Michigan student chapter of the American Institute of Chemical Engineers was established in 1922. Chemical engineering, among all branches of engineering, is the one most strongly and broadly based upon chemical and life sciences. Chemical engineers use their knowledge of thermodynamics, fluid mechanics, heat transfer, mass transfer, reaction kinetics, and process control to develop processes that change raw materials to more useful forms. Thanks to a broad and fundamental education, though, chemical engineers can contribute to society in many functions, including research, development, process design, product engineering, plant operation, environmental protection, marketing, sales, education, law, medicine, public health, or government work.

The work of the chemical engineer encompasses many industries, from the manufacture of chemicals and consumer products and the refining of petroleum, to biotechnology, food manufacturing and the production of pharmaceuticals. Because of this breadth, there are many fields in which chemical engineers may specialize. More information on careers for chemical engineers is available at the AIChE career page, <http://www.aiche.org/community/students/career-resources-k-12-students-parents>. The program allows 12 credits of general electives, 3 credits of engineering electives and 16 credits of Intellectual Breadth electives. A student may use this elective freedom to develop individual abilities and interests, or to prepare to continue their studies in engineering, medicine, law, business, education, public health or public policy, among many options. The electives also provide the opportunity for combined degree programs or for preparation in fields within or related to chemical engineering such as polymers, pharmaceuticals, environmental engineering, energy and fuels, and biotechnology. Students can choose to focus their elective courses by selecting a concentration within their Chemical Engineer-

ing degree.

## Department Administration

### Department Chair

Mark Burns  
3074 HH Dow Building

### Contacts

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## Mission Statement

### Mission

To provide a solid and current technical foundation that prepares students for a career in chemical engineering or related fields.

### Goals

To educate and support diverse students and prepare them to be leaders in chemical engineering or related fields.

## Objectives

Within a few years of graduation, UMChE graduates will have attained leadership roles among peers in chemical engineering, or another field, such as medicine, law, business and education, through:

- effectiveness as creative problem solvers and innovators
- ability to think critically to solve relevant problems
- effectiveness as communicators to gain and convey information

- competence and comfort in multifunctional and multicultural environments
- exhibiting and demanding high ethical standards

## Outcomes

The outcomes we desire are that graduates of the University of Michigan Chemical Engineering Program demonstrate:

- An ability to apply knowledge of mathematics, science and engineering to chemical engineering problems;
- An ability to design and conduct experiments, as well as to analyze and interpret data;
- An ability to design a system, component or process to meet desired needs;
- An ability to function on multi-disciplinary teams;
- An ability to identify, formulate and solve engineering problems;
- An understanding of professional and ethical responsibility;
- An ability to communicate effectively orally and in writing;
- The broad education necessary to understand the impact of engineering solutions in a global and societal context;
- A recognition of the need for and an ability to engage in life-long learning;
- A knowledge of contemporary issues;
- An ability to use the techniques, skills and modern engineering and computing tools necessary for engineering practice.

## Sample Schedule

### B.S.E. in Chemical Engineering

The Chemical Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <http://www.engin.umich.edu/che/undergraduate>.

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (53 Hours)</b>									
Mathematics 115+, 116+, 215+, 216+	16	4	4	4	4	-	-	-	-
Engineering 100, Introduction to Engineering +	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers +	4	-	4	-	-	-	-	-	-
Chemistry 130 <sup>1</sup>	3	3	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth (to include a course in micro or macro economics)	16	4	-	-	-	4	-	4	4
<b>Advanced Chemistry (11 Hours)</b>									
Chemistry 210/211, Structure and Reactivity I and Lab +	5	-	5	-	-	-	-	-	-
Chemistry 215/216, Structure and Reactivity II and Lab +	5	-	-	5	-	-	-	-	-
Chemistry 261 Introduction to Quantum Chemistry <sup>35</sup>	1	-	-	-	-	1	-	-	-
<b>Related Technical Subjects (11 Hours)</b>									
Biology/Life Science Elective (Typically Bio 172 or 174) <sup>3</sup>	4	-	-	-	-	-	4	-	-
Materials Elective (MSE 250 or MSE 220) +	4	-	-	-	-	-	-	4	-
Engineering Electives <sup>4</sup>	3	-	-	-	-	-	-	-	3
<b>Program Subjects (41 Hours)</b>									
CHE 230 Material and Energy Balances +	4	-	-	4	-	-	-	-	-
CHE 330 Chemical and Engineering Thermodynamics +	4	-	-	-	4	-	-	-	-
CHE 341 Fluid Mechanics +	4	-	-	-	4	-	-	-	-
CHE 342 Mass and Heat Transfer +	4	-	-	-	-	4	-	-	-
CHE 343 Separation Processes +	4	-	-	-	-	4	-	-	-
CHE 344 Reaction Engineering and Design +	4	-	-	-	-	-	4	-	-
CHE 360 Chemical Engineering Laboratory I +	4	-	-	-	-	-	4	-	-
CHE 460 Chemical Engineering Laboratory II +	4	-	-	-	-	-	-	-	4
CHE 466 Process Dynamics and Control	3	-	-	-	-	-	-	3	-
CHE 485 Chemical Engineering Process Economics +	1	-	-	-	-	-	1	-	-
CHE 487 Chemical Process Simulation and Design <sup>6</sup>	5	-	-	-	-	-	-	-	5
<b>General Electives (12 Hours)</b>									
<b>Total</b>	<b>128</b>	<b>15</b>	<b>18</b>	<b>21</b>	<b>12</b>	<b>16</b>	<b>16</b>	<b>14</b>	<b>16</b>

Candidates for the Bachelor of Science in Engineering in Chemical Engineering - B.S.E. in Chem E. - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> See department list for other courses that satisfy the Biology/Life Science elective requirement for students with BIO100x AP credit.

<sup>4</sup> Engineering courses are to be at the 200 or higher level and cannot include seminar courses. Engineering research hours at the 400 level or higher may be used to satisfy this requirement. Up to 8 hours of ChE 490 or ChE 695 research may be taken for a grade. Beyond that, ChE 490 or 695 hours must be taken pass/fail.

<sup>5</sup> Either Physics 390 or Materials Science 242 or Chemistry 370 can be taken to fulfill the Chemistry 261 requirement.

<sup>6</sup> ChE 488 and 489, the Chemical Product Design two-semester sequence, is available as a substitute for ChE 487 for a limited number of students.

(+) Students must earn a "C-" or better in prerequisite course indicated by the (+).

## Concentrations

Chemical Engineering students have the option of focusing their technical and some free electives in a specific area, fulfilling a concentration within their chemical engineering degree. Concentration areas include:

- BioPharmaceutical Engineering
- Electrical Engineering - Electronic Devices
- Energy Systems Engineering
- Environmental Engineering
- Life Sciences
- Materials Science and Engineering
- Mechanical Engineering
- Nuclear Engineering
- Petroleum and Gas Exploration

All optional concentrations consist of 12 credits and must include at least one 300 or higher level course. Only elective courses can be used as part of a concentration. Students may not earn a concentration in a field in which they are also enrolled for a dual degree. More information on concentration requirements is available at <http://www.engin.umich.edu/che/undergraduate/program/options>.

## Sequential Undergraduate/ Graduate Study (SUGS)

The following programs are available for chemical engineering students interested in pursuing joint B.S.E. and M.S.E. or M.Eng. degrees. For more information on each of these programs, including program requirements and graduate program contact information, please visit <http://www.engin.umich.edu/che/undergraduate/program/options/sgus>.

### **B.S.E. in Chemical Engineering / M.S.E. in Biomedical Engineering**

This SUGS program is open to all undergraduate students from Chemical Engineering who have achieved senior standing (85 credit hours of more) and have an overall cumulative GPA of 3.2 or higher.

### **B.S.E. in Chemical Engineering / M.S.E. in Chemical Engineering**

A University of Michigan undergraduate with a GPA of 3.5 or greater may apply, after completing the first term of the junior year, for admission to the departmental SUGS combined degree program leading to both the baccalaureate and master's degrees. Up to 9 hours of prior approved elective coursework may be applied toward both degrees (typically leading to a total of 128 for the B.S.E. plus 30 for the M.S.E.) for 149 total credit hours. The 9 double counted elective credits must be acceptable for Rackham credit. The 21 chemical engineering graduate credits may include up to 6 hours of CHE 698 (directed study or practical training under faculty supervision) or CHE 695 (research).

### **B.S.E. in Chemical Engineering / M.Eng. in Energy Systems Engineering**

The program aims to prepare students to design and implement energy systems for innovative applications. An overall GPA of 3.5 or above at time of admission is required.

### **B.S.E. in Chemical Engineering / M.S.E. in Environmental and Water Resources Engineering**

The program is open to all Chemical Engineering undergraduate students who have completed 75 or more credit hours with a cumulative GPA of at least 3.5.

### **B.S.E. in Chemical Engineering / M.S.E. in Industrial and Operations Engineering**

Non-IOE engineering students pursue the IOE master's degree for a number of reasons. Some students use it as the first step toward the IOE Ph.D. degree. Other students pursue the degree to enhance their qualifications for professional engineering careers. Applicants must have a minimum GPA of 3.5.

### **B.S.E. in Chemical Engineering / M.S.E. in Macromolecular Science and Engineering**

The Master's in Macromolecular Science and Engineering degree is a 30-credit program. There are several specializations or options from which to choose. A 3.5 GPA is required to apply for this program.

### **B.S.E. in Chemical Engineering / M.Eng. in Manufacturing**

The Master of Engineering in Manufacturing (M.Eng. in Mfg.) degree is a professional practice-oriented degree designed to further the education of engineers who already have experienced working in industry and plan to return to an industrial environment after completing their studies. The degree requirements can be completed in one calendar year (12 months). This degree combines course work from various engineering disciplines (80%) and business (20%). Applicants to this program must have completed 80 or more credits of course work with a GPA of 3.6 or better.

### **B.S.E. in Chemical Engineering / M.S.E. in Materials Science and Engineering**

Students who enter a Chemical Engineering program out of an interest in chemistry could opt to pursue a master's in Materials Science and Engineering. This master's degree enhances their understanding of the relationship between chemical structure, processing and material properties, which in turn prepares them to pursue careers in research, design or manufacturing of materials. A GPA of 3.5 is required to apply.

### **B.S.E. in Chemical Engineering / M.Eng. in Pharmaceutical Engineering**

The Master of Engineering (M.Eng.) degree is intended to focus more on professional practice in the pharmaceutical field than the traditional Master of Science in Engineering (M.S.E.) degree. A GPA of 3.5 is required to apply.

## **Graduate**

### **Graduate Degrees**

- Master of Science in Engineering (M.S.E.) in Chemical Engineering
- Doctor of Philosophy (Ph.D.) in Chemical Engineering

### **M.S.E. in Chemical Engineering**

The minimum requirement for the M.S.E. degree for a student entering with a baccalaureate degree in chemical engineering is 30 graduate credit hours with an av-

erage grade of "B." A thesis is not required. The course work must include at least 21 hours in chemical engineering (courses with a CHE prefix), of which up to 6 credit hours of research are accepted (e.g., CHE 695); and at least two courses outside the chemical engineering program. The required courses are Fluid Flow (CHE 527), Statistical and Irreversible Thermodynamics (CHE 538), Chemical Reactor Engineering (CHE 528), Transport Processes (CHE 542), Chemical Engineering Research Survey (CHE 595) and Math for Chemical Engineers (CHE 505). Each student is encouraged to develop a program to fit his or her professional objective and should consult with the graduate advisor concerning a plan of study.

### **Ph.D. in Chemical Engineering**

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in her/his broad field of knowledge through completion of a prescribed set of courses and passing a comprehensive examination.

The course requirements are the same as the M.S.E. degree, plus six (6) additional graduate level credits. Students must pass a comprehensive examination in chemical engineering and be recommended for candidacy for the doctorate. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

Information on the general procedure leading to the doctorate is available at the Graduate School website, <http://www.rackham.umich.edu>.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **CHE 230. Introduction to Material and Energy Balances**

*Prerequisite: ENGR 100, ENGR 101 (ENGR 151), Chem 130, and Math 116. (4 credits)*

An introduction to material and energy balances in chemical engineering applications, including environmental and biological systems. Engineering problem-solving, the equilibrium concept, first law of thermodynamics. Introduction to chemical engineering as a profession.

### **CHE 290. Directed Study, Research, and Special Problems**

*Prerequisite: First or second year standing, and permission of instructor. (1-16 credits)*

Provides an opportunity for undergraduate students to work in chemical engineering research or design problems. For each hour of credit, it is expected that the student will work four hours per week in a full term. Oral presentation and/or written report due at end of term. Not open to graduate students.

### **CHE 330. Chemical and Engineering Thermodynamics**

*Prerequisite: CHE 230. (4 credits)*

Development of fundamental thermodynamic property relations and complete energy and entropy balances. Analysis of heat pumps and engines and use of combined energy-entropy balance in flow devices. Calculation and application of total and partial properties in physical and chemical equilibria. Prediction and correlation of physical/chemical properties of various states and aggregates. Elements of statistical thermodynamics.

### **CHE 341. Fluid Mechanics**

*Prerequisite: Preceded by Physics 140 and Math 215, preceded or accompanied by CHE 230 and Math 216. (4 credits)*

Fluid mechanics for chemical engineers. Mass, momentum and energy balances on finite and differential sys-

tems. Laminar and turbulent flow in pipes, equipment and porous media. Polymer processing and boundary layers. Potential, two-phase and non-Newtonian flow.

### **CHE 342. Mass and Heat Transfer**

*Prerequisite: CHE 230, CHE 341, and Math 216. (4 credits)*

Theories and applications of mass and heat transport phenomena. Fick's law. Steady and unsteady diffusion. Mass transfer coefficients. Simultaneous momentum and mass transfer. Fourier's law. Steady and unsteady thermal conduction. Heat transfer coefficients. Heat exchangers. Condensation and boiling. Radiation. Kirchoff's law and view factors.

### **CHE 343. Separation Processes**

*Prerequisite: CHE 230, CHE 330 and preceded or accompanied by CHE 342. (4 credits)*

Introduction and survey of separations based on physical properties, phase equilibria and rate processes. Emphasis on analysis and modeling of separation processes. Staged and countercurrent operations. Includes applications to chemical, biological, and environmental systems.

### **CHE 344. Reaction Engineering and Design**

*Prerequisite: CHE 330, CHE 342. (4 credits)*

Fundamentals of chemical reaction engineering. Rate laws, kinetics and mechanisms of homogeneous and heterogeneous reactions. Analysis of rate data, multiple reactions, heat effects, bioreactors, Safety (Runaway reactions). Design of industrial reactors.

### **CHE 360. Chemical Engineering Laboratory I**

*Prerequisite: CHE 342, CHE 343. (4 credits)*

Experimentation in thermodynamics and heat, mass and momentum transport on a bench scale. Measurement error estimation and analysis. Lecture, laboratory, conferences and reports. Technical communications.

### **CHE 405 (ENGR 405). Problem Solving and Troubleshooting in the Workplace**

*Prerequisite: Senior standing. (3 credits)*

The course goals are to help students enhance their problem solving, critical thinking, creative thinking and troubleshooting skills and to ease the transition from college to the workplace. The course includes a few

speakers from industry. Students work in teams to complete the home problems and the term project.

#### **CHE 412 (MacroSE 412) (MATSCIE 412). Polymeric Materials**

*Prerequisites: MATSCIE 220 or 250. (4 credits)*

The synthesis, characterization, microstructure, rheology and properties of polymer materials. Polymers in solution and in the liquid, liquid-crystalline, crystalline and glassy states. Engineering and design properties, including viscoelasticity, yielding and fracture. Forming and processing methods. Recycling and environmental issues.

#### **CHE 431. Engineering Statistics and Problem Solving**

*Prerequisite: ChE 342 & ChE 343. Minimum grade required for enforced prerequisite is C-. (3 credits)*

Fundamentals of chemical and engineering kinetics from a molecular perspective. Relationship between kinetics and mechanisms. Kinetics of elementary steps in gas, liquid and supercritical fluid reaction media. Gas-solid and surface reactions. Heterogeneous and homogeneous catalysis. Kinetics and mechanisms of chemical processes such as polymerization, combustion and enzymatic reactions.

#### **CHE 444. Applied Chemical Kinetics**

*Prerequisite: Chem 260 or 261, CHE 344. (3 credits)*

Fundamentals of chemical and engineering kinetics from a molecular perspective. Relationship between kinetics and mechanisms. Kinetics of elementary steps in gas, liquid and supercritical fluid reaction media. Gas-solid and surface reactions. Heterogeneous and homogeneous catalysis. Kinetics and mechanisms of chemical processes such as polymerization, combustion and enzymatic reactions.

#### **CHE 460. Chemical Engineering Laboratory II**

*Prerequisites: CHE 343 and CHE 360. Minimum grade required for enforced prerequisite is C-. (4 credits)*

Experimentation in rate and separation processes on a scale which tests process models. Introduction to the use of instrumental analysis and process control. Laboratory, conferences and reports. Technical communications.

#### **CHE 466. Process Dynamics and Control**

*Prerequisites: CHE 343, CHE 344. (3 credits)*

Introduction to process control in chemical engineering. Control architecture design, notation and implementation. Mathematical modeling and analysis of open-loop and closed-loop process dynamics. Applications to the control of level, flow, heat exchangers, reactors and elementary multivariable systems. Statistical process control concepts.

#### **CHE 470. Colloids and Interfaces**

*Prerequisite: CHE 343, CHE 344. (3 credits)*

This is a first course in colloid and interface science. The repulsive forces and attractive forces at interfaces are described along with the dynamics of the interfaces. Topics include the stability of macroemulsions, the formulation and properties of microemulsions and surface metal-support interactions of catalysts.

#### **CHE 472. Polymer Science and Engineering**

*Prerequisite: Preceded or accompanied by CHE 344. (4 credits)*

Polymer reaction engineering, characterization and processing for chemical engineers. Polymerization mechanisms, kinetics and industrial equipment. Thermodynamics of polymer solutions, morphology, crystallization and mechanical properties. Polymer processing equipment and technology. Adhesives, diffusion in polymers, reactive polymeric resins and biological applications of macromolecules.

#### **CHE 485. Chemical Engineering Process Economics**

*Prerequisite: CHE 343 (1 credit)*

Economic and profitability analysis as applied to chemical engineering processes and products. Estimation of capital investment, cost of production, depreciation and cash flows. Discounted profitability analysis including net present value, internal rate of return and discounted payback period. Profitability decision making based on cost of capital and economic risk analysis. ChE process optimization based on economic profitability. Students will connect economics and business principles to real chemical engineering processes, as previously learned in the core chemical engineering courses of fluid mechanics, heat and mass transfer and separations.

#### **CHE 487. Process Simulation and Design**

*Prerequisite: CHE 360 and CHE 344, and (MSE 220 or MSE 250) or graduate standing; preceded or accompanied by CHE 485. (5 credits)*

Computer simulation of process and components. A major team design project with progress reports, oral presentation, and a technical report with engineering drawings and economics.

### **CHE 488. Chemical Product Design I**

*Prerequisite: CHE 360, CHE 344, CHE 485 and MATSCIE 220 or 250. (2 credits)*

Part one of a two-semester chemical product design sequence. Teams develop the process for a new chemical product that meets industrial, federal and local regulations. Survey development, literature research and development of an appropriate manufacturing process. Oral and written technology and economic feasibility reports. Safety, environmental and ethical issues.

### **CHE 489. Chemical Product Design II**

*Prerequisite: CHE 488. (3 credits)*

Part two of a two-semester chemical product design sequence. Teams produce a consumer-ready prototype of a chemical product. Development of control and regulatory tests to ensure the product meets all relevant industrial, federal and local regulations. Oral and written technology and economic reports. Safety, environmental and ethical issues.

### **CHE 490. Advanced Directed Study, Research and Special Problems**

*Prerequisite: CHE 230 & CHE 341 or CHE 290 or equivalent and permission of instructor. (1-16 credits)*

Provides an opportunity for undergraduate students to work in chemical engineering research or design problems. For each hour of credit, it is expected that the student will work four hours per week in a full term. Oral presentation and/or written report due at end of term. Not open to graduate students.

### **CHE 496. Special Topics in Chemical Engineering**

*Prerequisite: Permission of Instructor. (1-16 credits)*  
Selected undergraduate topics pertinent to chemical engineering.

### **CHE 497. Special Topics in Chemical Engineering**

*Prerequisite: Permission of Instructor. (1-16 credits)*

Selected topics pertinent to chemical engineering.

### **CHE 500/CEE 500/ENSCEN 500 Environmental Systems and Processes**

*Prerequisite: CEE 460. (3 credits)*

Concepts of environmental systems and principles of related transport and transformation phenomena and processes; development of fundamental models for articulation of relevant process dynamics; system and process scaling factors and methods; extension of process models to ideal and nonideal natural and engineered homogeneous environmental systems.

### **CHE 505. Applied Mathematics for Chemical Engineers**

*Prerequisite: Graduate standing. (3 credits)*

Analytical and numerical techniques applicable to statistical mechanics, transport phenomena, fluid mechanics and reaction engineering. Groups and linear spaces; tensors and linear operators; computational approaches to nonlinear systems and integration; special functions; spectral theory of ordinary and partial differential equations; series expansions; coordinate transformations; complex algebra and analysis; integral transformations.

### **CHE 510. Mathematical Methods in Chemical Engineering**

*Prerequisite: Graduate standing, differential equations. (3 credits)*

Linear algebra, ordinary and partial differential equations, integral equations with chemical engineering applications. Analytical techniques and preliminaries for numerical methods, including: spectral analysis, orthogonal polynomials, Green's functions, separation of variables, existence and uniqueness of solutions.

### **CHE 511 (MacroSE 511) (MATSCIE 511). Rheology of Polymeric Materials**

*Prerequisite: A course in fluid mechanics or permission of instructor. (3 credits)*

An introduction to the relationships between the chemical structure of polymer chains and their rheological behavior. The course will make frequent reference to synthesis, processing, characterization and use of polymers for high technology applications.

### **CHE 512. (MacroSE 512) (MATSCIE 512). Physical**

**Polymers**

*Prerequisite: Senior or graduate standing in engineering or physical science. (3 credits)*

Structure and properties of polymers as related to their composition, annealing and mechanical treatments. Topics include creep, stress-relaxation, dynamic mechanical properties, viscoelasticity, transitions, fracture, impact response, dielectric properties, permeation and morphology.

**CHE 516. Applied Pharmacokinetics and Toxicokinetics**

*Prerequisite: CHE 344 or equivalent. (3 credits)*

This course focuses on (1) ADME process (Absorption, Distribution, Metabolism, Elimination) and the major pathways and mechanisms (e.g. transporters, liver enzymes, etc.); (2) basic concepts of pharmacokinetics/pharmacodynamics and their application in drug discovery/development; (3) introduction to pharmacokinetic analysis using WINNONLIN.

**CHE 517 (MFG 517). Biochemical Engineering**

*Prerequisite: CHE 344, and Biochem 415 or equivalent; permission of instructor. (3 credits)*

Concepts necessary in the adaptation of biological and biochemical principles to industrial processing in biotechnology and pharmaceutical industries. Topics include rational screening, functional genomics, cell cultivation, oxygen transfer, etc. Lectures, problems and library study will be used.

**CHE 519 (Pharm 519). Pharmaceutical Engineering**

*Prerequisite: Senior or graduate standing, permission by instructor. (3 credits)*

Concepts necessary in the adaptation of engineering principles to pharmaceutical and life sciences related industries. Topics include process engineering in drug discovery, high throughput characterization and optimization of new chemical entities, solid-state engineering and intelligent pharmaceutical manufacturing systems.

**CHE 520 (Pharm 761). Population Pharmacokinetics**

*Prerequisite: Pharm Sci 560 or permission of instructor (2 credits)*

This course teaches the basic concepts in population

pharmacokinetic (PK) and pharmacodynamic (PD) modeling and its application in drug development. The material covers both the theoretical and practical aspects of the population approach. Software (WINNONLIN, NONMEN, and SPLUS) will be installed in a centralized area for hands-on training and learning.

**CHE 527. Fluid Flow**

*Prerequisite: CHE 341. (3 credits)*

Applications of fluid dynamics to chemical engineering systems. Theory and practice of laminar and turbulent flow of Newtonian and non-Newtonian fluids in conduits and other equipment. Multi-phase flow. Introduction to the dynamics of suspended particles, drops, bubbles, foams and froth. Selected topics relevant to chemical and other engineering disciplines.

**CHE 528. Chemical Reactor Engineering**

*Prerequisite: CHE 344. (3 credits)*

Analysis of kinetic, thermal, diffusive and flow factors on reactor performance. Topics include batch, plug flow, backmix reactors, empirical rate expressions, residence time analysis, catalytic reactions, stability and optimization.

**CHE 531. Introduction to Chemoinformatics**

*Prerequisite: Senior or graduate standing. Permission by Instructor. (3 credits)*

This course is designed to give students an overview of chemoinformatics techniques, in particular their application in the pharmaceutical industry. Topics include: representation and use of chemical structures, chemical databases, molecular modeling, 3D visualization and computation, ADME/tox prediction and hot topics in the pharmaceutical industry.

**CHE 538. Statistical and Irreversible Thermodynamics**

*Prerequisite: CHE 330. (3 credits)*

The laws of probability and statistics are applied to microscopic matter to yield properties of macroscopic systems. Relations between classical and statistical thermodynamics are developed. Coupling of irreversible processes is treated through the entropy balance and microscopic reversibility.

**CHE 540. Mathematical Methods for Biological Network Analysis**

*Prerequisite: Senior or graduate standing, permission by instructor. (3 credits)*

This course focuses on methods and applications. Methods include ordinary differential equations, mathematical programming, Bayesian networks and statistical analysis, etc. Applications to the modeling of various biological systems are discussed and students perform a critical evaluation of current literature as well as hands-on computational projects using high level computing languages.

**CHE 542. Intermediate Transport Phenomena**

*Prerequisite: Graduate standing. (3 credits)*

Foundations of transport phenomena. Heat and mass transfer with chemical reaction in three dimensions, selective motion. Unsteady energy and mass balances in three dimensions. Distributions in more than one variable. Boundary layer theory. Estimation of interfacial transport coefficients. Dispersive flows: Taylor Dispersion. Application to equipment design.

**CHE 543. Advanced Separation Processes**

*Prerequisite: CHE 343. (3 credits)*

Forces for adsorption, equilibrium adsorption isotherms, sorbent materials, pore size distribution, heterogeneity, predicting mixture adsorption, rate processes in adsorption/adsorbers, adsorber dynamics, cyclic adsorption processes, temperature and pressure swing adsorption, membrane separation processes, polymer membranes, dialysis electrolysis, pervaporation, reverse osmosis, research projects.

**CHE 548. Electrochemical Engineering**

*Prerequisite: CHE 344. (3 credits)*

Analysis of electrochemical systems from a theoretical and practical point of view. Topics include the application of electrochemical thermodynamics and kinetics to batteries, fuel cells, electroplating, electrosynthesis and corrosion.

**CHE 554 (MATSCIE 554). Computational Methods in MS&E and CHE**

*Prerequisite: None. (3 credits)*

Broad introduction to the methods of numerical problem solving in Materials Science and Chemical Engi-

neering. Topics include numerical techniques, computer algorithms and the formulation and use of computational approaches for the modeling and analysis of phenomena peculiar to these disciplines.

**CHE 557 (MATSCIE 557). Computational Nanoscience of Soft Matter**

*Prerequisites: Differential equations course, and a statistical thermodynamics or statistical mechanics course. (3 credits)*

Provides an understanding of strategies, methods, capabilities and limitations of computer simulation as it pertains to the modeling and simulation of soft materials at the nanoscale. The course consists of lectures and hands-on, interactive simulation labs using research codes and commercial codes. Ab initio, molecular dynamics, Monte Carlo and mesoscale methods.

**CHE 558 (MATSCIE 558) (Macro 558). Foundations of Nanotechnology**

*Prerequisite: Senior or graduate standing. (3 credits)*

The focus of this course is on the scientific foundations of nanotechnology. The effects of nanoscale dimensions on optical, electrical, and mechanical properties are explained based on atomistic properties and related to applications in electronics, optics, structural materials and medicine. Projects and discussions include startup technological assessment and societal implications of the nanotechnology revolution.

**CHE 559 (MATSCIE 559) (MACROMOL 559). Foundations of Nanotechnology II**

*Prerequisite: Senior or graduate standing. (3 credits)*

This course will cover the synthesis and processing of nano-sized metal, metal oxide, and semiconductor powders. It will also include organic/inorganic and nanobiomaterials. Emphasis will be on particle properties and their use in making nonstructured materials with novel properties.

**CHE 563 (BIOMEDE 563) (MATSCIE 563). Biomolecular Engineering of Interfaces**

*Prerequisite: senior or graduate standing. (3 credits)*

This class focuses on biomolecular engineering of surfaces and interfaces in contact with biological systems. Recent advances in the interfacial design of materials as well as methods that enable studying such systems

will be highlighted.

### **CHE 568. Fuel Cells and Fuel Processors**

*Prerequisite: ChE 344 and senior or graduate standing (3 credits)*

This course provides a comprehensive overview of the major fuel cell types, with emphasis on PEM and SOFC fuel cells. The scientific and engineering principles of fuel cell technology and catalytic fuel processing will be covered. The course also reviews hydrogen properties, storage and safety issues.

### **CHE 574. Engineering Principles in Drug Delivery and Targeting**

*Prerequisite: Senior or graduate standing. (3 credits)*

This course focuses on engineering aspects of designing Drug Delivery and Targeted Systems for human use. Sample topics include: carriers and biocompatibility issues in DDT; passive and active targeting; organ and disease specific targeting; and barriers to use of DDTS. Assessment will include problem sets, a student project and exams.

### **CHE 578. Molecular Heterogeneous Catalysis and Electro-Catalysis**

*Prerequisite: Senior or graduate standing. (3 credits)*

The course will address numerous topics including: 1) Chemical bonding on metal surfaces; 2) Various experimental and theoretical tools that are used to study chemical transformations on surfaces at molecular level. The material will be discussed through a number of examples addressing contemporary issues related to the fields of energy and environment. We will also discuss strategies that can be utilized to employ molecular insights to identify optimal electrocatalysts for different electrochemical processes.

### **CHE 580 (ENGR 580). Teaching Engineering**

*Prerequisite: Doctoral candidate. (3 credits)*

Aimed at doctoral students from all engineering disciplines interested in teaching. Topics include educational philosophies, educational objectives, learning styles, collaborative and active learning, creativity, testing and grading, ABET requirements, gender and racial issues.

### **CHE 584 (BiomedE 584) (Biomat 584). Tissue Engineering**

*Prerequisite: Biology 310 or 311, ChE 517, or equivalent biology course; senior standing. (3 credits)*

Fundamental engineering and biological principles underlying field of tissue engineering are studied, along with specific examples and strategies to engineer specific tissues for clinical use (e.g. skin). Student design teams propose new approaches to tissue engineering challenges.

### **CHE 588 (BIOMEDE 588). Global Quality Systems and Regulatory Innovation**

*Prerequisite: Senior or graduate students enrolled in the CoE and health related professional schools. (2 credits)*

This course is for scientists, engineers, and clinicians to understand and interpret various relevant global and regional quality systems for traditional and cutting edge global health technologies, solutions and their implementation. Speakers from academia, the FDA, and biomedical related industries will be invited to participate in teaching this course.

### **CHE 595. Chemical Engineering Research Survey (1 credit)**

Research activities and opportunities in Chemical Engineering program. Lectures by University of Michigan faculty and guest lecturers. Topics are drawn from current research interests of the faculty.

### **CHE 596 (Pharm 596). Health Science and Engineering Seminar**

*Prerequisite: Graduate standing advised. (1 credit)*

This seminar will feature invited speakers from pharmaceutical, biomedical and other life sciences-related industries, and academic institutions.

### **CHE 597 (Pharm 597). Regulatory Issues for Scientists, Engineers, and Managers**

*Prerequisite: Permission of instructor. (2 credits)*

Science- and technology-based rationale behind various regulatory issues involved in pharmaceutical and related industries.

### **CHE 598. Advanced Special Topics in Chemical Engineering**

*Prerequisite: None. (min. 2, max. 4 credits)*

Selected topics pertinent to chemical engineering.

**CHE 601. Chemical Engineering Seminar**

*Prerequisite: Graduate standing (1 credit)*

This seminar will feature various chemical engineering-related speakers.

**CHE 606. Microfluidic Science and Engineering**

*Advised Prerequisite: Graduate standing or permission from the instructor. (3 credits)*

This course exposes students to both the theoretical and applied aspects of microfluidics, with a particular emphasis on designing microfluidic biological assays. The class provides broad exposure to fluid dynamic, surface phenomena and mass transfer concepts related to microfluidics in an effort to provide a theoretical underpinning for microfluidic device design.

**CHE 616 (BiomedE 616). Analysis of Chemical Signaling**

*Prerequisite: Math 216, Biochemistry 415. (3 credits)*

Quantitative analysis of chemical signaling systems, including receptor/ligand binding and trafficking, signal transduction and second messenger production and cellular responses such as adhesion and migration.

**CHE 617 (Mfg 617). Advanced Biochemical Technology**

*Prerequisite: CHE 517 or permission of instructor. (3 credits)*

Practical and theoretical aspects of various unit operations required to separate and purify cells, proteins and other biological compounds. Topics covered include various types of chromatography, liquid/liquid extractions, solid/ liquid separations, membrane processing and field-enhanced separations. This course will focus on new and non-traditional separation methods.

**CHE 628. Industrial Catalysis**

*Prerequisite: CHE 528. (3 credits)*

Theoretical and experimental aspects of heterogeneous catalysis and surface science. Design, preparation, and characterization of catalysts. Kinetics of heterogeneous catalytic reactions, thermal and diffusional effects in catalytic reactors. Case studies of important industrial catalytic processes.

**CHE 629 (Physics 629). Complex Fluids**

*Prerequisite: CHE 527. (3 credits)*

Structure, dynamics, and flow properties of polymers, colloids, liquid crystals and other substances with both liquid and solid-like characteristics.

**CHE 686 (CEE 686) (ENSCEN 686). Case Studies in Environmental Sustainability**

*Prerequisite: Senior or graduate standing. (2-3 credits)*

Case studies focusing on utilization of principles of environmental sustainability in professional practice. Development of environmental literacy through study of both current and historical environmental issues.

**CHE 695. Research Problems in Chemical Engineering**

*Prerequisite: Graduate students and admitted SUGS students with graduate advisor's permission. (1-16 credits)*

Laboratory and conferences. Provides an opportunity for individual or group work in a particular field or on a problem of special interest to the student. The program of work is arranged at the beginning of each term by mutual agreement between the student and a member of the faculty. Any problem in the field of chemical engineering may be selected. The student writes a final report on his project.

**CHE 696. Selected Topics in Chemical Engineering**

*Selected topics pertinent to chemical engineering.*

**CHE 697. Problems in Chemical Engineering**

*(to be arranged)*

**CHE 698. Directed Study in Chemical Engineering (1-16 credits)**

This project course is intended to provide students with relevant industrial project experience. The program of work is arranged at the beginning of each term by mutual agreement between the student and a member of the faculty. Any problem in the field of chemical engineering may be selected. The student writes a final report on his project.

**CHE 751 (Chem 751) (MacroSE 751) (MATSCIE 751) (Physics 751). Special Topics in Macromolecular Science**

*Prerequisite: Permission of instructor. (2 credits)*

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Advanced topics of current interest will be stressed.  
The specific topics will vary with the instructor.

**CHE 990. Dissertation/Pre-Candidate***(1-8 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**CHE 995. Dissertation/Candidate***Prerequisite: Graduate School authorization for admission as a doctoral candidate. (4 or 8 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Civil Engineering and Environmental Engineering

## Overview

Civil and environmental engineers design, plan and construct infrastructure systems including buildings, bridges, highways, airports, tunnels, pipelines, channels, waste-water systems, waste site, remediation systems, power generating plants, manufacturing facilities, dams and harbors. These infrastructure systems are key to sustaining human development and activities, and civil and environmental engineers must consider technical as well as economic, environmental, aesthetic and social aspects.

To recognize the distinct qualifications of engineers entering the fields of Civil and Environmental Engineering, the department offers undergraduate programs leading to a Bachelor of Science in Engineering in Civil Engineering and a Bachelor of Science in Engineering in Environmental Engineering. The Civil Engineering major offers several focus areas of specialization including: Construction Engineering & Management, Environmental Engineering, Geotechnical Engineering, Hydraulic and Hydrological Engineering, Civil Engineering Materials, and Structural Engineering. The Environmental Engineering major allows curricular focus in the areas of Water Quality and Health, Earth Systems, Environmental Fluid Dynamics, and Environmental Policy and Sustainable Infrastructure.

For more information on these fields and majors, please visit <http://cee.umich.edu/research>.

A minor in Environmental Engineering is also offered through the department. Eligibility information and requirements of the minor are described at <http://cee.engin.umich.edu/minor-environmental-engineering>.

Students who do well in their undergraduate program are encouraged to consider graduate work and may take

some of their electives in preparation for graduate study. The Sequential Undergraduate/Graduate Studies programs available in this department are described <http://cee.engin.umich.edu/sequentialapplicants>.

Information and assistance regarding fellowships and assistantships for graduate studies may be obtained in the Graduate Student Services of the Department of Civil and Environmental Engineering.

## Department Administration

### Department Chair

Professor Kim Hayes  
2340 G. G. Brown Laboratory

### Contacts

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## Civil Engineering

### Mission

As a leading educational and research institution, we are driving the development of innovative technologies that:

- Enhance the performance and sustainability of civil and environmental infrastructure
- Have a favorable impact on the natural environment
- Manage complex issues at the intersection of built and natural systems.

We are committed to solving major societal problems by providing forward-looking education, enhancing multidisciplinary research and performing broad-based service.

## Goals

To accomplish our mission, we must:

- Provide an enriching educational environment, together with extracurricular and service opportunities, that prepare our students to:
  - Excel as leaders in the understanding, design, construction, operation and maintenance of civil and environmental infrastructural systems,
  - Be ethical stewards of the built and natural environments, and
  - Adapt to an ever-changing profession through lifelong learning.
- Recruit, educate and support students, researchers, staff and faculty from diverse backgrounds, and provide them with the foundation to become global leaders;
- Enhance the department's positive impact nationally and internationally and make transformative contributions within the State of Michigan;
- Champion the translation of research findings into professional practice;
- Provide a technical foundation for shaping policy that addresses the complex issues facing civil and environmental infrastructure systems and the natural environment;
- Foster a leading-edge collaborative environment that is well-positioned to address high-impact research issues and provide solutions to critical societal challenges; and
- Foster and support the spirit of entrepreneurship among our students, faculty, and staff.

## Objectives

The following set of objectives describes what our graduates are expected to achieve within several years of graduation.

- The graduates of the Civil Engineering Program at Michigan will have the necessary intellectual tools and technical skills to take on careers of leadership in the development of new technologies, construction of modern infrastructure and to contribute to

society through participation in policy making and governance. Graduates will have a solid foundation in civil engineering and will achieve success in graduate education and a broad range of career opportunities.

- Our graduates will become team leaders and will successfully address open-ended problems applying critical thinking.
- The U-M Civil Engineering graduates will become effective communicators of technical and professional information in written, oral, visual and graphical form.
- Professional careers of U-M graduates will be distinguished with a high degree of awareness of moral, ethical, legal and professional obligations to protect human health, human welfare and the environment.

## Outcomes

The outcomes we desire are that graduates of the University of Michigan Civil Engineering Program demonstrate:

- An ability to apply knowledge of mathematics, science and engineering within civil engineering;
- An ability to design and conduct experiments, and to critically analyze and interpret data;
- An ability to design a system, component or process to meet desired needs;
- An ability to function in multi-disciplinary teams;
- An ability to identify, formulate and solve engineering problems;
- An understanding of professional and ethical responsibility;
- An ability for effective oral, graphic and written communication;
- An understanding of the impact of engineering solutions in a global and societal context;
- A recognition of the need for, and an ability to engage in, life-long learning;
- A knowledge of contemporary issues that affect civil engineering;
- An ability to use the techniques, skills and modern engineering tools necessary for engineering practice;

- A proficiency in a minimum of four major civil engineering areas;
- An understanding of professional practice issues and the importance of licensure.

## Environmental Engineering

### Mission

To provide an outstanding education in environmental engineering that prepares students for leadership positions in the improvement of human and ecological health at the intersection of built and natural systems.

### Goals

To provide an enriching educational environment that prepares students with the environmental science and engineering design principles to develop sustainable solutions to environmental problems and the professional skills to become leaders in the discipline.

### Objectives

The following objectives describe what our graduates are expected to achieve within several years of graduation.

- Demonstrate the critical thinking, technical and communication skills that will allow their advancement into leadership positions in engineering practice or other professional careers that involve the application of analytic engineering thinking;
- Pursue lifelong learning through continued education including engineering graduate study, or other professional education;
- Exhibit a high degree of awareness of ethical and professional obligations through involvement in professional societies, community activities or educational outreach.

### Outcomes

The outcomes we desire are that graduates of the pro-

gram demonstrate:

- An ability to apply knowledge of mathematics, science and engineering;
- An ability to design and conduct experiments, and to critically analyze and interpret data;
- An ability to design a system, component or process to meet desired needs;
- An ability to function on multidisciplinary teams;
- An ability to identify, formulate and solve engineering problems;
- An understanding of professional and ethical responsibility;
- An ability to communicate effectively;
- The broad education necessary to understand the impact of engineering solutions in a global/societal context;
- A recognition of the need for and an ability to engage in life-long learning;
- A knowledge of contemporary issues;
- An ability to use the techniques, skills and modern engineering tools necessary for engineering practice;
- An ability to formulate material and energy balances, analyze the fate and transport of substances, and design environmental engineering systems that involve considerations of risk, uncertainty, sustainability and life-cycle impacts;
- An understanding of professional practice issues related to environmental engineering.

## Civil Engineering

Civil engineers design, plan, and improve the built environment and infrastructure systems, including buildings, power generation facilities, water supply networks, pollution control works, flood protection structures, dams, and canals, as well as vital network systems for commerce such as roadways, airports, railroads, and ports. Civil engineering encompasses several subdisciplines, including hydraulics and hydrology, structural, geotechnical, construction, environmental, civil engineering materials, and transportation engineering.

Coursework in the major builds especially on a strong

foundation in math and physics, and exposes students to these subdisciplines. An emphasis in the sustainable engineering of civil infrastructure is also provided by the curriculum.

## Civil Engineering Focus Areas

The following are areas of focus within Civil Engineering at Michigan:

### Construction Engineering and Management

Planning, estimating, scheduling and managing the construction of engineered facilities using modern construction methods, materials, and equipment; business and legal principles of construction contracting.

### Environmental Engineering

The principles, design and methods for implementation of sustainable environmental and earth systems; water resource development, management, conservation and systems design; engineering of water quality and pollution control processes and systems; treatment, distribution and collection networks and infrastructures for optimal municipal and industrial water use, recovery and recycle; environmental design for efficient energy and resource utilization and minimization of water and air pollution and solid wastes generation; modeling of the fate and transport of contaminants in environmental media and systems and quantitative assessment of associated human and ecological risks.

### Geotechnical Engineering

Evaluation of soil properties and environmental conditions in foundations of earth-supported structures; mass stability in excavations and surface construction; use of soil characteristics and properties and soil classification in design and construction of highways, railways, airports, and other surface facilities; landslides, levees and slope stability.

### Hydraulic and Hydrological Engineering

Development of surface water and ground-water resources; flood prediction and flood control, flow of contaminant transport in surface and ground waters, transients in pipelines and channels, coastal engineer-

ing and design of structures to interface with the water environment.

### Civil Engineering Materials

Analysis, engineering, and testing of civil engineering materials pertaining to infrastructure renewal and high-performance structures, including the study of infrastructure rehabilitation (including bridge and pavement technology), advanced emerging materials (including cement-based composites, polymers, and ceramics), micro-mechanics of composite materials, and durability of materials.

### Structural Engineering

Theory, analysis, design, and construction of structures such as bridges, buildings, towers, and housing, involving the use of steel, reinforced concrete, pre-stressed concrete, fiber reinforced concrete, advanced composites and wood; studies of inelastic behavior of materials and structures; studies of dynamic forces and their effects on structures. Response of structures to earthquakes, fires, and terrorist attacks.

## Environmental Engineering

Environmental engineers design systems to provide safe water, air, and land for human habitation, and to address the impact of human activities on the environment. For example, environmental engineers may be involved in the design of technologies to remove emerging contaminants from drinking water, monitor and mitigate greenhouse gas compounds, recover resources and energy from waste streams, design sustainable alternative energy sources, cleanup hazardous waste sites, or restore streams and lakes damaged by human activities.

In this major, a strong foundation in math, chemistry, physics, biology, and earth science is important, and the engineering tools to apply them are provided in the curriculum. The social and policy issues associated with environmental problems are also explored.

## Sample Schedules

### B.S.E. in Civil Engineering

The Civil Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <http://cee.engin.umich.edu/academics/undergrad-studies/advising>.

Matriculation Fall 2011 and later

	Total Credit Hours	Terms:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, 215, 216	16	4	4	4	4	-	-	-	-
Engineering 100, Introduction to Engineering	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	-	4	-	-	-	-	-	-
Chemistry 130 and 125/126 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141 <sup>2</sup>	5	-	5	-	-	-	-	-	-
Physics 240 with Lab 241 <sup>2</sup>	5	-	-	5	-	-	-	-	-
Intellectual Breadth (includes Economics 101 or 102)	16	4	4	-	4	-	-	-	4
<b>Mathematical Methods (7 hours) +</b>									
CEE 270, Statistical Methods	3	-	-	-	-	3	-	-	-
CEE 303, Computational Methods	4	-	-	-	-	-	4	-	-
<b>Required Program Subjects (26 hours)<sup>3</sup> +</b>									
CEE 200, Intro to Civil and Environmental Engineering	1	-	-	-	1	-	-	-	-
CEE 211, Statics and Dynamics	4	-	-	4	-	-	-	-	-
CEE 212, Solid and Structural Mechanics	3	-	-	-	3	-	-	-	-
CEE 230, Thermodynamics and the Environment or CEE 375, Sensors and Circuits	3	-	-	3 or 3	-	-	-	-	-
CEE 265, Sustainable Engineering Principles	3	-	-	3 or 3	-	-	-	-	-
CEE 325, Fluid Mechanics	4	-	-	-	-	4	-	-	-
CEE 345, Geotechnical Engineering	4	-	-	-	-	4	-	-	-
CEE 402, Professional Issues & Design	4	-	-	-	-	-	-	-	4
<b>Science Elective (3 hours) +</b>									
Biology 171, 172, or 174	3	-	-	-	-	-	-	3	-
Earth & Environmental Sciences 119, 201, 222, 284, or 320									
CEE 482/582, Environmental Microbiology									
<b>Program Electives (16 hours)<sup>4</sup> +</b>									
CEE 312, Structural Engineering	16	-	-	-	-	4	8	4	-
CEE 351, Civil Engineering Materials									
CEE 365, Environmental Engineering Principles									
CEE 421, Hydrology and Floodplain Hydraulics									
CEE 431, Construction Contracting									
<b>Technical Electives (9 hours)<sup>5</sup> +</b>									
Construction: CEE 534, CEE 536, CEE 537	9	-	-	-	-	-	-	6	3
Structural: CEE 413*, CEE 415*, CEE 412									
Materials: CEE 547*, CEE 574*									
Geotechnical: CEE 540, CEE 545, CEE 546, CEE 549									
Hydraulics/Hydrology: CEE 526*, CEE 428, CEE 521, CEE 522									
Environmental: CEE 465*, CEE 480, CEE 481/581, CEE 482/582									
Transportation: CEE 470									
<b>General Electives (12 hours)</b>									
	12	-	-	-	-	-	4	4	4
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>15</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>15</b>

Candidates for the Bachelor of Science degree in Engineering (Civil Engineering) - B.S.E. (C.E.) - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

**Notes:**

Fall Winter

(+) Civil Engineering students must earn a C- or better in all courses whose categories are marked with a plus.

\* Mandatory Course in that focus area.

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams, or transfer credit from another institution for Chemistry 130/125/126, you will have met the Chemistry Core Requirement for the College of Engineering

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams, or transfer credit from another institution for Physics 140/141 and 240/241, you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> CEE will accept equivalent courses offered by other departments in the College of Engineering. Please see program advisor.

<sup>4</sup> At least four of the five program electives are required.

<sup>5</sup> At least two of the three technical electives must be in the same focus area.

## B.S.E. in Environmental Engineering

The Environmental Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <http://cee.engin.umich.edu/academics/undergrad-studies/advising>.

	Total Credit Hours	Terms:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, 215, 216	16	4	4	4	4	-	-	-	-
Engineering 100, Introduction to Engineering	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	-	4	-	-	-	-	-	-
Chemistry 130 and 125/126	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141 <sup>2</sup>	5	-	5	-	-	-	-	-	-
Physics 240 with Lab 241 <sup>2</sup>	5	-	-	5	-	-	-	-	-
Intellectual Breadth (includes Economics 101 or 102)	16	4	4	-	-	-	4	4	-
<b>Mathematical Methods (7 hours) +</b>									
CEE 270, Statistical Methods	3	-	-	-	-	3	-	-	-
CEE 303, Computational Methods	4	-	-	-	-	-	4	-	-
<b>Technical Core Subjects (32 hours)<sup>3+</sup></b>									
Chemistry 210, Structure & Reactivity I	4	-	-	-	4	-	-	-	-
CEE 200, Intro to Civil & Environmental Engineering	1	-	-	-	1	-	-	-	-
CEE 211, Statics and Dynamics	4	-	-	4	-	-	-	-	-
CEE 230, Thermodynamics and the Environment	3	-	-	3	-	-	-	-	-
CEE 265, Sustainable Engineering Principles	3	-	-	-	3	-	-	-	-
CEE 325, Fluid Mechanics	4	-	-	-	4	-	-	-	-
CEE 365, Environmental Engineering Principles	4	-	-	-	-	4	-	-	-
CEE 366, Environmental Engineering Laboratory	2	-	-	-	-	-	2	-	-
CEE 421, Hydrology and Floodplain Hydraulics	4	-	-	-	-	-	-	4	-
CEE 465, Environmental Process Engineering	3	-	-	-	-	-	3	-	-
<b>Environmental Sciences (9 hours) +</b>									
Earth Science Elective: AOSS 320, 410, or 475; EARTH 305, 315, 321, 323, 427, 442, or 477	3	-	-	-	-	3	-	-	-
CEE 481/581, Aquatic Chemistry	3	-	-	-	-	-	3	-	-
CEE 482/582, Environmental Microbiology	3	-	-	-	-	-	-	3	-
<b>Environmental Engineering Design (4 hours) +</b>									
CEE 402, Professional Issues and Design	4	-	-	-	-	-	-	-	4
<b>Technical Electives (9 hours)<sup>4+</sup></b>									
<i>Water Quality and Health:</i> CEE 428*, CEE 480*, CHE 342, EHS 500	9	-	-	-	-	-	-	3	6
<i>Atmospheric and Earth Systems:</i> CEE 549, CEE 563*, AOSS 463, AOSS 467, EARTH 413									
<i>Environmental Fluid Dynamics:</i> CEE 428*, CEE 521, CEE 522, CEE 526*									
<i>Energy and Sustainable Infrastructure:</i> CEE 567, UP 423, EARTH 344									
<i>Environmental Policy and Entrepreneurship:</i> ENGR 520, NRE 475, AOSS 480									
<b>General Electives (12 hours)</b>	12	-	-	-	-	4	-	2	6
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>14</b>	<b>16</b>	<b>16</b>	<b>16</b>

Candidates for the Bachelor of Science degree in Engineering (Environmental Engineering) - B.S.E. (Env.E.) - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

### Notes:

Fall Winter

(+) Environmental Engineering students must earn a C- or better in all courses whose categories are marked with a plus.

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams, or transfer credit from another institution for Chemistry 130/125/126, you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams, or transfer credit from another institution for Physics 140/141 and 240/241, you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> CEE will accept equivalent courses offered by other departments in the College of Engineering. Please see program advisor.

(\*) <sup>4</sup> At least two of the three technical electives must be CEE courses, including one design course: CEE 428, 480, 526, or 563

## Program in Sustainable Engineering

Sustainable engineering is achieved by finding economically viable technology solutions that reduce important environmental and societal concerns. Sustainable Engineering includes finding market and policy pathways to implement technologies that allow people and the planet to prosper and thrive.

The Program in Sustainable Engineering is an academic program that allows undergraduate engineering students to take 9 credit hours of courses focused on sustainability to earn the following notation on their transcript: "Program in Sustainable Engineering". In-person advising available in 2334 G.G. Brown (Matt Blank, CEE Department). Course requirements and additional information can be found on the PISE website, <http://pise.engin.umich.edu>.

## Sequential Undergraduate/Graduate Study (SUGS)

SUGS is a program of the Rackham Graduate School which enables students to pursue a five-year combined B.S.E./M.S.E. Civil and Environmental Engineering undergraduate students who have a cumulative GPA of at least 3.5 may apply. Students earning dual bachelor's degrees are not eligible for SUGS. Please contact the department or see the website for more information visit <http://cee.engin.umich.edu/sequentialapplicants>.

The following degree combinations are available through SUGS:

- B.S.E in Civil Engineering / M.S.E. in Civil Engineering
- B.S.E. in Civil Engineering / M.S.E. in Construction Engineering and Management
- B.S.E. in Civil Engineering / M.Eng. in Construction Engineering and Management
- B.S.E. in Civil Engineering / M.S.E. in Environmental Engineering
- B.S.E. in Environmental Engineering / M.S.E. in Environmental Engineering

## Graduate

### Civil and Environmental Engineering Graduate Programs

Graduate programs of advanced study, research and design are available in the five major areas listed below. The strength of the curriculum is enhanced by a variety of complementary programs of study and research available throughout the University of Michigan.

#### Construction Engineering and Management

- Construction Organization
- Construction Project
- Construction Operations

#### Environmental and Water Resources Engineering

Graduate degrees offered in either Civil or Environmental Engineering.

- Ecohydrology and Hydraulic Engineering
- Environmental Microbiology and Biotechnology
- Environmental Chemistry and Soil Physics
- Energy and Clean Tech

#### Geotechnical Engineering

- Site Characterization
- Foundation Design
- Stability of Earth Masses
- Soil Improvement
- Soil and Foundation Dynamics
- Geotechnical Earthquake Engineering
- Engineering Geology
- Rock Mechanics
- Soil Behavior
- Numerical and Analytical Modeling

## Structural and Materials Engineering

- Earthquake Resistant Design
- Behavior of Buildings and Bridges under Extreme Loading
- Design and Validation of Smart Structure Technologies
- Evaluation and Improvement of New and Existing Highway Bridges
- Design and Development of High Performance Mechanistic Evaluation of Properties of Concrete Pavement

## Infrastructure Systems

- Dynamical Modeling of Complex Infrastructure Systems
- Cyber-Physical Infrastructure Systems
- Resilience Through Adaptation
- Ultra-low Power Sensing and State Estimation for Civil Infrastructure Systems
- Advanced Functional Materials for Intelligent Infrastructure Systems
- Integrated Structure and Materials Design for Infrastructure Resiliency and Sustainability
- Intelligent Water Grids
- Energy Harvesting

## Graduate Degrees

- Master of Science in Engineering (M.S.E.) in Civil Engineering
- Master of Science in Engineering (M.S.E.) in Construction Engineering and Management
- Dual M.S.E. in Construction Engineering and Management/Master of Architecture
- Dual M.S.E. in Construction Engineering and Management/Master of Business Administration
- Master of Engineering (M.Eng.) in Construction Engineering and Management
- Master of Engineering (M.Eng.) in Structural Engineering
- Dual M.Eng. in Construction Engineering and Management/Master of Architecture
- Dual M.Eng. in Construction Engineering and Management/Master of Business Administration

- Master of Science in Engineering (M.S.E.) in Environmental Engineering
- Dual M.S.E. in Environmental Engineering/M.S. in Natural Resources and Environment
- Doctor of Philosophy (Ph.D.) in Civil Engineering
- Doctor of Philosophy (Ph.D.) in Environmental Engineering

## Master of Science Programs / Master of Engineering Programs

The Department of Civil and Environmental Engineering (CEE) offers three Master of Science in Engineering (M.S.E.) degree programs and two Master of Engineering (M.Eng.) degree programs, as well as multiple options for dual degrees in collaboration with other programs at the university. The M.S.E. and M.Eng. programs require 30 credit hours of graduate work (typically 10 courses) and do not require a thesis or other major research project. At least two courses, of which one is mathematically oriented, must be taken in departments other than CEE.

The Graduate Record Examination (GRE) is required for application to the M.S.E. program. Letters of recommendation are also required. Degree programs differ in the undergraduate degrees they require for regular admission.

Students who do not meet undergraduate degree requirements for regular admission may be granted conditional admission. Students may be required to take courses without graduate credit to remedy the deficiencies in their undergraduate programs.

## M.S.E. in Civil Engineering

This program requires at least 15 hours of CEE courses. A student should expect to take at least eight hours in the area of specialization but will not be permitted to apply more than 21 hours in one area of specialization toward the M.S.E. degree. Study programs are available in the following areas of specialization:

- Construction Engineering and Management
- Geotechnical Engineering

- Hydraulic and Hydrologic Engineering
- Infrastructure Systems
- Materials and Highway Engineering
- Structural Engineering

Regular admission is open to students holding an undergraduate degree in Civil Engineering or an equivalent.

### **M.S.E. in Construction Engineering and Management**

This program requires at least 18 hours of graduate courses in the Construction Engineering and Management Program. Regular admission is open to students holding a degree in any engineering discipline.

### **Dual M.S.E. in Construction Engineering and Management / Master of Business Administration**

The dual degree program requires the 12 hours of core courses and 9 hours of graduate construction electives in the M.S.E. (CE&M) program and the 30 hours of core courses and 15 hours of electives in the MBA program. Students also take a 3-hour independent study course (CEE 630) to integrate general Construction Engineering and Management skills. Students also take Construction Contracting (CEE 431) if they have not taken it or its equivalent previously. The dual degree program combines the two-year, 60-hour MBA program with the one-year, 30-hour M.S.E. (CE&M) program, resulting in a two-year (including Spring and/or Summer terms) 66- or 69-hour program. The dual degree program can be completed in two years if the first year is devoted to core MBA courses.

### **Dual M.S.E. in Construction Engineering and Management / Master of Science in Engineering**

Dual M.S.E. degree programs combine a 30-hour M.S.E. (CE&M) program with another 30-hour Master's program resulting in a 51-hour program, 9 hours of which satisfy requirements for both programs. Usu-

ally these 9 hours are core courses from the other Master's program, used as electives in the Construction Engineering and Management program. An applicant who has recently received or is working toward a Master's degree in another area of engineering at Michigan can complete the M.S.E. (CE&M) with an additional 21 hours of coursework.

### **M.Eng. in Construction Engineering and Management**

This program requires at least 18 hours of graduate courses in the Construction Engineering and Management Program. Regular admission is open to students holding a degree in any engineering discipline. Applicants with bachelor's degrees in architecture or other non-engineering programs may be granted admission if they have taken a year of calculus and a year of physics.

### **Dual M.Eng in Construction Engineering and Management / Master of Architecture**

The dual degree program combines the two-year 60-hour M.Arch. program with the one-year, 30-hour M.Eng. (CE&M) program, resulting in a two and one-half year, 75-hour program.

### **Dual M.Eng in Construction Engineering and Management / Master of Business Administration**

The dual degree program requires the 12 hours of core courses and 9 hours of graduate construction electives in the MEng (CE&M) program and the 30 hours of core courses and 15 hours of electives in the MBA program. Students also take a 3-hour independent study course (CEE 630) to integrate general Construction Engineering and Management skills. Students also take Construction Contracting (CEE 431) if they have not taken it or its equivalent previously. The dual degree program combines the two-year, 60-hour MBA program with the one-year, 30-hour M.Eng. (CE&M) program, resulting in a two-year (including Spring and/or

Summer terms) 66- or 69-hour program. The dual degree program can be completed in two years if the first year is devoted to core MBA courses.

### **M.Eng. in Structural Engineering**

A minimum of 30 credit hours is required to complete the M.Eng. in Structural Engineering degree. Students will elect a broad array of structural engineering courses. Features of the program include the requirement to have a minor area of professional emphasis either within or outside the CEE Department, and the requirement for a structural engineering project based on professional practice in structural engineering.

### **M.S.E. in Environmental Engineering**

This program requires at least 18 hours of graduate courses in the Environmental and Water Resources Engineering Program. Specific course requirements are given in the departmental Guidelines for this M.S.E. degree. Students holding an engineering or science degree will be considered for regular admission.

### **Dual M.S.E. in Environmental Engineering / M.S. in Natural Resources and Environment: "Engineering Sustainable Systems: Specialization in Sustainable Water Resources or Energy Systems"**

This dual degree program combines a Master of Science in Engineering (M.S.E.) in Civil Engineering or in Environmental Engineering, and a Master of Science (M.S.) degree in Natural Resources and Environment. More detailed information is available in the program guidelines.

### **Environmental Sustainability Concentration**

The Department of Civil and Environmental Engineering participates actively in the College of Engineering Concentrations in Environmental Sustainability (ConsEnSus) Program for M.S., M.S.E. and Ph.D. stu-

dents. The general description of the ConsEnSus program can be found here. Students interested in further details on implementation of this program in the Department of Civil and Environmental Engineering should contact one of the Department ConsEnSus Advisors.

### **Ph.D. Programs**

The Department of Civil and Environmental Engineering (CEE) offers the Doctor of Philosophy (Ph.D.) with two designations: Civil Engineering and Environmental Engineering. Ph.D. programs usually include 50 to 60 hours of graduate coursework beyond the bachelor's degree level. Foreign languages are not required. The focus of doctoral studies is the student's dissertation research, which must make a significant contribution to professional knowledge in the field. Major steps toward the Ph.D. degree include:

- qualifying examination (usually taken after completion of one or two terms of coursework beyond the master's degree)
- appointment of dissertation committee
- completion of coursework and English proficiency requirement
- preliminary examination
- advancement to candidacy
- completion of dissertation
- final oral examination

Admission to the Ph.D. program is granted only to students who show promise and provide sufficient evidence that they can meet scholastic requirements of study, including independent research, at an advanced level. The qualifying examination is only open to students with a GPA of better than B+.

### **Ph.D. in Civil Engineering**

Areas of specialization include:

- Construction Engineering and Management
- Geotechnical Engineering
- Hydraulic and Hydrologic Engineering
- Infrastructure Systems

- Materials and Highway Engineering
- Structural Engineering

## Ph.D. in Environmental Engineering

Areas of specialization include:

- Environmental Chemistry and Microbiology
- Hazardous Substance Treatment and Control
- Hydraulics and Fluid Mechanics
- Management Policy and Economics
- Surface and Groundwater Hydrology
- Watershed Hydrology and Ecohydrology
- Water Quality Engineering
- Geostatistical Modeling and Optimization
- Atmospheric Modeling

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### CEE 200. Introduction to Civil and Environmental Engineering

*Prerequisite: None. Mandatory pass/fail. (1 credit)*

An introduction to the nature and scope of the civil and environmental engineering disciplines and specialty programs. Includes case studies from practice and information about academic and professional opportunities for CEE students.

### CEE 211. Statics and Dynamics

*Prerequisite: Physics 140. (4 credits)*

Statics: review of vector mathematics; moment and force resultants; static equilibrium in two & three dimensions; centroids; center of gravity; distributed loadings. Dynamics: review of concepts of velocity and acceleration; dynamics of particles and rigid bodies; concepts of work, energy, momentum; introduction to vibrations. Four lectures per week.

### CEE 212. Solid and Structural Mechanics

*Prerequisite: CEE 211 or equivalent. (3 credits). No credit granted to those who have completed or are enrolled in MECHENG 211.*

Fundamental principles of solid and structural mechan-

ics and their application in engineering disciplines.

Covered: concepts of stress and strain, stress and strain transformations, axial, torsion, bending and combined loading and elastic deformations.

### CEE 230. Thermodynamics and the Environment

*Prerequisites: Math 116; Chem 130 & 125/126 or Chem 210 & 211 advised. (3 credits)*

The First and Second Laws of thermodynamics are applied to systems impacting built and natural environments to determine the performance requirements and thermodynamic efficiencies of engineered processes. Topics of coverage include the properties of pure substances and mixtures, phase changes, reaction and phase equilibrium, heating, air conditioning, and power generation.

### CEE 265. Sustainable Engineering Principles

*Prerequisites: Chem 130, Math 116. (3 credits)*

Sustainable engineering principles include calculations of environmental emissions and resource consumption. Mass and energy balance calculations in context of pollution generation and prevention, resource recovery and life-cycle assessment. Economic aspects of sustainable engineering decision-making. Social impacts of technology system design decisions including ethical frameworks, government legislation and health risks.

### CEE 270. Statistical Methods for Data Analysis and Uncertainty Modeling

*Prerequisites: Math 116 and ENGR 101. (3 credits)*

Introductory probability and statistics with emphasis on data analysis and uncertainty modeling for engineering and environmental systems. Descriptive statistics, graphical representation of data, linear regression, correlation, discrete and continuous probability distributions, conditional probability, estimation, statistical inference, extreme events, reliability analysis and techniques for design under uncertainty.

### CEE 303. Computational Methods for Engineers and Scientists

*Prerequisites: ENGR 101, Math 216. (4 credits)*

Applications of numerical methods to infrastructure and environmental problems. Development of mathematical models and computer programs using a compiled language (FORTRAN). Formulation and solution

of initial and boundary-value problems with emphasis on structural analysis, fluid flow and transport of contaminants. Lecture, recitation and computation.

### **CEE 312. Structural Engineering**

*Prerequisite: CEE 212 or equivalent. (4 credits)*

Introduction to the field of structural engineering. Discussion of structural analysis techniques and concepts such as virtual work, flexibility method, stiffness method, influence lines and matrix structural analysis. Training in AutoCAD and exposure to commonly used structural analysis computer program(s). Discussion of basic design concepts and principles.

### **CEE 325. Fluid Mechanics**

*Prerequisites: CEE 211. (4 credits)*

Principles of mechanics applied to real and ideal fluids. Fluid properties and statics; continuity, energy, and momentum equations by control volume analysis; differential equations of motion for laminar and turbulent flow; dimensional analysis and similitude; boundary layers, drag and lift; incompressible flow in pipes; fluid measurement and turbomachinery. Lecture and laboratory.

### **CEE 345. Geotechnical Engineering**

*Prerequisite: Physics 140. (4 credits)*

Soil origins, classification and index properties; phase relationships; earth moving and soil compaction; groundwater seepage; compressibility and consolidation; settlement; shear strength and failure; applications to foundations; retaining structures and slopes. Lecture and laboratory.

### **CEE 351. Civil Engineering Materials**

*Prerequisite: CEE 212 or equivalent. (4 credits)*

Discussion of basic mechanical and physical properties of a variety of civil engineering materials such as concrete, asphalt, wood and fiber composites. Evaluation and design for properties, load-time deformation characteristics, response to typical service environments. Lecture and laboratory.

### **CEE 365. Environmental Engineering Principles**

*Prerequisites: CHEM 130, MATH 116. (4 credits)*

An introduction to mass balance modeling of contaminant fate, transport and removal in the environment;

commonly used reactor configurations for water and air quality control; partitioning of contaminant types and sources; regional and global contemporary environmental issues.

### **CEE 366. Environmental Engineering Laboratory**

*Prerequisites: Prior or concurrent enrollment in CEE 270 and CEE 365. (2 credits)*

Weekly lecture and experimental projects designed to illustrate key analytical measurements of water and air quality parameters, soil properties, and environmental process engineering. Emphasis on data analysis, report writing, oral presentations, experimental design and teamwork.

### **CEE 375. Sensors, Circuits, and Signals**

*Prerequisites: Physics 240. (3 credits)*

This course introduces students to the fundamentals of collecting and processing experimental data. The course begins with an introduction to DC and AC circuits. The design and operation of sensors are then introduced followed by an introduction to digital signal processing.

### **CEE 402. Professional Issues and Design**

*Prerequisite: Senior standing. (4 credits)*

Multidisciplinary team design experience including consideration of codes, regulations, alternate solutions, economic factors, sustainability, constructability, reliability and aesthetics in the solution of a civil or environmental engineering problem. Professionalism and ethics in the practice of engineering.

### **CEE 412. Matrix Structural Analysis**

*Prerequisite: Math 216 and CEE 312 or equivalent. (3 credits)*

Displacement-based linear analysis of truss, beam, frame, and cable structures, including axial loading and structural pre-tension effects. Analytical derivation of stiffness equations from first principles. Matrix assembly techniques and implementation of computational solution techniques. Approximate stability analysis. Elementary plasticity analysis, using incremental loading techniques. Introduction to structural dynamics.

### **CEE 413. Design of Metal Structures**

*Prerequisite: CEE 312. (3 credits)*

Design of metal members and connections and their use in buildings and bridges. Application of relevant design specifications with emphasis on structural steel.

#### **CEE 415. Design of Reinforced Concrete Structures**

*Prerequisite: CEE 312. (3 credits)*

Design of reinforced concrete members and slabs, and their use in buildings and bridges. Application of relevant design specifications.

#### **CEE 421. Hydrology and Floodplain Hydraulics**

*Prerequisites: CEE 303, CEE 325. (4 credits)*

Fundamentals of surface-water hydrology, flow in open channels and flood hazard mitigation. Rainfall-runoff relations. Unit hydrograph method. Uniform and nonuniform flow in open channels. Measurement and control of river flow. Flood waves in rivers, floodplains and reservoirs. Design of storage basins, storm channels and culverts. Lecture, laboratory and computation.

#### **CEE 428 (ENSCEN 428). Groundwater Hydrology**

*Prerequisite: CEE 325 and (CEE 345 or CEE 366) advised. (3 credits)*

Basic principles which govern the flow of water in the subsurface. Development and solution of groundwater flow and contaminant transport equations, in presence and absence of pumping wells, for both confined and phreatic aquifers. Measurement and estimation of parameters governing flow and transport. Use of computer software for the simulation of flow.

#### **CEE 430. Special Problems in Construction Engineering**

*Prerequisite: Permission of instructor. (1-3 credits)*

Individual student may choose his or her special problem from a wide range of construction engineering and management areas.

#### **CEE 431. Construction Contracting**

*Prerequisite: Senior standing. (4 credits)*

Construction contracting for contractors, architects, owners. (1) Organization and administration; industry structure; construction contracts, bonds, insurance. (2) Planning, estimating and control; quantity takeoff and pricing; labor and equipment estimates; estimating excavation and concrete; proposal preparation; schedul-

ing; accounting and cost control. Students use contract documents to prepare detailed estimate.

#### **CEE 446. Engineering Geology & Site Characterization**

*Prerequisite: CEE 345 or permission of instructor. (3 credits)*

Composition and properties of rocks and soil, geologic processes, geologic structures and engineering consequences, mapping and map analysis, airphoto interpretation, in-situ testing of soils and rock, field demonstration, civil engineering facility siting.

#### **CEE 465. Environmental Process Engineering**

*Prerequisite: CEE 325 and CEE 365. (3 credits)*

An introduction to the analysis, characterization and principles of physical, chemical and biological processes, operations and reactor configurations commonly used for water quality control; preliminary design of specific water and wastewater treatment processes and operations; discussion of economic and legislative constraints and requirements.

#### **CEE 470. Introduction to Transportation Engineering**

*Prerequisite: MATH 116. (3 credits)*

Fundamentals of planning, design and operation of highway transportation facilities. Topics covered include driver and vehicle performance characteristics, highway geometric design principles, basics of traffic analysis and transportation planning.

#### **CEE 480. Design of Environmental Engineering Systems**

*Prerequisite: CEE 465 advised. (3 credits)*

Design and theoretical understanding of environmental processes; biological, physical and chemical processes and reactor configurations commonly used for water quality control; applications to the design of specific water and wastewater treatment operations; discussion of pollution prevention and green engineering options.

#### **CEE 481. Aquatic Chemistry**

*Prerequisite: CHEM 130 advised. (3 credits)*

Chemical principles applicable to the analysis of the chemical composition of natural waters and engineered water treatment systems; covers acid-base, precipitation

-dissolution, complexation and oxidation-reduction reactions; emphasis on graphical and analytical specification methods; presented in the context of contemporary environmental issues including water quality, climate change and pollution prevention and abatement.

### **CEE 482. Environmental Microbiology**

*Prerequisite: CHEM 130 advised. (3 credits)*

Introductions to microbial metabolic processes and nutrition, thermodynamics of growth and energy generation, genetic and metabolic diversity, evolution and systematics, and microbial ecology. Emphasis is placed on the application of these concepts to environmental biotechnology.

### **CEE 490. Independent Study in Civil and Environmental Engineering**

*Prerequisite: Permission of instructor. (1-4 credits)*

Individual or group experimental or theoretical research in any area of Civil and Environmental Engineering. The program of work is arranged at the beginning of each term by mutual agreement between the student and a faculty member. Written and oral reports may be required.

### **CEE 500. Environmental Systems and Processes**

*Prerequisite: CEE 460. (3 credits)*

Concepts of environmental systems and principles of related transport and transformation phenomena and processes; development of fundamental models for articulation of relevant process dynamics; system and process scaling factors and methods; extension of process models to ideal and nonideal natural and engineered homogeneous environmental systems.

### **CEE 508. Design of Masonry Structures**

*Prerequisites: CEE 312. (3 credits)*

Use and design of masonry in structural applications. Topics include ancient masonry, masonry materials and how their properties affect performance, reinforced beams and lintels, masonry walls (reinforced and unreinforced), masonry columns and pilasters and shear walls. Students will be exposed to both working stress and strength analysis/design provisions.

### **CEE 509. (MECHENG 512) Theory of Elasticity**

*Prerequisites: MECHENG 412 or MECHENG 511. (3*

*credits)*

Stress, strain and displacement, equilibrium and compatibility. Use of airy stress function in rectangular and polar coordinates, asymptotic fields at discontinuities, forces and dislocations, contact and crack problems, rotating and accelerating bodies. Galerkin and Papcovich-Neuber solutions, singular solutions, spherical harmonics. Thermoelasticity. Axisymmetric contact and crack problem. Axisymmetric torsion.

### **CEE 510 (NAVARCH 512) Finite Element Methods in Solid and Structural Mechanics**

*Prerequisite: Graduate standing. (3 credits)*

Basic equations of three-dimensional elasticity. Derivation of relevant variational principles. Finite element approximation. Convergence requirements. Isoparametric elements in two and three dimensions. Implementation considerations. Locking phenomena. Problems involving non-linear material behavior.

### **CEE 511. Dynamics of Structures**

*Prerequisite: CEE 412 or equivalent. (3 credits)*

Dynamic equilibrium of structures. Response of a single degree of freedom system to dynamic excitation: free vibration, harmonic loads, pulses and earthquakes. Response spectra. Response of multi-degree-of-freedom systems. Seismic behavior of buildings and the basis for seismic building codes.

### **CEE 512. Nonlinear Analysis of Structures**

*Prerequisite: CEE 412 or equivalent. (3 credits)*

Extension of matrix structural analysis to solve geometric and material nonlinear problems in structural engineering. Topics include elastic stability of columns, P-delta effects, large-displacement analysis of cable structures, inelastic analysis of frames using lumped and distributed plasticity models, and solution algorithms for nonlinear systems of equations.

### **CEE 513. Plastic Analysis and Design of Frames**

*Prerequisite: CEE 413. (3 credits)*

Plastic analysis and design of steel framed structures. Stepwise incremental load and mechanism methods. Behavior beyond elastic range; failure mechanisms. Use of computer programs and AISC specifications. Application to earthquake resistant design.

**CEE 514. Prestressed Concrete***Prerequisite: CEE 415. (3 credits)*

Fundamental principles of prestressing; prestressing materials; prestress losses; allowable stress and ultimate strength design methods; analysis and design of beams for flexure, shear and deflection; composite construction; bridges; slab systems; partial prestressings; FRP tendons.

**CEE 515. Advanced Design of Reinforced Concrete Structures***Prerequisite: CEE 415. (3 credits)*

Analysis and design of concrete structural systems including two-way floor systems, slender columns, members subjected to torsion, structural walls and connections. Applications of computer-aided design programs. Use of design code provisions. Design projects.

**CEE 516. Bridge Structures***Prerequisites: CEE 413, CEE 415. (3 credits)*

Advanced concepts and modern trends in design of bridges. Rehabilitation, repair and retrofit of existing bridges. Use of relevant codes. Study of alternative structural forms and materials for efficiency and economy. Design problems and reports.

**CEE 517. Reliability of Structures***Prerequisite: CEE 270 or equivalent. (3 credits)*

Fundamental concepts related to structural reliability, safety measures, load models, resistance models, system reliability, optimum safety levels and optimization of design codes.

**CEE 519. Hybrid and Composite Structures***Prerequisites: CEE 415 or equivalent and CEE 413 or equivalent. (3 credits)*

Behavior and design of hybrid and composite structural members, connections and systems, including composite frame construction, structural walls systems and braced frames; design of advanced fiber cementitious materials and applications in new and deficient structural systems; Fiber Reinforced Polymers (FRP) for structural repair and retrofit.

**CEE 520. Physical Processes of Land-Surface Hydrology***Prerequisites: CEE 421 or graduate standing. (3 credits)**its)*

Key elements of land-surface hydrology. Water in the atmosphere; dry adiabatic and pseudoadiabatic processes. Vapor turbulent transfer. Heat fluxes and surface energy budgets. Mass transfer and energy budget methods for estimating evapotranspiration. Soil physical properties; water flow in unsaturated soils; infiltration. Snow hydrology. Runoff generation. Probabilistic approaches to describing spatial variability.

**CEE 521. Flow in Open Channels***Prerequisite: CEE 325 or equivalent. (3 credits)*

Conservation laws for transient flow in open channels; shallow-water approximation; the method of characteristics; simple waves and hydraulic jumps; non-reflective boundary conditions; dam-break analysis; overland flow; prediction and mitigation of flood waves.

**CEE 522. Sediment Transport***Prerequisite: CEE 325 or equivalent. (3 credits)*

Mechanics of sediment transport processes in fluvial systems; initiation of motion; bed forms; resistance to flow; suspended sediment transport; bed load transport; cohesive sediments; geomorphology principles.

**CEE 524. Environmental Turbulence***Prerequisite: CEE 325 or equivalent. (3 credits)*

Introduction to the topic of turbulence with special emphasis on physical processes; characterization of fundamental turbulent flows such as shear layers, wakes, jets, plumes and thermals; effect of stratification on turbulence; forcing and control of turbulence by acceleration and pulsation.

**CEE 525. Turbulent Mixing in Buoyant Flows***Prerequisite: CEE 325 or equivalent. (3 credits)*

Environmental regulations relating to mixing zones; analysis of submerged turbulent buoyant jets; scaling relations; consideration of ambient effects including density stratification, ambient currents, and limited depth; numerical models for buoyant jet mixing; hydraulics of two-layer stratified flow and control on mixing processes.

**CEE 526. Design of Hydraulic Systems***Prerequisite: CEE 325 or equivalent. (3 credits)*

Hydraulic design of piping systems including pumps and networks; pump system design including variable speed operation, cavitation and wet well design; waterhammer and other transient phenomena; control valves and flow metering considerations; hydraulic control structures.

### **CEE 527. Coastal Hydraulics**

*Prerequisite: CEE 325 or equivalent. (3 credits)*

General description of wave systems including spectral representation; solutions to oscillatory wave equation; wave breaking; harbor resonance; wave shoaling, refraction and diffraction; wave forecasting; selection of design wave conditions; forces on coastal structures; shoreline erosion processes.

### **CEE 528. (ENSCEN 528) Flow and Transport in Porous Media**

*Prerequisite: CEE 428 or equivalent. (3 credits)*

Basic principles governing flow and transport in porous media; development of mathematical models at pore and continuum levels; single and multiphase flow; solute transport and dispersion theory; parameter estimation; application to saturated and unsaturated groundwater flow, flow in fractured media, petroleum reservoirs, saltwater intrusion and miscible and immiscible subsurface contamination.

### **CEE 529. Hydraulic Transients I**

*Prerequisite: CEE 421. (3 credits)*

Incompressible unsteady flow through conduits; numerical, algebraic and graphical analysis of waterhammer; solution of transient problems by the method of characteristics; digital computer applications to pump failures, complex piping systems; valve stroking and liquid column separation.

### **CEE 530. Construction Professional Practice Seminar**

*Prerequisite: Permission of instructor; mandatory satisfactory/unsatisfactory. (1-3 credits)*

Construction industry speakers, field trips, team projects. Student teams investigate construction technologies and work with construction industry clients as volunteer consultants to address industry, organization and project problems. Teams prepare and present written and oral reports to seminar and clients.

### **CEE 531. Construction Cost Engineering**

*Prerequisites: Graduate standing and preceded or accompanied by CEE 431. (3 credits)*

Cost engineering for construction organizations, projects and operations. Construction financing; break-even, profit and cash flow analyses; capital budgeting. Equipment cost and procurement decisions. Construction financial accounting, cost accounting, cost control systems, databases. Cost indices, parametric estimates, unit price proposals, measuring work and settling claims.

### **CEE 532. Construction Project Engineering**

*Prerequisites: Graduate standing and preceded or accompanied by CEE 431. (3 credits)*

Project, company organization. Manpower training, planning, procurement; union, nonunion construction. Job site layout. Material equipment procurement, submittals. Construction operation planning, supervision, measurement, analysis, improvement. Dimensions of performance: safety, quality, quality of work life, productivity, innovation. Examples, cases from construction.

### **CEE 533. Advanced Construction Systems**

*Prerequisite: Preceded or accompanied by CEE 431. (3 credits)*

Human-machine interactions. Automation and robotics. Ergonomics, job analysis and job design. Work physiology, environmental factors. Occupational health and safety with focus on underlying causes and prevention of illnesses and injuries rather than on regulation. Risk, safety and loss management.

### **CEE 534. Construction Engineering, Equipment, and Methods**

*Prerequisite: Junior standing. (3 credits)*

Major construction equipment and concrete construction. Selection of scrapers, dozers, cranes, etc. based on applications, methods, and production requirements. Power generation, transmission, and output capacity of equipment engines. Calculation of transport cycle times. Concrete methods include mixing, delivery and placement. Design of forms for concrete walls and supported slabs.

### **CEE 535. Excavation and Tunneling**

*Prerequisite: CEE 345. (3 credits)*

Selection of methods of attack for excavation of tunnels and deep vertical-sided openings. Tunneling procedures based on behavioral characteristics of soil and rock.

Study of tunnel boring machines, shielded and drill-and-blast operations, linings. Soil liner interaction. Deep excavation procedures related to support of excavation systems, methods of installation and dewatering.

**CEE 536 (MFG 536). Critical Path Methods**

*Prerequisite: Senior or graduate standing. (3 credits)*

Basic critical path planning and scheduling with arrow and precedence networks; project control; basic overlapping networks; introduction to resource leveling and least cost scheduling; fundamental PERT systems.

**CEE 537. Construction of Buildings**

*Prerequisite: CEE 351. (3 credits)*

Material selection, construction details, manufacture, fabrication and erection of building structures using steel, light wood, timber, cast-in-place concrete, precast concrete and masonry; and materials for roof, floor and wall surfaces. Zoning, building codes and other legal issues. Introduction to HVAC and electrical systems. Field trips to construction sites.

**CEE 538. Concrete Construction**

*Prerequisite: CEE 351. (3 credits)*

Selection of concrete, batch design, additives and batch plant. Structural design, construction of concrete formwork for buildings, civil works. Transporting, placing and finishing equipment and methods. Plant and on-site pre-casting and prestressing methods and field erection. Sprayed, vacuum and preplaced aggregate concrete applications. Industrialized concrete systems. Concrete grouting, repair.

**CEE 539. Construction Management Information Systems**

*Prerequisite: Senior or graduate standing (3 credits)*

Automation of construction engineering and management functions using modern analysis, design and productivity tools. Modeling and graphical 3D visualization of construction processes and products. Mobile computing and information systems to support field engineering tasks. Students apply computerized systems to solve construction problems and case studies.

**CEE 540. Advanced Soil Mechanics**

*Prerequisite: CEE 345 or equivalent. (3 credits)*

Deformation and strength of soils; total and effective stress; drained and undrained behavior. Constitutive description: elastic-plastic, hardening/softening, Cam clay model, critical states. Stress paths, and testing of soils. Modeling of reinforced soil: multi-component model and homogenization approach; fiber-reinforced soil. Theorems of limit analysis; applications in stability assessment.

**CEE 541. Soil Sampling and Testing**

*Prerequisite: Preceded or accompanied by CEE 345. (3 credits)*

Field and laboratory practice in sampling and testing of soils for engineering purposes. Field sampling and testing; standard split-spoon sampler, Dutch Cone penetrometer, field vane, Iowa borehole shear device. Lab tests; direct shear, unconfined compression, triaxial compression, consolidation. Laboratory and lecture.

**CEE 542. Soil and Site Improvement**

*Prerequisite: CEE 345 or equivalent. (3 credits)*

Analysis of geotechnical problems affecting site use including weak, compressible soil; high shrink-swell potential; and liquefiable soils. Stabilization techniques including compaction, earth reinforcement, admixture stabilization, deep mixing, grouting, precompression, thermal and electrokinetic stabilization and vibro-compaction.

**CEE 543. Numerical Modeling in Geotechnical Engineering**

*Prerequisite: CEE 345 or equivalent advised. (3 credits)*

Finite element method formulation, constitute laws for geotechnical materials including elastic-perfectly plastic and nonlinear elasto-plastic. Critical state framework for modeling soil behavior. Finite element program PLAXIS for performing static analyses of earth structures. Soil structure interaction. Finite difference method and discrete element method. Advanced soil models.

**CEE 544. Rock Mechanics**

*Prerequisite: CEE 212 or equivalent. (3 credits)*

Engineering properties and classification of rocks.

Strength and deformability of intact and jointed rock; in situ stresses; lab and field test methods. Stereonets and structural geology. Rock slopes; stability and reinforcement. Foundations on rock.

#### **CEE 545. Foundation Engineering**

*Prerequisite: CEE 345 or equivalent. (3 credits)*

Application of principles of soil mechanics to: determination of bearing capacity and settlement of spread footings, mats, single piles and pile groups; site investigation, evaluation of data from field and laboratory tests; estimation of stresses in soil masses; soil structure interaction.

#### **CEE 546. Slopes, Dams and Retaining Structures**

*Prerequisite: CEE 345 or equivalent. (3 credits)*

Slope stability analyses, seepage through soils, settlements and horizontal movements in embankments, earthen embankment and dam design, landslide and embankment stabilization, earth pressures and retaining structure design.

#### **CEE 547. Soils Engineering and Pavement Systems**

*Prerequisite: CEE 345 or equivalent. (3 credits)*

Soils engineering as applied to the design, construction and rehabilitation of pavement systems. The design, evaluation and rehabilitation of rigid, flexible and composite pavements.

#### **CEE 548. Geotechnical Earthquake Engineering**

*Prerequisite: CEE 345 or equivalent recommended. (3 credits)*

Ground motion attenuation relationships, seismic site response analysis, evaluation and modeling of dynamic soil properties, soil structure interaction, evaluation and mitigation of soil liquefaction, seismic code provisions and practice, seismic earth pressures, slope stability and deformation analysis, safety of dams and embankments, performance of pile foundations and additional current topics.

#### **CEE 549. Geoenvironmental Engineering**

*Prerequisite: CEE 345 or equivalent. (3 credits)*

Waste generation/disposal; waste types; waste facilities regulations; geoenvironmental site characterization; soil-water-contaminant interactions; design and construction of base and cover containment systems; geo-

synthetic materials in geoenvironmental applications; landfill settlement and stability; introduction to bioreactor landfills and emerging technologies for waste disposal; technologies for site restoration and clean up.

#### **CEE 550. Quality Control of Construction Materials**

*Prerequisite: CEE 351. (3 credits)*

Construction material specification and test procedures. Sampling methods, data collection and statistical data distributions. Quality control charts, development of quality assurance specifications and acceptance plans. Examples using data from actual field construction and laboratory experiments collected by destructive and non-destructive methods.

#### **CEE 551. Rehabilitation of Constructed Facilities**

*Prerequisite: CEE 351. (3 credits)*

Infrastructure needs. Rehabilitation studies of buildings, underground construction, bridges, streets and highways. Types of distress; numerical condition surveys for foundation, structural and functional deterioration; design criteria; materials and techniques; predictive performance models; evaluating alternatives; databases; maintenance management.

#### **CEE 552. Bituminous and Cement Mixes for Construction**

*Prerequisite: CEE 351. (3 credits)*

Types and properties of bituminous, Portland and other cements used in construction. Natural and synthetic aggregate characteristics and uses. Compositions and properties of different mixtures used for highways, airports, parking areas, reservoir linings and other constructed facilities. Laboratory experiments with selected compositions.

#### **CEE 555. Sustainability of Civil Infrastructure Systems**

*Prerequisite: None. (3 credits)*

Life Cycle Cost Analysis and Life Cycle Analysis - Methods and Applications in Civil Infrastructure Systems; Building Energy Modeling and Simulation; Energy Management in Buildings; Impact of Building Occupants and Behavioral Challenges; Renewable Energy and Efficiency in Buildings; Existing Buildings and Technical/Social Challenges of Energy Retrofits; and

Building Certifications (e.g., LEED).

### **CEE 563. Air Quality Engineering Fundamentals**

*Prerequisite: CEE 230 and CEE 325 or equivalents. (3 credits)*

Fundamental engineering principles for preventing or reducing air pollutant emissions. Combustion modifications to prevent pollutant formation. Gas adsorption and absorption processes, including carbon capture and sequestration. Particle filtration processes. Emissions and control of metals and air toxins. Indoor air pollutants and their control. Selected case studies. Economics and cost estimation.

### **CEE 565 (ESENG 501). Seminars on Energy Systems Technology and Policy**

*Prerequisite: Graduate student or permission of instructor (3 credits)*

This course is intended to provide students with an understanding of the critical issues in energy technologies. Researchers, industry leaders, entrepreneurs and policymakers discuss technology, policy and economic drivers for sustainable global energy systems. Students complete homework assignments and a term paper on an energy-themed subject.

### **CEE 567 (ESENG 567). Energy Infrastructure Systems**

*Prerequisite: CEE 230 or MechE 336 or ChemE 330 or equivalent recommended (3 credits)*

Technologies and economics of electric power generation, transmission and distribution are discussed. Centralized versus distributed generation and fossil fuels versus renewable resources, are considered in regard to engineering, market and regulatory principles. Students develop an understanding of energy challenges confronting society and investigate technologies that seek to address future needs.

### **CEE 570 (NRE 569). Introduction to Geostatistics**

*Prerequisite: CEE 270 (statistics and probability) or equivalent. (3 credits)*

Sampling design and data representativity. Univariate and bivariate data analysis: continuous and categorical environmental attributes. Description and modeling of spatial variability. Deterministic vs. stochastic models. Spatial interpolation of environmental attributes. Soil

and water pollution data will be analyzed using geostatistical software.

### **CEE 571 (AEROSP 550) (EECS 560) (MECHENG 564). Linear Systems Theory**

*Prerequisite: Graduate standing. (4 credits)*

Linear spaces and linear operators. Bases, subspaces, eigenvalues and eigenvectors, canonical forms. Linear differential and difference equations. Mathematical representations: state equations, transfer functions, impulse response, matrix fraction and polynomial descriptions. System-theoretic concepts: causality, controllability, observability, realizations, canonical decomposition, stability.

### **CEE 572. Dynamic Infrastructure Systems**

*Prerequisite: Math 417 or equivalent advised. (3 credits)*

Introduction to the fundamentals of dynamics system theory applied to infrastructure systems including system modeling as well as monitoring and controlling structural, transportation, hydraulic, and electrical grid systems. Continuous-time and discrete-time linear systems are emphasized but elementary concepts in nonlinear systems are also presented.

### **CEE 573. Data Analysis in Civil and Environmental Engineering**

*Prerequisite: CEE 270 or equivalent. (3 credits)*

Course topics address practical problems of analysis of manipulation and monitoring datasets in environmental sciences and engineering: hypothesis testing, uncertainty, linear regressions, data of high dimension and time domain and frequency domain analysis of series. Examples are drawn from the fields of environmental and civil engineering and surface and subsurface hydrology.

### **CEE 574 (ARCH 595). Materials Selection for Sustainable Design**

*Prerequisite: CEE 212 or ARCH 324 or equivalent. (3 credits)*

Integrated study of material properties, performance and economic and environmental cost, as related to engineering and architectural design. Topics include material properties and selection, materials database, processing and design, ecological considerations and opti-

mization. Examples will be drawn from cementitious materials and ceramics, metals, polymers and composites.

### **CEE 575. Sensing for Civil Infrastructure Systems**

*Prerequisite: Physics 240. (3 credits)*

Sensor technologies for civil infrastructure. Fundamentals of sensor theory, fabrication, operation and deployment. Data acquisition and management methods for large-scale sensor networks. Optimal sensor placement. Data to decision support systems. Physics-based and data-driven interrogation methods for system identification, estimation and control. Case studies of deployments in built and natural environments.

### **CEE 576. Stochastic Systems**

*Prerequisite: CEE 270 and CEE 571 or equivalent. (3 credits)*

Analysis of discrete- and continuous-time linear stochastic processes with primary application to engineering dynamics. Ito calculus and mean-square analysis. Continuous-time Poisson counters and Wiener processes. Stochastic response of nonlinear systems, and the Fokker-Planck Equation. Stationary analysis. Approximate techniques for nonlinear stochastic response.

### **CEE 580. Physicochemical Processes in Environmental Engineering**

*Prerequisite: CEE 460. (3 credits)*

Physicochemical separated and transformation processes in natural and engineered environmental systems; process modeling; design of operations involving state and phase transformation; chemical oxidation, reduction, sorption, stripping and exchange processes, membrane separations, particle aggregation and coagulation, sedimentation and filtration.

### **CEE 581 (EARTH 581). Aquatic Chemistry**

*Prerequisite: Chem 130 and senior or graduate standing. (3 credits)*

Chemical principles applicable to the analysis of the chemical composition of natural waters and engineered water treatment systems; covers acid-base, precipitation-dissolution, complexation and oxidation-reduction reactions; emphasis on graphical, analytical and computer-speciation methods; presented in the context of contemporary environmental issues including water quality,

climate change and pollution prevention and abatement.

### **CEE 582. Environmental Microbiology**

*Prerequisite: Chem 130 and senior or graduate standing. (3 credits)*

Introductions to microbial metabolic processes and nutrition, thermodynamics of growth and energy generation, genetic and metabolic diversity, evolution and systematics, laboratory methods and microbial ecology. Emphasis is placed on the application of these concepts to environmental biotechnology, including microbial treatment of water and wastewater, bioenergy production and pollutant degradation.

### **CEE 583. Surfaces and Interfaces in Aquatic Systems**

*Prerequisite: CEE 581 or permission of instructor. (3 credits)*

Introduction to the principles of surface and interfacial aquatic chemistry, surface complexation theory, and interfacial phenomena. Topics covered include capillarity, wettability, surface tension, contact angle and surface active agents; surface-chemical aspects of adsorption, ion-exchange, and electrical double layer theory. Discussion of the effects of surfaces and interfaces on transformation reactions of aquatic pollutants.

### **CEE 584 (EIHLTH 667). Hazardous Waste Processes**

*(3 credits)*

The study of thermal, chemical and other systems and processes used in the detoxification of hazardous wastes, other than radioactive wastes.

### **CEE 585 (ENSCEN 585). Solid Waste Management**

*(3 credits)*

The study of methods for managing the solid wastes generated by urban communities, evaluating alternatives and design of disposal facilities. Methods for minimizing adverse effects on the human health and environment are included.

### **CEE 586 (NRE 557). Industrial Ecology**

*Prerequisite: Senior standing. (3-4 credits)*

Analysis of material and energy flows in industrial systems to enhance eco-efficiency and sustainability.

Methods: life cycle assessment quantifies energy, waste, emissions (greenhouse gases) for materials production, manufacturing, product use, recovery/disposition. Life cycle design integrate environmental, performance, economic and regulatory objectives. Multi-objective analysis, engineering design analysis, cross-functional teamwork, large sea modeling skills.

### **CEE 587 (NRE 558). Water Resource Policy**

*Prerequisite: Senior or graduate standing. (3 credits)*

Consideration of policy processes associated with the development and utilization of water resources. Special attention is given to the history and development of policy related to water quality. Multi-objective planning is presented. Consideration of institutional problems associated with the implementation of water policy in the federal, state, regional and local arenas.

### **CEE 589 (NRE 595). Risk and Benefit Analysis in Environmental Engineering**

*Prerequisite: Senior or graduate standing. (3 credits)*

Introduction to techniques of risk-benefit analysis as applied to water resources and environmental engineering. Techniques of multi-objective water resource planning. The engineering political interfaces; consideration of political bargaining and decision-making.

### **CEE 590. Stream, Lake, and Estuary Analysis**

*Prerequisite: CEE 460 or permission of instructor. (3 credits)*

Development of mass balance equations for the characteristics and spatial and temporal distributions of contaminants in natural aquatic systems. Role of biochemical kinetics and mass transfer processes on oxygen resources in streams, lakes and estuaries. Demonstration of case studies and applied problems.

### **CEE 591. Environmental Fluid Mechanics**

*Prerequisite: CEE 325 or equivalent (3 credits)*

Fundamentals of fluid mechanics applications to the environment. Gravity and tidal waves. Internal waves and stratified flow. Models for turbulent flow. Effects of the earth's rotation, wind-driven currents and boundary resistance. Mass transfer at interfaces, entrainment and mixing. Flocculation and settling of colloidal particles. Shear dispersion in stream and estuaries.

### **CEE 592. Biological Processes in Environmental Engineering**

*Prerequisite: CEE 460. (3 credits)*

Theoretical principles, qualitative and quantitative description of suspended growth and biofilm processes, as applicable to wastewater treatment and the bioremediation of soils, sediments and groundwater. Bioremediation processes discussed include bioventing and bio-sparging, in situ intrinsic and enhanced bioremediation of chlorinated and non-chlorinated compounds.

### **CEE 593. Environmental Soil Physics**

*Prerequisite: CEE 428 or CEE 345. (3 credits)*

Principles of soil physics with emphasis on environmental problems. Topics include characteristics of solid, liquid and gaseous components of soil; capillarity, air entrapment and the static distribution of water in the unsaturated zone; infiltration, exfiltration and the redistribution of water. Extension of principles to movement of organic liquids in subsurface.

### **CEE 594. Environmental Soil Chemistry**

*Prerequisite: CEE 581. (3 credits)*

Introduction to the principles of soil chemistry. Topics covered include chemical composition of soils, chemical structure of minerals and soil organic matter, soil colloidal phenomena, sorption, ion-exchange, surface complexation theory, reactivity of soil constituents with inorganic and organic environmental contaminants. Emphasis on the relationship between chemical structure and reactivity.

### **CEE 595. Field Methods in Hydrogeochemistry**

*Prerequisite: CEE 428. (3 credits)*

Intensive field laboratory and lecture sessions providing hands-on experience in sampling and analysis of groundwater and aquifer materials for hydrogeologic and geochemical purposes. The course emphasizes field experimental design, execution and evaluation at actual sites of ground-water/soil contamination.

### **CEE 596. Chemical Fate and Transport**

*Prerequisite: CEE 365 or equivalent. (3 credits)*

Analysis of the fate, transport and persistence of chemical using fugacity-based modeling methods. Identification of key chemical properties affecting fate and transport. Characterization of environmental and bio-

logical media. Distribution mechanisms: partitioning, advection, reaction, diffusion. Hierarchical assessment of chemical fate for steady-state, transient, equilibrium and non-equilibrium conditions. Application to multimedia environmental systems; bioaccumulation in food webs; pharmacokinetic modeling; exposure and risk assessment.

#### **CEE 597. Environmental Organic Chemistry**

*Prerequisite: CHEM 130 or equivalent. (3 credits)*

The behavior and transformation of anthropogenic chemicals in the environment. Specific topics will include sorption, volatilization, air-water exchange, and transformation processes (e.g. hydrolysis, photolysis, redox, etc.). Predictive tools for the fate and transport of chemicals in the environment are developed using chemical molecular properties.

#### **CEE 599 (EIHLTH 699). Hazardous Wastes: Regulation, Remediation, and Worker Protection**

*Prerequisites: Graduate standing and EIHLTH 503 or EIHLTH 508 or EIHLTH 541 or EIHLTH 650 or EIHLTH 667 or permission of instructor. (3 credits)*

Integration of information on current regulatory climate and governmental guidelines with case studies in hazardous wastes/substances. Case studies provide examples of hazardous waste and remedial actions, with emphasis on site worker exposure and protection and community exposures to chemical and radiological agents. Lectures, problem-solving sessions and guest speakers.

#### **CEE 611. Earthquake Engineering**

*Prerequisites: CEE 511, and CEE 512, or equivalent. (3 credits)*

This course is to serve as an introduction to the field of earthquake engineering, specifically the seismic behavior and design of structures. Topics include: tectonic theory; engineering characterization of earthquakes; probabilistic hazard analysis; structural modeling and analysis; response of structures during earthquakes; performance-based design; seismic detailing considerations; selected advanced topics.

#### **CEE 613. Metal Structural Members**

*Prerequisite: CEE 413. (3 credits)*

Elastic and inelastic behavior of beams and columns. Torsion of open and box members. Combined bending

and torsion. Buckling of beams and beam-columns. Frame buckling. Behavior of steel and aluminum structural members in studies with reference to their code design procedures.

#### **CEE 614. Advanced Prestressed Concrete**

*Prerequisite: CEE 514. (3 credits)*

Prestressing in statically indeterminate structures: prestressed concrete slabs; analysis and design of partially prestressed concrete beams; nonlinear analysis; optimum design; members prestressed with unbonded tendons; external prestressing; prestressed tensile members; prestressing with FRPs. Special research and/or application related topics.

#### **CEE 615. Reinforced Concrete Members**

*Prerequisite: CEE 415. (3 credits)*

Inelastic behavior of reinforced concrete beams, columns and connections. Combined bending, shear and torsion in beams. Use of strut and tie models. Behavior under load reversals and development of appropriate hysteresis models.

#### **CEE 621. Free Surface Flow**

*Prerequisite: CEE 325 or equivalent. (3 credits)*

Transient, incompressible flow in three space dimensions. Reynolds averaging and large eddy simulation of turbulent flows. Kinematic and dynamic conditions at air-water interfaces. Numerical solution by finite element and finite volume methods. Algorithms for locating a free surface. Applications to river, lake and estuary models.

#### **CEE 622. Special Problems in Hydraulic Engineering or Hydrology**

*Prerequisites: Permission of instructor. (to be arranged)*

Assigned work on an individual basis. Problems of an advanced nature may be selected from a wide variety of topics.

#### **CEE 624. Restoration Fundamentals and Practice in Aquatic Systems**

*Prerequisite: (3 credits)*

The topics to be covered in the lectures are Sediment transport, Fluid mechanics/bluff body flows—Hydraulics, Geomorphology, Dimensional analysis,

Field measurement techniques—Particle Image Velocimetry, Acoustic Doppler Velocimetry, flow and wave gauges. Biological overview: fishes, macrobenthos, plants. Current restoration techniques in a variety of environments.

**CEE 625 (NRE 624). Geostatistical Modeling of Uncertainty**

*Prerequisite: CEE 570. (3 credits)*

Risk assessment: parametric and non-parametric approaches. Optimal estimates. Decision making in the face of uncertainty. Classification of categorical attributes. Stochastic spatial simulation: continuous and categorical environmental attributes. Propagation of uncertainty. Soil and water pollution data will be analyzed using geostatistical software.

**CEE 628. Numerical Modeling of Subsurface Flow**

*Prerequisites: CEE 528 or CEE 593 and Math 471. (3 credits)*

Application of numerical solution methods, including finite differences, finite elements, boundary elements and method of characteristics to various subsurface flow problems: saturated isothermal flow, solute transport, multiphase flow, geothermal reservoirs, use and modification of existing models in addition to new code development.

**CEE 630. Directed Studies in Construction Engineering**

*Prerequisite: Graduate standing. (1-3 credits)*

Selected reading in specific construction areas.

**CEE 631. Construction Decisions Under Uncertainty**

*Prerequisite: A course in probability or statistics such as Stat 310 or Stat 311 or SMS 301. (3 credits)*

Construction project and organization decisions for the uncertain future. Selection of construction method, equipment, contract, markup and financing alternatives having the highest expected values. Uses decision theory, competitive bid analysis, probabilistic modeling and simulation and multiple regression analysis in managing construction.

**CEE 645. Theoretical Soil Mechanics**

*Prerequisite: Permission of instructor. (3 credits)*

Stress conditions for failure of soils; earth pressures and retaining walls; arching in soils; theories for elastic and plastic deformations of soil masses; theory of bearing capacity; theories for stresses in semi-infinite and layered elastic solids; theory of elastic subgrade reaction.

**CEE 646. Geophysical Techniques in Environmental Geotechnology**

*Prerequisite: CEE 345. (3 credits)*

Introduction to geophysical techniques currently available for use in environmental geotechnology. Principles on which methods are based. Site characterization, pore fluid identification, buried object location by these non-intrusive, non-destructive tests. AI programming for selection of appropriate methods. Case studies in use of geophysical methods.

**CEE 648. Dynamics of Soils and Foundations**

*Prerequisite: CEE 345. (3 credits)*

Transient and steady state vibrations of foundations; phase plane analysis of foundations with one and two degrees of freedom; dynamic properties of soils; vibration transmission through soils.

**CEE 649. Civil Engineering Vibrations Laboratory**

*Prerequisites: CEE 611, preceded or accompanied by CEE 648. (2 credits)*

Field and laboratory determination of dynamic material properties; measurement of vibration of structures and foundations; introduction to electronics for dynamic measurements; introduction to holographic interferometry.

**CEE 650. Advanced Fiber Reinforced Concrete for Sustainable Infrastructure**

*Prerequisite: CEE 351 or graduate standing. (3 credits)*

This course surveys scale linkage in built infrastructure systems and its interaction with the natural environment. Fundamental analytic tools from fracture mechanics and micromechanics are introduced. Topics include elastic crack mechanics, energy principles, fiber cement composite design, infrastructure durability and material damage mechanics as it impacts infrastructure life cycle analyses.

**CEE 651. Directed Studies in Civil Engineering Materials**

*Prerequisite: graduate standing. (1-3 credits)*

Individual studies in specific civil engineering materials areas.

**CEE 679. Infrastructure Systems Project**

*(3 credits)*

This course provides students in the Infrastructure Systems program with an integrated view of how fundamental system theory is applied to the civil and environmental engineering domains. Students undertake a semester long research project as an independent study effort and are expected to attend weekly seminars involving students and faculty.

**CEE 682. Special Problems in Environmental Engineering**

*Prerequisite: Permission of instructor. (to be arranged)*

Special problems designed to develop perspective and depth of comprehension in selected areas of sanitary, environmental or water resources engineering.

**CEE 686 (CHE 686). Case Studies in Environmental Sustainability**

*Prerequisite: Senior or graduate standing. (2-3 credits)*

Case studies focusing on utilization of principles of environmental sustainability in professional practice. Development of environmental literacy through study of both current and historical environmental issues.

**CEE 687 (EIHLTH 617). Special Problems in Solid Waste Engineering**

*Prerequisites: CEE 585 and permission of instructor; mandatory satisfactory/unsatisfactory. (to be arranged)*

Application of principles presented in CEE 585 to engineering and environmental health problems in the collection and disposal of solid wastes; comprehensive analysis and report assigned on individual student basis.

**CEE 692. Biological and Chemical Degradation of Pollutants**

*Prerequisite: CEE 582 or permission of instructor. (3 credits)*

Biological and chemical mechanisms and pathways of organic pollutant degradation under environmental conditions. Biological: substitution, elimination, redox reactions; enzyme participation. Chemical: substitution, elimination reactions, linear free-energy, applications. Pollutants include: aliphatic and aromatic compounds, both with and without halogen substituents.

**CEE 693. Environmental Molecular Biology**

*Prerequisite: CEE 592 or permission of instructor. (3 credits)*

Principles and techniques of molecular biology with an emphasis on genetic analysis of enzymatic systems capable of pollutant degradation: Genetic systems and gene probing in unusual prokaryotes: Use of molecular biological techniques for the enumeration and characterization of natural microbial communities: Biochemistry and kinetics of enzymatic systems. Lectures and laboratory.

**CEE 810. Special Topics in Structures and Materials**

*(to be arranged)*

Preparation and presentation of reports covering assigned topics.

**CEE 811. Structural Engineering Project**

*Prerequisite: Enforced: CEE 413 or CEE 415 or equivalent.*

This course provides structural engineering students an integrated view of analysis and design aspects for various structural systems. Topics include evaluation of gravity, wind and earthquake load and displacement demands, selection and proportioning of structural systems and foundation design. The course features bi-weekly seminars involving students, faculty and practicing engineers.

**CEE 812. Structural Engineering Graduate Seminar**

*Prerequisite: Graduate standing. (1 credit)*

Presentation and discussion of selected topics relating to structural engineering practice and research by invited lecturers.

**CEE 830. Construction Engineering and Management Seminar***(to be arranged)*

Assigned reading and student reports on problems selected from the field of construction engineering and management.

**CEE 840. Geotechnical Engineering Seminar***Prerequisite: Graduate standing (1 credit)*

Presentation and discussion of selected topics relating to geotechnical engineering practice and research by invited lecturers.

**CEE 880. Seminar in Environmental and Water Resources Engineering***Prerequisite: None. (1 credit)*

Presentation and discussion of selected topics relating to environmental and water resources engineering. Student participation and guest lecturers.

**CEE 881. Environmental and Water Resources Engineering Seminar***Prerequisite: Graduate standing (1 credit)*

Presentation and discussion of selected topics relating to environmental and water resources engineering. Student participation and guest lectures.

**CEE 910. Structural Engineering Research***(to be arranged)*

Assigned work in structural engineering as approved by the professor of structural engineering. A wide range of subject matter is available, including laboratory and library studies.

**CEE 921. Hydraulic and Hydrological Engineering Research***Prerequisite: Permission of instructor. (to be arranged)*

Assigned work in hydraulic and hydrological research; a wide range of matter and method permissible.

**CEE 930. Construction Engineering Research***(to be arranged)*

Selected work from a wide range of construction engineering areas including planning, equipment, methods, estimating and costs.

**CEE 946. Soil Mechanics Research***(to be arranged)*

Advanced problems in soil mechanics, foundations or underground construction, selected to provide the student with knowledge of recent application and development in engineering design and construction practice. Assigned problems must be carried to a stage of completion sufficient for a written report which will normally be required for credit.

**CEE 950. Structural Materials Research***Prerequisite: Permission of instructor. (to be arranged)*

Topics dealing with mechanics and engineering of structural materials. Assigned reading and student reports.

**CEE 970. Infrastructure Systems Engineering Research***Prerequisite: Permission of instructor. (1-16 credits)*

Advanced problems in infrastructure systems engineering; a wide range of subject matter and method is available, including field investigations, laboratory experimentation, library and public record searches, and engineering design work.

**CEE 980. Research in Environmental Engineering***Prerequisite: Permission of instructor. (to be arranged)*

A research study of some problems relating to water resource development and water supply, waste treatment and pollution control or sanitation and environmental health; a wide range of both subject matter and method is available, including field investigations, laboratory experimentation, library and public record searches and engineering design work.

**CEE 990. Dissertation/Pre-Candidate***(2-8 credits); (1-4 credits)*

Dissertation work by doctoral student not admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**CEE 995. Dissertation/Candidate***Prerequisite: Graduate School authorization for admission as a doctoral candidate. (8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Climate and Space Sciences and Engineering

## Overview

Climate & Space interests bridge both engineering and science and prepare students to answer a growing demand for expertise in atmospheric, climate and space science. Climate & Space programs focus on the description of atmospheric characteristics and phenomena on the Earth and other planets and the interrelationships between the Earth and the Sun. Because of the integrated nature of the program, Climate & Space students have an extensive background in atmospheric and space science, weather and climate, and the engineering of complex and highly reliable space systems and instrumentation.

Climate & Space students are prepared for positions in space engineering, climate, meteorology, and space science research and teaching, environmental assessment, resource management, risk management, or in one of the growing number of fields interested in climate change. Climate & Space has actively participated in the Nation's space program since its inception. For more than 60 years, Climate and Space Sciences and Engineering faculty members have been at the forefront of many engineering and theoretical breakthroughs. In 1946, a probe was deployed on a V-2 rocket to measure electrons in the upper atmosphere. In 1956, Climate & Space researchers were studying atmospheric pollution by aeroallergens, penetration of particulates into buildings, dynamic wind loading of structures, and industrial air pollution. Climate & Space was involved with NASA's Pioneer Venus and Dynamic Explorer Program from its inception in the early 1970s to its completion in the 1990s. Today, Climate & Space researchers are involved in many space missions exploring Mercury, Earth, Mars, Jupiter, and Saturn as well as new initiatives in climate change.

Climate & Space offers high quality academic programs that combine extensive hands-on experience at all levels with a strong emphasis on the theoretical and applied aspects of a student's area of concentration.

Atmospheric scientists are focused on the weather and climate of the Earth, with topics ranging from fundamental research of basic processes to preparing for adaptation to climate change. The focus of planetary/space scientists includes the effects of space weather on Earth, planetary atmospheres and environments, and the construction of satellite-platform instruments for observation of the Earth-atmosphere-ocean system.

## Department Administration

### Department Chair

James A. Slavin, Ph.D.

1517 Space Research Laboratory

### Contacts

Climate and Space Sciences and Engineering

Space Research Building

2455 Hayward St.

Ann Arbor, MI 48109-2143

E-mail: [clasp-um@umich.edu](mailto:clasp-um@umich.edu)

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## Undergraduate

### Undergraduate Degree Programs

The department of Climate and Space Sciences and Engineering offers two degree programs in Climate and Meteorology (CM) and Space Science and Engineering (SSE). CM students begin to understand the interactions among all of the Earth system components while gaining in-depth knowledge in one of two concentrations: Meteorology or Climate Science and Impact Engineering. SSE students begin to understand the space environments of the Sun and planets (especially Earth) as they develop a deep understanding of the fundamental physical processes of energy transfer throughout the solar system.

The B.S.E. degrees in Climate & Space prepares graduates for employment in the National Weather Service,

private weather forecasting companies, air- and water-quality management firms, NASA and the growing number of fields interested in climate change. As importantly, Climate & Space students who complete either of the two degree programs will be exceptionally well prepared for graduate studies in atmospheric science, environmental sciences, space science or space engineering.

Graduates of the Space Sciences and Engineering degree program are prepared to pursue graduate degrees in the space sciences or join the space industry, which is facing a severe workforce shortage. They can also join government agencies and federal laboratories that deal with space related disciplines.

In addition to the College of Engineering core courses, all Climate & Space undergraduate students take five Climate & Space core courses that introduce the various aspects of atmospheric, oceanic and space sciences, emphasizing the common elements of, and the interactions between, the various disciplines and the scientific basis of the phenomena that are observed. Additional courses are specific to the degree and concentration. Students have a number of technical and general electives they may also take to complete 128 credit hours. The electives must be at the 300 level or above. Completion of a concentration will be noted on the student's transcript. For the most current information, visit <http://clasp.engin.umich.edu>.

## Sample Schedule

### B.S.E. in Climate and Meteorology

Not an ABET accredited program. Additional information can be found on the department advising website:

<http://clasp.engin.umich.edu/pages/undergraduate>

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, 215, and 216	16	4	4	4	4	-	-	-	-
Engineering 100, Introduction to Engineering	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	-	4	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	4	4	-	-	-	-
<b>Required Core Subjects (38 hours)</b>									
CLIMATE 320, Earth and Space System Evolution	3	-	-	3	-	-	-	-	-
CLIMATE 321, Earth and Space System Dynamics	3	-	-	-	3	-	-	-	-
CLIMATE 323, Earth System Analysis	4	-	-	-	4	-	-	-	-
CLIMATE 350, Atmospheric Thermodynamics	3	-	-	-	-	3	-	-	-
CLIMATE 380, Introduction to Radiative Transfer	3	-	-	-	-	3	-	-	-
CLIMATE 401, Geophysical Fluid Dynamics	3	-	-	-	-	3	-	-	-
CLIMATE 410, Earth System Modeling	4	-	-	-	-	-	-	4	-
CLIMATE 414, Weather Systems	3	-	-	-	-	-	3	-	-
CLIMATE 462, Instrumentation for Atmos & Space Sciences	4	-	-	-	-	-	4	-	-
CLIMATE 405, Data Analysis and Visualization <sup>3</sup>	4	-	-	-	-	-	4	-	-
CLIMATE 455, Capstone Design <sup>4</sup>	4	-	-	-	-	-	-	-	4
<b>Concentrations: (select one)</b>									
<b>Meteorology (35 hours total)</b>									
CLIMATE 411, Cloud and Precipitation Process	3	-	-	-	-	-	-	-	3
CLIMATE 405, Remote Sensing <sup>5</sup>	3	-	-	-	-	-	-	-	3
CLIMATE 422, Boundary Layer Meteorology	4	-	-	-	-	4	-	-	-
CLIMATE 440, Meteorological Analysis Laboratory	4	-	-	-	-	-	-	4	-
<b>Technical Electives</b>	12	-	-	-	-	4	-	4	4
<b>General Electives</b>	9	-	-	-	-	3	3	3	-
<b>Total</b>	128	17	17	16	15	17	17	15	14
<b>Climate Sciences and Impacts Engineering (35 hours total)<sup>6</sup></b>									
CLIMATE 473, Climate Physics	3	-	-	-	-	-	-	-	3
Statistics/GIS Elective	3	-	-	-	-	3	-	-	-
Climate/Climate Change Elective <sup>6</sup>	3	-	-	-	-	-	-	-	3
Energy/Sustainability Elective <sup>6</sup>	3	-	-	-	-	-	-	3	-
Interactions Elective <sup>6</sup>	4	-	-	-	-	-	-	-	4
<b>Technical Electives</b>	10	-	-	-	-	3	-	4	3
<b>General Electives</b>	9	-	-	-	-	3	3	3	-
<b>Total</b>	128	17	17	16	15	15	17	14	17

Candidates for the Bachelor of Science in Engineering in Climate and Meteorology must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

#### Notes:

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> New Course

<sup>4</sup> New Course. Students may take year-long (2 hours each term) CLIMATE 499 Directed Study as a Senior Thesis option.

<sup>5</sup> New Course. Student may elect to take NRE 541 Remote Sensing (4 hours).

<sup>6</sup> See department undergraduate program office for list of approved courses.

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## Concentrations

### Climate Science and Impact Engineering Concentration

The aim of the Climate Science and Impact Engineering concentration is to provide a flexible program for those interested in pursuing further graduate education or careers in industry. The Climate Science and Impact Engineering concentration prepares you for graduate studies, climate modeling, and a position in "value added" industries that provide water resource, agricultural, seasonal recreation, and transportation industries with near-term climate analyses and predictions. Positions in government agencies serving to make policy or federal laboratories conducting climate research also are open to you. The program also provides students who are interested in both climate science and in a second area of expertise, such as the traditional engineering disciplines, policy, or law course options. There is a need for scientists and engineers who can carry out evaluation and engineering activities that require expertise both in climate science and in the engineering disciplines. These include issues related to air quality, energy engineering, sustainability, and water resources.

### Meteorology Concentration

Graduates with a concentration in Meteorology are prepared for careers in weather forecasting, corporations that are increasingly the source of weather analyses and predictions modeling, and for graduate studies in meteorology and the technologies that enable weather and climate prediction.

Students electing this concentration are encouraged to complete an internship in a weather forecasting office.

## Sample Schedule

### B.S.E. in Space Sciences and Engineering

Not an ABET accredited program. Additional information can be found on the department advising website:

<http://clasp.engin.umich.edu/pages/undergraduate>

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, 215, and 216	16	4	4	4	4	-	-	-	-
Engineering 100, Introduction to Engineering	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	-	4	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	4	4	-	-	-	-
<b>Required Core Subjects (53 hours)</b>									
SPACE 320, Earth and Space System Evolution	3	-	-	3	-	-	-	-	-
SPACE 321, Earth and Space System Dynamics	3	-	-	-	3	-	-	-	-
SPACE 323, Earth System Analysis	4	-	-	-	4	-	-	-	-
PHYSICS 340, Waves, Heat and Light	3	-	-	-	-	3	-	-	-
SPACE 370, Solar-Terrestrial Relations	4	-	-	-	-	4	-	-	-
SPACE 380, Introduction to Radiative Transfer	3	-	-	-	-	3	-	-	-
PHYSICS 405, Intermediate Electricity and Magnetism	3	-	-	-	-	-	3	-	-
PHYSICS 390, Modern Physics	3	-	-	-	-	-	3	-	-
SPACE 462, Instrumentation for Atmos & Space Sciences	4	-	-	-	-	-	4	-	-
NERS 471, Introduction to Plasmas	3	-	-	-	-	-	-	3	-
SPACE 478, Space Environment	4	-	-	-	-	-	-	3	-
SPACE 405, Data Analysis and Visualization <sup>3</sup>	4	-	-	-	-	-	-	-	4
SPACE 477, Space Weather Modeling	4	-	-	-	-	-	-	-	4
SPACE 495/595/598 <sup>4</sup>	4	-	-	-	-	-	-	-	4
SPACE 499 <sup>5</sup>	4	-	-	-	-	-	-	2	2
<b>Technical Electives (11 hours)</b>	<b>10</b>	-	-	-	-	-	4	4	3
<b>General Electives (10 Hours)</b>	<b>10</b>	-	-	-	-	3	4	3	-
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>15</b>	<b>14</b>	<b>17</b>	<b>15</b>	<b>17</b>

Candidates for the Bachelor of Science in Engineering in Space Sciences and Engineering must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

#### Notes:

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> New Course.

<sup>4</sup> Students should take one of these courses (each offered every other year).

<sup>5</sup> New Course. Student may take either year-long (2 hours each term) SPACE 499, Directed Study as a Senior Thesis option, or SPACE 455 Senior Capstone Design.

## Climate and Space Sciences and Engineering Minor

The primary goal of the Climate and Space Sciences and Engineering (Climate & Space) Minor is to provide exposure to research opportunities in atmospheric, climate and space science and engineering for those students who wish to work in the geoscience or space industry but are not majoring in Climate and Space Sciences and Engineering. The secondary goal is to increase awareness of the Climate and Space Sciences and Engineering and the educational and research opportunities within Climate & Space within the College of Engineering as a whole. This program is for undergraduate students in the College of Engineering.

Students must have:

- Registered no later than the last day to add courses for the semester in which they complete the last courses for the minor,
- Submitted his or her program of study for the minor to the Climate & Space undergraduate advisor.
- Attained a minimum GPA of 2.0 in the designated courses
- Completed the Climate & Space Minor as part of a degree program

### Requirements

#### A. Prerequisite coursework:

Math (8 Credits)

MATH 115 ,and

MATH 116;

Physics: (10 Credits)

PHYSICS 140, 141, and

PHYSICS 240, 241;

#### B. Required Coursework (9 credits)

One course from SPACE 101 (Introduction to Rocket Science – 3 credits),

CLIMATE 102 (Extreme Weather – 3 credits), SPACE 103 (Introduction to Space Weather – 3 credits) or CLI

MATE 105 (Our Changing Climate – 3 credits)

CLIMATE 320/SPACE 320 (Earth and Space System Evolution, 3 credits)

CLIMATE 321/SPACE 321 (Earth and Space System Dynamics, 3 credits)

#### C. Core Focus Courses (minimum 6 credits)

At least two courses from one of the following tracks:

- Meteorology
- Climate Science and Impacts Engineering
- Space Sciences
- Space Engineering

For additional information go to:

<http://clasp.engin.umich.edu>

## Sequential Undergraduate/Graduate Study (SUGS)

In our increasingly technical world, master's degrees are becoming the minimum accepted level of education in the industry. Climate & Space SUGS programs are designed to provide a comprehensive knowledge of atmospheric/space sciences or space engineering and to increase your depth of knowledge beyond the baccalaureate degree level. The SUGS program offers breadth, depth and hands-on experience in both areas of concentration. Students interested in completing their undergraduate and master's level education in five years may select either the SUGS in Atmospheric Science or in Space Engineering.

Each degree (B.S.E. and M.S. or M.Eng.) is awarded upon completion of the requirements. Students will typically enter the SUGS program by provisional enrollment in the junior year. Once SUGS students are within six credit hours of completing the required undergraduate degree, they must officially enroll in the Climate & Space M.S. program for a minimum of two full terms, normally the last two semesters, and pay full graduate tuition for these two terms. Students are allowed to "double count" a certain number of credit hours for the two degrees.

## SUGS in Applied Climate

The Climate & Space M.Eng. in Applied Climate, effectively a subset of the broad discipline of environmental engineering, is a professional degree designed for students whose interests lie in applying a basic understanding of climate science to engineered solutions requiring: adaptation to intensities and frequencies of extremes of weather associated with regional climate change, and mitigation of regional and global climate change through actions such as altered emission of short- and long-lived radiatively active gases and aerosols.

## SUGS in Atmospheric/Space Science

The program is designed to provide a comprehensive knowledge of atmospheric or space science and the various components of each system. Students enjoy extensive computational facilities as well as laboratories for measurement of the chemical and physical properties of the atmosphere and space weather. Climate & Space atmospheric scientists and students are solving problems related to short- and long-term forecasting, air quality, atmospheric turbulence and convection, biogeochemical cycling, and precipitation processes, among a growing list of areas. Space Science faculty and students are studying planetary, solar and cosmic weather used in determining the systemic relationships between a planet and its atmosphere.

## SUGS in Space Engineering

For students interested in studying the scientific, engineering and management aspects of space engineering, this program, developed with Aerospace Engineering and Electrical Engineering and Computer Science, allows them to structure the program to a specific area of interest. The program is designed to provide a comprehensive knowledge of space science and engineering and their interrelationship; to teach the systems approach to conceiving, designing, manufacturing, managing and operating complex space systems; and to provide practical experience in space system design,

project development and management. Eight program concentrations are currently available: Space Science; Propulsion; Plasma Electrodynamics and Sensors; Instrumentation and Sensor Payloads; Launch Vehicles; Telemetry and Spacecraft Communication; Astrodynamics; and Computer Control and Data Handling.

The most up-to-date information on the Climate & Space SUGS programs, including example concentration course schedules is available at: <http://clasp.engin.umich.edu/SGUS>. Or, for more information, contact one of the SUGS Advisors at: [http://clasp.engin.umich.edu/sgus\\_advisors](http://clasp.engin.umich.edu/sgus_advisors) or Sandra Pytlinski at [clasp.um@umich.edu](mailto:clasp.um@umich.edu).

## Graduate

### Graduate Degrees

- Master of Engineering (M.Eng.) in Applied Climate
- Master of Engineering (M.Eng.) in Space Engineering
- Master of Science (M.S.) in Atmospheric, Oceanic and Space Sciences
- Doctor of Philosophy (Ph.D.) in Atmospheric, Oceanic and Space Sciences

### M.S. in Atmospheric, Oceanic and Space Sciences

Applicants to the master's program may have a bachelor's degree in any field of study, but they are expected to have completed minimum requirements in mathematics, physics and chemistry. Normally this would include five semesters of mathematics; eight credit hours of physics including two laboratories; and five credit hours of chemistry. Thirty semester hours are required for the master's degree, fifteen of which must be from the Department's offerings. A minimum of four additional hours must be in mathematics and/or natural science. A student will select a research topic if required in conjunction with an appropriate faculty member, who will guide the student in the preparation of both the research and the thesis or research essay. Satisfactory completion of the thesis or research essay will normally count for six credit hours of the total thirty hours required for the Master of Science degree.

## Ph.D. in Atmospheric, Oceanic, and Space Sciences

Applicants for a doctorate are expected to have the ability and scholarship of a high order in one of the following areas: atmospheric science, space and planetary physics, or geoscience and remote sensing. Doctoral students are expected to carry a course load of nine to twelve semester hours (three to four courses) each semester until the dissertation work is begun. There are no foreign language requirements. During the first year, students must select courses from among the core courses for their particular program. After the second year, students must pass a qualifying examination before they can be advanced to candidacy. After reaching candidate status, students will concentrate on a dissertation topic under the guidance of an advisor.

## Ph.D. in Atmospheric, Oceanic and Space Sciences

This program gives students the basic courses to allow them to specialize later in a broad range of sub-disciplines. Students are expected to learn the basic morphology of the atmosphere and the space environment, as well as the necessary physics, chemistry, and mathematics.

Offered as an option, is a concentration in Geoscience and Remote Sensing, which explores the science and engineering behind remote measurements from space of the structure, composition and dynamics of Earth and planetary atmospheres and their underlying surface.

The most up-to-date information on the A.O.S.S. graduate programs is available online at <http://aoss.engin.umich.edu/grad/>.

## M.Eng. in Applied Climate

The A.O.S.S. M.Eng. Program in Applied Climate combines theoretical and applied aspects of weather and climate with a significant design or monitoring project. This design ensures that students graduate with skills necessary for success as practicing engineers. The

Program offers an interdisciplinary education at the nexus of Earth system science and engineering, with opportunities for breadth through courses in such areas as public policy, public health, or business. Students are allowed to structure their coursework to meet the needs of their individual areas of interest. Specific concentrations are suggested to assist students and their advisors with course planning.

Students will learn:

- Current tenets of climate science and practices useful for their continuing education in this evolving science;
- An engineering approach to managing the complexity of the Earth's climate-related environment, its systems components, and a number of closely coupled internal sub-systems including those involving human society;
- A set of tools and skills useful in practical engineering problem solving in team environments; and
- Technologies of climate adaptation and associated mitigation strategies that minimize risks to commercial and government operations, and to their physical assets.

## Areas of Study

Course concentrations will be defined through discussions between students and their program advisors to match the student's career aspirations.

- Climatological and meteorological observing systems
- Emission inventory modeling principles, methods and practices
- Data analysis, Geographical Information Systems (GIS) and processing tools
- Climate and Weather modeling
- The intersection of climate and water resources
- Integrated Assessment

## M.Eng. in Space Engineering

The A.O.S.S. M.Eng. program in Space Engineering combines strong emphasis on both theoretical and applied aspects with extensive hands-on experience at all

levels. The program is designed to develop students into a new type of interdisciplinary engineer prepared for future managerial and systems engineering roles in space related industries and government agencies.

If you are interested in studying the scientific, engineering and management aspects of space engineering, this program, developed with the Aerospace Engineering and Electrical Engineering and Computer Science Departments, allows you to structure the program to your specific area of interest.

### Program Objectives

- To provide a comprehensive knowledge of space science and engineering and their interrelationship.
- To increase depth beyond the baccalaureate level in a space-related discipline.
- To teach the systems approach to conceiving, designing, manufacturing, managing, and operating complex space systems.
- To provide practical experience in space system design, project development and management.

### Program Concentrations

While your specific concentration curriculum will be decided through discussions with your program advisors, suggested programs have been developed in the following areas:

- Space Science Program
- Propulsion Program
- Plasma Electrodynamics and Sensors Program
- Instrumentation and Sensor Payloads Program
- Launch Vehicles Program
- Telemetry and Spacecraft Communications Program
- Astrodynamics Program
- Computer Control and Data Handling Program

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### SPACE 101 (ASTRO 183). Rocket Science

*Prerequisite: None. (3 credits)*

An introduction to the science of space and space exploration. Topics covered include history of space-flight, rockets, orbits, the space environment, satellites, remote sensing and the future human presence in space. The mathematics will be at the level of algebra and trigonometry.

### CLIMATE 102 (EARTH 122) (ENVIRON 102). Extreme Weather

*Prerequisite: None. (3 credits)*

This course provides an introduction to the physics of extreme weather events. The course uses examples of the thunderstorms, jet stream, floods, lake-effect snow storms, lightning, thunder, hail, hurricanes and tornadoes to illustrate the physical laws governing the atmosphere. Participants apply these principles in hands-on storm forecasting and weather analysis assignments.

### SPACE 103. Intro Space Weather

*Prerequisite: None. (3 credits)*

"Space weather" is an emerging discipline of space science that studies the conditions in space that impact society and Earth's technological systems. Space weather is a consequence of the behavior of the sun, the nature of Earth's magnetic field and atmosphere, and our location in the solar system.

### CLIMATE 105 (Chemistry 105) (ENSCEN 105) (ENVIRON 105). Our Changing Atmosphere

*Prerequisite: None. (3 credits)*

The science of the greenhouse effect, stratospheric ozone depletion, polar ozone holes and urban smog. These phenomena and their possible consequences are discussed, along with the properties and behavior of the atmosphere and its interactions with other components of the environment.

### AOSS 110. Climate and Space Science and Engineering Seminar

*Prerequisite: None. (1 credit)*

Seminars by noted speakers, faculty and research scientists, designed to acquaint undergraduates with contemporary science and engineering problems, technologies and broader issues in the global climate and space sciences. Technical communication assignments include

written and/or oral reports based upon the seminars.

**CLIMATE 171 (Biology 110) (Univ Course 110) (EARTH 171). Introduction to Global Change-Part I**

*Prerequisite: None. (4 credits)*

The course will consider the evolution of the universe, the Earth and its environments and the evolution of living organisms. Consideration will be given to fundamental processes by which organisms grow and reproduce, how they interact with their environments and the distribution of major groups of organisms on earth.

**CLIMATE 172 (Univ Course 111) (EARTH 172) (SNRE 172) (Sociology 111). Introduction to Global Change-Part II**

*Prerequisite: None. (4 credits)*

An introduction to the evolution of life and the human species on earth, with focus on problems of global change produced by recent human advances in technology and institutions.

**SPACE 204 (ASTRO 204) (EARTH 204). The Planets: Their Geology and Climates**

*Prerequisite: None. (3 credits)*

Structure, composition and evolutionary history of the surfaces and atmospheres of the planets and their satellites, with special emphasis given to comparative aspects of geology and climatology. Intended for non-science majors with a background in high school math and science.

**AOSS 205. Mathematics of Rocket Science**

*Prerequisite: None. (1 credit)*

This class delves into the mathematics and computer programming involved in launching a satellite into orbit, changing orbits, and planetary and lunar missions.

**CLIMATE 280 (SPACE 280). Undergraduate Research Experience**

*Prerequisites: None. (1-4 credits)*

Individual or group research experience in atmospheric and space sciences. The Individual or group research experience in atmospheric and space sciences. The program of work is arranged at the beginning of the semester by mutual agreement between the student and a faculty member. Written and/or oral reports will be re-

quired.

**AOSS 300. Global Environmental Impact of Technological Change**

*Prerequisite: CHEM 130, MATH 116. (3 credits)*

This course provides a scientific exploration of the unexpected global environmental side effects of technological innovation. Case studies are presented and discussed illustrating how technological advances can sometimes produce unexpected and undesirable environmental results. Lessons learned from previous environmental crises including new tools for assessing risk are discussed and applied.

**CLIMATE 320. (SPACE 320) (EARTH 320) Earth System Evolution**

*Advised Prerequisites: MATH 115, MATH 116. Minimum grade of C for advised prerequisites. (3 credits)*

Introduction to the physics and chemistry of Earth and space. Gravitational energy, radiative energy, Earth's energy budget and Earth tectonics are discussed along with chemical evolution and biogeochemical cycles. The connections among the carbon cycle, silicate weathering and the natural greenhouse effect are discussed.

**CLIMATE 321 (SPACE 321) (EARTH 321). Earth and Space Systems Dynamics**

*Advised Prerequisites: CLIMATE/SPACE 320. Preceded or accompanied by MATH 215 and MATH 216. (3 credits)*

This course will describe the major wind systems and ocean currents that are important to climate studies. The primary equations will be developed and simple solutions derived that will explain many of these motions. The relations among the dynamics and other parameters in the climate system will be illustrated by examples from both paleo and present day systems.

**CLIMATE 323 (SPACE 323) (EARTH 323). Earth System Analysis**

*Prerequisite: None. (4 credits)*

Introduction to the analysis of Earth and Atmospheric Science Systems. Topics include linear systems, harmonic analysis, sampling theory and statistical error analysis. Lectures emphasize underlying mathematical concepts. Labs emphasize application of mathematical

methods to analysis of field data in a computer programming environment. Applications include turbulent air motion in the planetary boundary layer, cloud and precipitation microphysical composition, oceanic wave propagation, stratospheric ozone depletion and satellite remote sensing.

### **CLIMATE 350 (SPACE 350) (EARTH 350). Atmospheric Thermodynamics**

*Prerequisite: MATH 216 or equivalent. Minimum grade of C<sup>+</sup> required for enforced prerequisite. (3 credits)*

Fundamentals of thermodynamics are presented, including the First, Second and Third Laws, ideal gases, adiabatic processes, phase changes, vapor pressure, humidity and atmospheric stability. The Kinetic Theory of Gases provides a molecular perspective on the various forms of atmospheric water substance and on macroscopic phenomenology in general.

### **SPACE 370 (EARTH 370). Solar Terrestrial Relations**

*Prerequisite: MATH 216, Physics 240. (4 credits)*

Introduction to solar terrestrial relations with an overview of solar radiation and its variability on all time-scales. The effects of this variability on the near-Earth space environment and upper atmosphere are considered, as well as effects on the lower and middle atmosphere with connections to weather and climate. Subjects are approached through extensive data analysis, including weekly computer lab sessions.

### **CLIMATE 380 (SPACE 380) (EARTH 381). Introduction to Atmospheric Radiation**

*Prerequisite: MATH 216 or equivalent. Minimum grade of C<sup>+</sup> required for enforced prerequisite. (3 credits)*

Basic concepts and processes of radiative transfer including radiometric quantities, electromagnetic spectrum, absorption, emission and scattering. The physics laws governing these processes including the Planck Law and the Kirchhoff Law. Radiative properties of atmospheric constituents. Reflection and refraction. Introductory-level descriptions of relevant applications in atmospheric sciences and climate physics.

### **CLIMATE 381 (SPACE 381). Undergraduate Re-**

### **search Experience II**

*Prerequisites: CLIMATE 280, SPACE 280 or junior/senior standing. (1-4 credits)*

Individual or group research experience in atmospheric, space science or space technology. The program of work is arranged at the beginning of the semester by mutual agreement between the student and a faculty member. Written and/or oral reports will be required.

### **CLIMATE 401 (EARTH 401). Geophysical Fluid Dynamics**

*Advised Prerequisites: Physics 240, MATH 215, MATH 216, CLIMATE 323, SPACE 323. (4 credits)*

Dynamics of the oceans and atmosphere. Equations of motion in spherical coordinates, beta-plane approximation, wave properties in the oceans and atmosphere.

### **CLIMATE 405 (SPACE 405). Special Topics**

*Prerequisite: None. (1-4 credits)*

Advances in specific fields of Atmospheric, Oceanic and Space Sciences as revealed by recent research.

### **AOSS 407. Mathematical Methods in Geophysics**

*Prerequisite: MATH 216. (4 credits)*

Vector calculus and Cartesian tensors; Sturm-Liouville systems, Green's Functions and solution of boundary value problems; Fourier series, Fourier and Laplace transforms, discrete Fourier transform, fast Fourier transforms, and energy spectra and singular perturbation theory.

### **CLIMATE 410. Earth System Modeling**

*Advised Prerequisites: CLIMATE 320, CLIMATE 321, SPACE 320, SPACE 321. (4 credits)*

Introduction to Earth System Modeling; discussion of energy balance models, carbon cycle models and atmospheric chemistry models with multiple time scales; methods for numerical solution and practice building and analyzing results from models.

### **CLIMATE 411 (EARTH 411). Cloud and Precipitation Processes**

*Advised Prerequisites: CLIMATE 350, SPACE 350, MATH 216. (3 credits)*

The special nature of water substance; nucleation of phase changes in the free atmosphere; the structure and content of clouds; the development of physical charac-

teristics of precipitation; and the dynamics of rain systems.

**CLIMATE 414 (EARTH 414). Weather Systems**

*Advised Prerequisites: CLIMATE 350, SPACE 350, CLIMATE 401 or CLIMATE 551. (3 credits)*

Introduction to the basic characteristics, thermodynamics and dynamics of atmospheric weather systems on Earth and other planets. The students are exposed to observations of weather systems while reviewing non-dimensional analysis, dynamics and thermodynamics. Weather systems on earth are compared to that of other planets and analytical tools are used to gain insights into their basic physics.

**AOSS 420 (NAVARCH 420) (ENSCEN 420). Environmental Ocean Dynamics**

*Prerequisite: NAVARCH 320 or AOSS 305 or CEE 325. (4 credits)*

Physical conditions and physical processes of the oceans; integration of observations into comprehensive descriptions and explanations of oceanic phenomena. Emphasis on wave and current prediction, optical and acoustical properties of sea water, currents, tides, waves and pollutant transport.

**AOSS 421. (EARTH 421) (ENVIRON 426). Introduction of Physical Oceanography**

*Prerequisite: Introductory science course, MATH 115 and MATH 116 or permission of instructor. (3 credits)*

This course examines the fundamentals of physical oceanography; the physical properties of the ocean and water masses; circulation of the atmosphere; wind-driven and buoyancy-driven ocean circulation; tides; surface and internal waves; eddies; and mixing.

**CLIMATE 422 (EARTH 423). Boundary Layer Meteorology**

*Advised Prerequisite: CLIMATE 350, SPACE 350 or equivalent. (4 credits)*

Explores processes in the atmospheric boundary layer, which plays an important role in the exchange of energy, mass and momentum between land and atmosphere. Topics include applications of governing atmospheric equations, atmospheric turbulence, turbulent kinetic energy, the surface energy balance and the collection and analysis of field flux tower data.

**AOSS 431 (EECS 430). Radiowave Propagation and Link Design**

*Prerequisite: Physics 405 or EECS 330. (4 credits)*

Fundamentals of electromagnetic propagation and radiation; radiowave propagation in different environments (near Earth, troposphere, ionosphere, indoor and urban); antenna parameters; practical antennas; link analysis; system noise; fading and multipath interference. Course includes lectures, labs and a project in which student teams develop and implement practical wireless systems.

**CLIMATE 440 (EARTH 454). Meteorological Analysis Laboratory**

*Advised Prerequisites: CLIMATE 350, SPACE 350, CLIMATE 401. (4 credits)*

This course provides an introduction into the analysis of both surface-based and remotely-sensed meteorological data. The development and application of operational numerical forecast models will be discussed. Techniques for the prediction of both synoptic and mesoscale meteorological phenomena will also be presented.

**CLIMATE 441. Meteorology and Climate of the Rockies**

*Advised Prerequisite: CLIMATE/SPACE 320, CLIMATE/SPACE 321, CLIMATE/SPACE 323. (3 credits)*

This course introduces principles of atmospheric and environmental sciences using the Rocky Mountains as a field laboratory. Students will develop an understanding of meteorological processes to explain variations in microclimates, and the importance of mountainous regions on the earth's climate. Students will gain field-based knowledge of mountain climates and instrumentation.

**CLIMATE 442 (ENSCEN 442). Oceanic Dynamics I**

*Prerequisite: CLIMATE 401. (3 credits)*

Wave motions; group velocity and dispersion. Gravity waves, wave statistics and prediction methods; long period waves; the tides. Steady state circulation, including theories of boundary currents and the thermocline.

**AOSS 450. Geophysical Electromagnetics**

*Prerequisite: MATH 216. (4 credits)*

The fundamentals of electricity, magnetism and electrodynamics in the context of the Earth. The first segment will cover electrostatics, the electric structure and circuit of the Earth, electricity in clouds and lightning. The second segment will cover magnetostatics, currents, the magnetic field and magnetic dynamo of the Earth, and the Earth's magnetosphere. The third segment will cover electrodynamics, electromagnetic waves, radiation in the Earth environment, waveguides and radiation from sources.

**CLIMATE 451 (ENSCEN 451) (EARTH 457). Atmospheric Dynamics I**

*Advised Prerequisites: CLIMATE 401 or MATH 450. (4 credits)*

Quasi-geostrophic energetics; fronts; the mean circulation; planetary and equatorial waves: overview of the dynamics of the middle atmosphere; wave-mean flow interaction; spectral methods; and tropical meteorology.

**CLIMATE 462. Instrumentation for Atmospheric and Space Sciences**

*Advised Prerequisite: CLIMATE 350, SPACE 350. (4 Credits)*

Introduction to fundamentals of atmospheric, space-based and meteorological instrumentation. Includes basics of electronic sensors, optics, lasers, radar, data acquisition/management, error analysis and data presentation. Consists of two lectures and one lab each week, and a team-based term project.

**AOSS 463 (ENSCEN 463). Air Pollution Meteorology**

*Prerequisite: MATH 215. (3 credits)*

Weather and motion systems of the atmosphere; topographic influences on winds, atmospheric stability and inversions; atmospheric diffusion; natural cleansing processes; meteorological factors in plant location, design and operation.

**CLIMATE 466. Carbon-Climate Interaction**

*Advised Prerequisite: For undergraduates: CLIMATE/SCIENCE 320 and CLIMATE/SCIENCE 321. (3 credits)*

The class will focus on the exchange of carbon among reservoirs in the Earth system -- atmosphere, ocean,

lithosphere and biosphere -- and the role of carbon dioxide, CO<sub>2</sub>, as a greenhouse gas.

**CLIMATE 467 (CHEM 467) (EARTH 465) (ENSCEN 467) (Environ 467). Biogeochemical Cycles**

*Prerequisite: MATH 116, CHEM 210, Physics 240. (3 credits)*

The biogeochemical cycles of water, carbon, nitrogen and sulfur; the atmosphere and oceans as reservoirs and reaction media; the fate of natural and man-made sources of carbon, nitrogen, and sulfur compounds; the interactions among the major biogeochemical cycles and resultant global change; greenhouse gases, acid rain and ozone depletion.

**AOSS 473. Climate Physics**

*Advised Prerequisite: Senior or graduate standing in science or engineering (3 credits)*

Introduction to physical mechanisms that determine climate, including relevant atmospheric, hydrologic, cryospheric, solar/orbital, volcanic and human processes. Discusses qualitative and descriptive techniques to understand how radiative, thermodynamic and dynamic processes distribute energy throughout the Earth System, drive climate feedbacks and determine the sensitivity of Earth's climate to external perturbations.

**AOSS 474 (EARTH 474). Ice Sheets, Glaciers and Climate Change**

*Advised Prerequisite: Math 115 and 116. (3 credits)*

The dynamics and mass balance of ice sheets and glaciers introduced along with mathematical theories describing how ice sheets and glaciers flow and current methods of observation. The course integrates lectures, assignments and discussion of journal articles.

**CLIMATE 475 (ENSCEN 475) (EARTH 475). Earth System Interactions**

*Prerequisite: Senior standing in science or engineering. (4 credits)*

Students will work on open-ended research problems with mathematical models from Earth System Science. The models may include, for example, surface characteristics, hydrology, solar-land-ocean-atmosphere exchanges and space-based observations. Numerical experiments will promote further understanding and inter-

pretation of earth system interactions, team building and scientific communication.

### **CLIMATE 476. Ocean Dynamics and Climate**

*Advised Prerequisite: CLIMATE 401 or CLIMATE 551 or SPACE 551. (4 credits)*

Large-scale physical oceanography and the role of the ocean in climate. Theory and observations in the wind-driven and thermohaline circulation, vortices and planetary waves.

### **AOSS 477. Space Weather Modeling**

*Prerequisite: SPACE 370. Minimum grade of C<sup>+</sup> required for enforced prerequisites. (4 credits)*

An introduction to a variety of models of the space environment, including models of the sun, magnetosphere, ring current, ionosphere, thermosphere and ionospheric electrodynamics. Students will learn the origins of different models, what each represents, to run the models and become familiar with the output.

### **CLIMATE 478. Engineering for Space Environment**

*Advised Prerequisite: Senior or graduate standing advised. (4 credits)*

This course will cover the basics of the Sun and the solar wind and their influence on the space environment. In addition, atmospheric effects on spacecraft are considered. We discuss not only the physics of the drivers of space weather, but also the implications for satellite systems and their design and operation.

### **AOSS 479 (ENSCEN 479). Atmospheric Chemistry**

*Prerequisite: CHEM 130, MATH 216. (4 credits)*

Thermochemistry, photochemistry and chemical kinetics of the atmosphere; geochemical cycles, generation of atmospheric layers and effects of pollutants are discussed.

### **CLIMATE 480 (NRE 480). Climate Change: The Move to Action**

*Advised Prerequisite: Senior or graduate standing, MATH 216. (3 credits)*

All sectors of society are affected by climate change: science, policy, business, economics, public health, energy, ecosystems, environmental engineering, journalism, religion, etc. This course explores the intersec-

tions of these communities and exposes students the factual and contextual elements that will allow effective participation in the adaptation to climate change.

### **SPACE 495 (ENSCEN 495). Upper Atmosphere and Ionosphere**

*Prerequisite: None. (4 credits)*

Basic physical and chemical processes important in controlling the upper/middle atmosphere and ionosphere: photochemistry, convection, diffusion, wave activity, ionization, heating and cooling. The terrestrial, as well as planetary atmospheres and ionospheres are to be considered.

### **CLIMATE 498 (SPACE 498). Practicum in Climate and Space Science**

*Prerequisite: Permission of instructor. (1 or 2 credits)*

Course may be repeated to a maximum of 8 credit hours. Students taking this course will participate in research and/or engineering tasks. Supervision will be undertaken by faculty and engineers of the Climate & Science department. Reporting requirements include a final written summary. Diverse tasks include aircraft spacecraft and rocket payload design field campaign support calibration simulation test. Students will join an active research program of Climate & Science for a given semester.

### **CLIMATE 499 (SPACE 499). Directed Study**

*Prerequisite: Permission of instructor. (1-4 credits)*

Offers research or directed study experience for students in an area of interest to the student and faculty member. An oral presentation and/or written report is due at the end of the term.

### **CLIMATE 501. Seminars in Climate, Atmospheres and Space Sciences**

*Prerequisite: Graduate standing. (1 credit)*

Current research efforts will be presented by graduate students and faculty dealing with all phases of the climate, atmospheric and space sciences.

### **AOSS 511. Aerosol Physics and Chemistry**

*Prerequisite: Senior or graduate standing (3 credits)*

Introduction to fundamental principles and latest developments in aerosol science. The dependence of aerosol composition and size distributions on the underlying

atmospheric thermodynamics, dynamics, chemistry and physics will be presented. Recent observations and theoretical treatments are used to illustrate aspects of aerosol science that are poorly quantified at present.

**CLIMATE 524 (ENSCEN 524). General Circulation**

*Prerequisite: Previous or concurrent with CLIMATE 401. (3 credits)*

Processes that maintain the general circulation of the Earth's atmosphere; the observed general circulation; energetics; balance requirements; comparison of observations with simple theories and results from general circulation model simulations.

**AOSS 528 (NAVARCH 528) (ENSCEN 529). Remote Sensing of Ocean Dynamics**

*Prerequisite: AOSS 425 (NAVARCH 425) or permission of instructor. (3 credits)*

The dynamics of ocean wave motion, both surface and internal waves, and ocean circulation are explored utilizing active and passive remote sensing techniques. Emphasis is placed upon the synoptic perspective of ocean dynamics provided by remote sensing which is not obtainable by conventional means.

**AOSS 530. Using Climate-Change Knowledge in Planning and Design**

*Prerequisite: Basic knowledge of climate change and its impact. (2 credits)*

This seminar focuses on special topics on the use of climate-change data and knowledge in planning, design, engineering and management. Topics include, for example, uncertainty in the context of decision making, nonstationarity in design and engineering, and vulnerability and risk assessment.

**AOSS 532. Radiative Transfer**

*Prerequisite: Graduate standing. (3 credits)*

Radiative transfer (thermal and scattering) applicable to planetary atmospheres. Macro and microscopic form of transfer equation. Line broadening mechanisms, band models, Rayleigh and Mie scattering. Discrete ordinate, successive order of scattering and adding and doubling methods of solution. Non LTE formulation. Applications to, and results from, climate studies.

**AOSS 545. High Energy Density Physics**

*Prerequisite: MATH 450, Physics 405 & Physics 406. (3 credits)*

Introduces students to fundamental tools and discoveries of high-energy density physics, where pressures are above a million atmospheres. Discusses fundamental physical models, equations of state, hydrodynamics including shocks and instabilities, radiation transport, radiation hydrodynamics, experimental technique, inertial fusion, experimental astrophysics and relativistic systems.

**AOSS 550 (NA 550). Offshore Engineering I**

*Prerequisite: NAVARCH 420 (AOSS 420). (3 credits)*

Design and analysis requirements of off-shore engineering structures. Hydrodynamic loads on offshore platforms and slender bodies. Marine riser mechanics: dynamics and structural stability. Mooring mechanics: nonlinear stability and design. Vortex induced vibrations: analysis and model testing. Marine renewable energy. Hydrokinetic energy harnessing.

**CLIMATE 551 (SPACE 551). Fluid Dynamics for Climate and Space Sciences**

*Advised Prerequisite: MATH 215, MATH 216, and MATH 450. (4 credits)*

Covers the fundamentals of fluid dynamics. The purpose of the course is to provide fundamental grounding in fluid dynamics and in fundamental mathematical technique at the level required to do serious quantitative graduate research that involves fluid dynamics effects. The emphasis of the examples is on geophysical and space applications.

**AOSS 555. Spectral Methods**

*Prerequisite: MATH 216. Knowledge of FORTRAN. (4 credits)*

An introduction to numerical methods based on Fourier Series, Chebyshev polynomials and other orthogonal expansions. Although the necessary theory is developed, the emphasis is on algorithms and practical applications in geophysics and engineering, especially fluid mechanics. Many homework assignments will be actual problem-solving on the computer.

**CLIMATE 563 (ENSCEN 563). Air Pollution Dispersion Modeling**

*Prerequisite: CLIMATE 463. (3 credits)*

Principles of modeling air pollution transport and dispersion. Discussion of models for line sources, area sources and point sources. Analysis of individual model data requirements, founding assumptions and inherent limitations. Practical experience using currently operational models.

**CLIMATE 564 (ENSCEN 564)(SPACE 564). The Stratosphere and Mesosphere**

*Prerequisite: CLIMATE 464. (3 credits)*

Physical, chemical and dynamical properties of the atmosphere between the tropopause and the turbopause. Among the topics covered are the heat and radiation budgets, atmospheric ozone, stratospheric warmings, the biennial stratospheric oscillation, airglow.

**AOSS 565. Planetary Atmospheres**

*Prerequisite: Graduate standing. (4 credits)*

Radiative, photochemical, thermodynamic and aeronomical processes in the atmospheres of the planets and satellites, with the objective of understanding the composition, structure, origin and evolution of the atmospheres; theoretical and empirical results, including planetary observations by space probes.

**AOSS 567 (CHEM 567). Chemical Kinetics**

*Prerequisite: CHEM 461 or AOSS 479. (3 credits)*

A general course in chemical kinetics, useful for any branch of chemistry where reaction rates and mechanisms are important. Scope of subject matter: practical analysis of chemical reaction rates and mechanisms, theoretical concepts relating to gas and solution phase reactions.

**AOSS 574 (AEROSP 574). Introduction to Space Physics**

*Prerequisite: Senior or graduate standing. (4 credits)*

A graduate level introduction to physical and aeronomical processes in the space environment. Discussion of theoretical tools, the Sun, solar wind, heliosphere, magnetosphere, ionosphere and the upper atmosphere. Spacecraft interaction with radiation, spacecraft-plasma interactions.

**CLIMATE 575 (ENSCEN 575). Air Pollution Monitoring**

*Advised Prerequisite: CLIMATE 463, CLIMATE 578, NRE 538 (previously or concurrently). (3 credits)*

A practical introduction to the fundamentals of gas and aerosol measurements with a focus on ozone and acidic gases, their precursors and aerosols; operation of the suite of instruments, detection and sampling techniques and calibration practices. An important feature will be team-oriented tasks involving air quality monitoring.

**CLIMATE 576 (ENSCEN 576). Air Quality Field Project**

*Advised Prerequisite: CLIMATE 578, NRE 538, CLIMATE 575, or CLIMATE 563. (4 credits)*

Practical experience in all aspects of air quality field measurements from the design and planning stage through implementation and data analysis and interpretation. Emphasis on research design, sampling, data management systems, sample tracking, computerized data acquisition and processing, error analysis and reporting; team-oriented practicum for modelers and experimentalists.

**CLIMATE 578 (ENSCEN 578). Air Pollution Chemistry**

*Prerequisite: CLIMATE 479 or CHEM 365. (3 credits)*

Tropospheric and stratospheric air pollution are discussed following a review of thermochemistry, photochemistry and chemical kinetics. Gaseous and particulate air pollutants are considered in terms of their origins and transformations.

**AOSS 580. Remote Sensing and Geographic Information System Project Laboratory**

*Prerequisite: MATH 216, Physics 140. (2 credits)*

Lectures and hands-on demonstrations train students in acquiring and processing remote sensing and field data using computer based image processing and geographic information systems. Students apply this knowledge in individual and small team projects oriented toward student interests. Research project results are communicated in formal presentations and written reports.

**AOSS 581 (AEROSP 581). Space Policy and Management**

*Prerequisite: Graduate standing. (3 credits)*

The first part of the course will provide detailed information on how space policy is developed in the United

States and the international space community and how these policies result in specific missions. The second part will provide detailed information on modern management techniques and processes. Project managers from NASA centers and industry will lecture on the detailed management techniques and processes.

### **AOSS 582 (AEROSP 582). Spacecraft Technology**

*Prerequisite: Graduate standing. (4 credits)*

Systematic and comprehensive review of spacecraft and space mission design and key technologies for space missions. Discussions on project management and the economic and political factors that affect space missions. Specific space mission designs are developed in teams. Students of AEROSP 483/583 choose their projects based on these designs.

### **AOSS 583 (AEROSP 583). Management of Space Systems Design**

*Prerequisite: AEROSP/AOSS 582. (4 credits)*

Meets with AEROSP 483 (Space System Design), or other senior design course when appropriate topic is chosen. Students in this course lead teams in high level project design of a space system. Modern methods of concurrent engineering manufacturing, marketing and finance, etc., are incorporated.

### **AOSS 584. Space Instrumentation**

*Prerequisite: Senior or graduate standing. (4 credits)*

This class teaches students how to design, build, test and deploy a completely autonomous, sophisticated system that is designed to accomplish a specific task. The primary system is a small-satellite, deployed on a high-altitude balloon. This system involves communication, position tracking, microcontrollers, instruments and a power system.

### **AOSS 585. Introduction to Remote Sensing and Inversion Theory**

*Prerequisite: Graduate standing. (3 credits)*

Introduction to active (radar and lidar) and passive (thermal emission) visible, infrared and microwave remote sensing. Fundamentals of electromagnetic emission, absorption and scattering. Sensor performance characteristics. Mathematical methods for inversion of integral transforms and ill-conditioned systems of equations commonly encountered in remote sensing applica-

tions.

### **AOSS 586. Climate Data Analysis**

*Prerequisite: Graduate standing (3 credits)*

Objective methods are introduced for analyzing climate data with inherent spatial and/or temporal correlation scales. These include time series analysis, pattern recognition techniques, regression and linear modeling. The emphases are both the usage of such methods and critical evaluation of literatures that employ them.

### **AOSS 587 (EECS 532). Microwave Remote Sensing I: Radiometry**

*Prerequisite: EECS 330, graduate standing. (3 credits)*

Radiative transfer theory: blackbody radiation; microwave radiometry; atmospheric propagation and emission; radiometer receivers; surface and volume scattering and emission; applications to meteorology, oceanography and hydrology.

### **AOSS 588. Regional Scale Climate**

*Prerequisite: Graduate standing. (4 credits)*

Regional scale climate processes are introduced along with the tools needed for their analysis, including downscaling techniques. The course integrates lectures, assigned journal papers and hands-on data analysis. In a course project, students will apply the analytical tools to a subject chosen by the student.

### **AOSS 589. The Art of Climate Modeling**

*Prerequisite: Graduate standing, basic understanding of Atmospheric dynamics and the general circulation of the atmosphere; Unix; higher level programming language; numerical methods. (4 credits)*

The course introduces the newest climate modeling techniques by surveying the design decisions in atmospheric General Circulation Models (GCMs), the trends in GCM and dynamical core modeling and how GCMs are coupled. It is built upon hands-on GCM modeling and data projects, journal paper discussions, lectures, shared cyber-infrastructure and computational tools.

### **AOSS 590. Space Systems Projects**

*Prerequisite: Graduate standing. (1-4 credits)*

Space science and application mission related team project. Student teams will participate in ongoing projects in the Space Physics Research Laboratory in con-

junction with industry and government sponsors.

### **CLIMATE 591. Climate Practicum I**

*Advised Prerequisite: Senior or graduate standing. (4 credits)*

Introduction to individual and team research on real-world problems in the area of applied climate. A mentor from a commercial or governmental laboratory will pose the problem and help to guide the research. Students will learn how to apply knowledge they have already acquired. This course followed by CLIMATE 592.

### **CLIMATE 592. Climate Practicum II**

*Prerequisite: Senior or graduate standing and CLIMATE 591. (4 credits)*

Introduction to individual and team research on real-world problems in the area of applied climate. On a research project started in CLIMATE 591 and guided by a mentor from a commercial or government laboratory, students will apply the principles of risk analysis and objective assessment of adaptive strategies.

### **AOSS 595 (EECS 518). Magnetosphere and Solar Wind**

*Prerequisite: Graduate standing. (3 credits)*

General principles of magnetohydrodynamics; theory of the expanding atmosphere; properties of solar wind, interaction of solar wind with the magnetosphere of the Earth and other planets; bow shock and magnetotail, trapped particles, auroras.

### **AOSS 596. Gaskinetic Theory**

*Prerequisite: Graduate standing. (3 credits)*

Maxwell-Boltzmann distribution, kinetic determination of equation of state, specific heats of gases. Dynamics of two-particle collisions. Elementary transport theory, molecular effusion, hydrodynamic transport coefficients, mean free path method. Advanced transport theory, the Boltzmann equation, collision terms, Chapman-Enskog transport theory. Aerodynamics of free-molecular flow. Shock waves.

### **AOSS 597 (AEROSP 597). Fundamentals of Space Plasma Physics**

*Prerequisite: Senior-level statistical physics course. (3 credits)*

Basic plasma concepts, Boltzmann equation, higher order moments equations, MHD equations, double adiabatic theory. Plasma expansion to vacuum, transonic flows, solar wind, polar wind. Collisionless shocks, propagating and planetary shocks. Fokker-Planck equation, quasilinear theory, velocity diffusion, cosmic ray transport, shock acceleration. Spacecraft charging, mass loading.

### **AOSS 598. The Sun and the Heliosphere**

*Prerequisites: AOSS 464 & Physics 505 or equivalent. (3 credits)*

A complete description of the physical processes that govern the behavior of the Sun and the heliosphere with emphasis on recent theoretical and observational results.

### **CLIMATE 605 (SPACE 605). Current Topics in Climate and Space Sciences and Engineering**

*Prerequisite: None. (1-4 credits)*

Advances in specific fields of climate and space sciences, as revealed by recent research. Lecture, discussion and assigned reading.

### **CLIMATE 606 (SPACE 606). Computer Applications to Geo-Fluid Problems**

*Advised Prerequisite: CLIMATE 442 or CLIMATE 451, ENGR 103, MATH 450. (3-4 credits)*

Solution of geo-fluid problems by numerical techniques using a digital computer. Lectures, laboratory, exercises using the digital computer.

### **CLIMATE 651 (SPACE 651). Dynamics of Planetary Atmospheres and the Upper Atmosphere**

*Advised Prerequisite: CLIMATE 451. (3 credits)*

Dynamic meteorology of other planets (Mars, Venus, Jupiter and Titan), the Earth's middle atmosphere and thermosphere. Tides, solitary waves, quasi-geostrophic turbulence and dynamics and chemistry are among the phenomena discussed.

### **AOSS 690. Thesis/Master of Science**

*Prerequisite: Permission of instructor; graduate standing. (2-6 credits)*

Provides credit for research and writing of a Masters Thesis under direction of a faculty member.

**AOSS 701. Special Problems in Meteorology and Oceanography**

*Prerequisite: Permission of instructor.*

Supervised analysis of selected problems in various areas of meteorology and oceanography.

**CLIMATE 747 (SPACE 747). CLaSP Student Seminar**

*Prerequisite: None. (1 credit)*

Students take turns presenting short research seminars (20 minutes) and/or short talks introducing upcoming speakers in CLIMATE/SPACE 749. Some class time will also be devoted to discussions of effective oral and poster presentations and professional ethics.

**CLIMATE 749 (SPACE 749). CLaSP Seminar**

*Prerequisite: None. (1 credit)*

Presentations from UM researchers and outside speakers about current research results, covering a broad range of topics in climate, atmosphere and space science. In this class students take turns serving as seminar chair. Questions from students will be handled before those from faculty. Conditions for credit are participation in this seminar and the completion of a short paper in which each student follows up on one talk given as part of this seminar series.

**AOSS 990. Dissertation/Pre-Candidate**

*(2-8 credits); (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**AOSS 995. Dissertation/Candidate Graduate School**

*Prerequisite: Authorization for admission as a doctoral candidate. (8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Electrical Engineering and Computer Science

## Overview

The expanding roles of electrical engineers, computer engineers, and computer scientists in today's society reflect the variety and scope of these exciting professions. In recognition of the distinct qualifications required of engineers and scientists entering these fields, the Electrical Engineering and Computer Science Department offers undergraduate programs in the following five areas: an electrical engineering program leading to a Bachelor of Science in Engineering (Electrical Engineering) - B.S.E. (E.E.); a computer engineering program leading to a Bachelor of Science in Engineering (Computer Engineering) - B.S.E. (C.E.); a data science program leading to a Bachelor of Science in Engineering (Data Science) - B.S.E. (D.S.); a computer science program leading to a Bachelor of Science in Engineering (Computer Science) - B.S.E. (C.S.) offered through the College of Engineering; or a Bachelor of Arts or Bachelor of Science degree offered through the College of LS&A. (Please consult the LS&A Bulletin for information about completing a computer science or data science degree through LS&A. LS&A also offers a Bachelor of Science degree in Data Science through the department of Statistics.)

Throughout each program, students work with modern laboratory equipment and computer systems, and they are exposed to the most recent analytical techniques and technological developments in their field. Students have many opportunities to associate with outstanding faculty, most of whom are actively engaged in research and/or professional consulting. Such interaction serves to acquaint students with the opportunities and rewards available to practicing electrical or computer engineers and scientists. Our students are encouraged to seek an advanced degree if further specialization and a higher degree of competence in a particular area is desired.

## Department Administration

### Department Chair, CSE Division

Marios Papaefthymiou, Ph.D.  
3713 Bob & Betty Beyster Building

### Department Chair, ECE Division

Khalil Najafi, Arthur F Thurnau Professor and Schlumberger Professor  
3303 Electrical Engineering & Computer Science Building

## Contacts

**Departmental Website:** <http://www.eecs.umich.edu/>

### Electrical Engineering & Computer Science Department

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## Computer Engineering

### Mission

To provide a solid technical foundation that prepares students for a career that can adapt to rapidly changing technology in computer engineering.

### Goals

To educate students with a broad and in-depth knowledge of computing systems, and to develop leaders in this field.

## Objectives

- Graduates should be able to apply the technical skills necessary to design and implement low level computer systems and applications.
- Graduates should have the theoretical and practical skills needed for advanced graduate education.
- Graduates should be able to work effectively on teams, to communicate in written and oral form, to practice life-long learning, and to develop the professional responsibility needed for successful technical leadership positions.

## Outcomes

The outcome we desire is that our graduates demonstrate:

- An ability to apply knowledge of mathematics, science, and engineering.
- An ability to design and conduct experiments, as well as to analyze and interpret data.
- An ability to design, implement, test, and evaluate a computer system, component, or algorithm to meet desired needs.
- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate, and solve engineering problems.
- An understanding of professional and ethical responsibility.
- An ability to communicate effectively.
- The broad education necessary to understand the impact of computer engineering solutions in a global and societal context.
- A recognition of the need for an ability to engage in life-long learning.
- A knowledge of contemporary issues.
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
- A knowledge of probability and statistics, including applications appropriate to computer engineering.
- A knowledge of mathematics through differential and integral calculus, basic sciences, and engineering sciences necessary to analyze and design complex systems containing hardware and software

components, as appropriate to program objectives.

- A knowledge of discrete mathematics.

## Computer Science

### Mission

To provide each student with a solid foundation in the scientific, engineering, and societal aspects of computing that prepares the student for a career that can advance the creation and application of computing technologies for the benefit of society.

### Goals

To educate students with core knowledge of the software, hardware, and theory of computing; to give each student in-depth knowledge in one or more computing areas; and to develop leaders in this field.

### Objectives

- To provide the necessary foundation in the principles and methods of computer science while preparing students for a broad range of responsible technical positions in industry and/or advanced graduate education.
- To provide the technical skills necessary to design and implement computer systems and applications, to conduct open-ended problem solving, and apply critical thinking.
- To provide an opportunity to work effectively on teams, to communicate in written and oral form, and to develop an appreciation of ethics and social awareness needed to prepare graduates for successful careers and leadership positions.

### Outcomes

The outcome we desire is that our graduates demonstrate:

- An ability to apply knowledge of mathematics, science, and engineering.

- An ability to design and conduct experiments, as well as to analyze and interpret data.
- An ability to design, implement, test, and evaluate a computer system, component, or algorithm to meet desired needs.
- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate, and solve computer science problems.
- An understanding of professional and ethical responsibility.
- An ability to communicate effectively.
- The broad education necessary to understand the impact of computer science solutions in a global and societal context.
- A recognition of the need for an ability to engage in life-long learning.
- A knowledge of contemporary issues.
- An ability to use the techniques, skills, and modern tools necessary for computer science practice.
- A knowledge of probability and statistics, including applications appropriate to computer science.
- A knowledge of mathematics, basic sciences, and engineering sciences necessary to analyze and design complex computing systems, as appropriate to program objectives.

## Electrical Engineering

### Mission

To provide an outstanding education for engineers in electrical engineering and to develop future leaders.

### Goals

To provide students with the education for a rewarding and successful career.

### Objectives

- Graduates should be prepared for entry-level engineering jobs, for graduate school, or for entrepreneurial activities based on their rigorous education in the fundamentals and applications of electrical engineering, including laboratory and design work.

- Graduates should be able to pursue a variety of careers, based on a curriculum that allows for a balance between a deep education in one area and a broad education in several areas.
- Graduates should be able to work effectively on diverse teams, to communicate in written and oral form, to practice life-long learning, and to develop the professional skills and ethics needed for successful technical leadership positions.

## Outcomes

The outcome that we desire is that our graduates demonstrate:

- An ability to apply knowledge of mathematics, science, and engineering.
- An ability to design and conduct experiments, as well as to analyze and interpret data.
- An ability to design a system, component, or process to meet desired needs.
- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate, and solve engineering problems.
- An understanding of professional and ethical responsibility.
- An ability to communicate effectively.
- The broad education necessary to understand the impact of electrical engineering solutions in a global and societal context.
- A recognition of the need for an ability to engage in life-long learning.
- A knowledge of contemporary issues.
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

## Data Science

### Contacts

**CSE Undergraduate Advising Office:**

EECS Department

2808 Beyster Bldg.

ugadmin@eecs.umich.edu

(734) 763-6563

**Department Website:** <http://www.eecs.umich.edu/eecs/undergraduate/datascience>

**Chief Program Advisor:**  
dsengadvisor@umich.edu

## Mission

To provide a solid and current foundation to students in the data science area.

## Goals

To produce students with intellectual understanding of both statistical and computing principles for exploring methods and algorithms related to data science so as to enable knowledge creation and decision-making in various application domains.

## Objectives

- To provide the necessary foundation in the principles and methods of data science while preparing students for a broad range of responsible technical positions in industry and/or advanced graduate education.
- To provide the technical skills necessary to ingest, curate, manage, query, analyze, and transform data
- To provide an opportunity to communicate in written and oral form, to develop an appreciation of ethics, security, and privacy in the digital world, and to prepare graduates for successful careers and leadership positions.

## Outcomes

The outcome we desire is that our graduates demonstrate:

- An ability to apply knowledge of mathematics, science, and engineering to problem solving.
- Knowledge of probability and statistics, including applications appropriate to data science.
- An ability to design and conduct experiments, as well as to analyze and interpret data.

- An ability to select ways of storing and analyzing data to meet desired needs, both in memory and on persistent storage.
- An ability to design and implement automated or semi-automated methods to help curate, query, and transform data.
- An ability to apply machine learning and statistical techniques to help analyze large datasets and to create prediction models or decision models.
- An ability to analyze data in the context of an application domain.
- An understanding of professional and ethical responsibility.
- An ability to communicate effectively.
- The broad education necessary to understand the impact of data science solutions in a global and societal context.

## Undergraduate

### Degree Program

#### Computer Engineering

The program in Computer Engineering provides each student with a broad and well-integrated background in the concepts and methodologies that are needed for the analysis, design, and utilization of information processing systems. Although such systems are often popularly called "computers," they involve a far wider range of disciplines than merely computation, and the Computer Engineering Program is correspondingly broad. A set of required technical courses (along with the college-wide requirements) gives the essential material in circuits, digital logic, discrete mathematics, computer programming, data structures, signals and systems, and other topics. Following completion of this work, the student can select courses in a wide range of subject areas. These include operating systems, programming languages and compilers, computer architecture, microprocessor-based systems, computer aided design and VLSI, digital signal processing, and computer networking, among others. A broad selection from several areas is recommended for most undergraduate students. Specialization in particular areas is

more typical of graduate programs of study.

## Computer Science

Computer scientists are experts on the theory and practice of computation, including the fundamental capabilities and limitations of computation and how computational thinking can be practically applied. A computer scientist understands how to design and analyze algorithms, how to retrieve, transform, and store information efficiently, how computers work to execute algorithms, and how to develop software systems that solve complex problems. Specialists within computer science might have expertise in developing software applications, designing computer hardware, protecting computer systems against attacks, developing algorithms, analyzing large data sets, and many other current and emerging possibilities.

The computer science (CS) program at the University of Michigan is available to students in both the Colleges of Engineering and of Literature, Science, and the Arts. The program requires students to have a solid foundation in computer software, hardware, and theory, but also gives a student ample opportunity to take advanced electives in areas of computer science such as databases, architecture, networks, artificial intelligence, and graphics, or in emerging interdisciplinary areas such as electronic commerce, web information systems, and computer game design.

## Electrical Engineering

The Electrical Engineering program provides students with a fundamental background in the basic theoretical concepts and technological principles of modern electrical engineering. A flexible curriculum allows students to emphasize a wide variety of subject areas within the field, including: analog and digital circuits, communication systems, control systems, electromagnetics, integrated circuit (microprocessor) design, signal processing, microelectromechanical devices, solid state electronics, and optics and photonics.

As seen from the list of subject areas, a degree in electrical engineering can lead to a wide range of work opportunities. Automotive applications include engine

control processors, sensors to trigger airbags or activate antilock brake systems, development of sophisticated audio systems, and the systems that power electric vehicles. Electrical engineers work in the wireless communications field, including mobile phone systems and global positioning systems. Electrical engineers also work in remote sensing to infer characteristics of a region of the earth from the air or from space to study the environment and climate change. They design, manufacture, test and market the microprocessor, analog and RF integrated circuits from which computers, digital movie and still cameras, the internet, communication systems, and many other modern conveniences are made. Electrical engineers develop signal processing algorithms and hardware for multimedia devices and develop control algorithms and electronics for mechanical systems such as automobiles, robotics, planes and spacecraft. They embed microprocessors in everything from entertainment gadgets to industrial plants. Electrical engineers develop optical fiber communication systems and laser technology for applications ranging from astrophysics to eye surgery. Electrical engineers use semiconductor fabrication technology to make high-efficiency solar cells, light emitting diodes for lighting, and miniature machines called microelectromechanical devices. The signal processing algorithms, optical devices, and miniature systems invented and developed by electrical engineers are providing breakthrough technologies in the biomedical world for health and wellness and the diagnosis and treatment of diseases. A common effort of electrical engineers is to make components smaller, faster, more energy efficient and less costly.

## Data Science

Data Science has emerged as a major field of study that is at the intersection of Computer Science and Statistics. The collection, management, analysis, and interpretation of such data, with complex structures in the form of text, video, streaming data, are leading to exciting new research opportunities.

Huge amounts of data are being collected in all areas, made possible by rapid technological advances over the last few decades. This is further enabling the use of

data-driven approaches to fundamentally transform the way corporations do business and is also leading to new discoveries in science and engineering. Data Science affects research and applications in many domains, including education, biological sciences, medical informatics, engineering, healthcare, social sciences, and the humanities.

The Data Science (DS) program at the University of Michigan draws on our expertise in Computer Science, Statistics, and Mathematics, complementing them with exposure to application domains to provide a multidisciplinary degree that develops future generations of data scientists.

The Data Science program for the College of Engineering is administered by the Computer Science Program in the Department of Electrical Engineering and Computer Science.

## Requirements

Candidates for the Bachelor of Science in Engineering in Computer Engineering - B.S.E. in C.E., the Bachelor of Science in Engineering degree in Computer Science - B.S.E. in C.S., and Bachelor of Science in Engineering in Electrical Engineering - B.S.E. in E.E. must complete the respective degree requirements. The following Sample Schedules are examples that lead to graduation in eight terms. Candidates for the Bachelor of Science or Bachelor of Arts degree in Computer Science through the College of Literature, Science, and the Arts should consult the LS&A Bulletin for degree requirements.

## C- Rule

Among science, engineering and mathematics courses, a grade of C- or below is considered unsatisfactory.

## Repeat Policy

Students are limited to attempting each of the three 200-level courses (EECS 203, EECS 280, EECS 281) at

most twice. An attempt includes, but is not limited to, a notation of any letter grade (A-F), withdraw (W), pass/fail (P/F), transfer (T), or incomplete (I) posted on the U-M transcript.

## Declaration Requirements

The EECS Department follows the College of Engineering rules for Program Selection (i.e., Declaration). For more information see the Academic Rules, Declaring (or Changing) Major section of the bulletin.

## Sample Schedules

### B.S.E. in Computer Engineering

The Computer Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <http://www.eecs.umich.edu/eecs/undergraduate/staff.html>.

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, and 216	12	4	4	-	4	-	-	-	-
Mathematics 215						4			
Engineering 100, Introduction to Engineering	4	-	4	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	4	-	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	-	4	-	4	-	-
<b>Program Subjects (32 hours)</b>									
EECS 203, Discrete Mathematics	4	-	-	4	-	-	-	-	-
EECS 215, Introduction to Circuits <sup>3</sup>	4	-	-	-	4	-	-	-	-
EECS 216, Introduction to Signals and Systems	4	-	-	-	-	4	-	-	-
EECS 270, Introduction to Logic Design	4	-	-	4	-	-	-	-	-
EECS 280, Programming and Elementary Data Structures	4	-	-	-	4	-	-	-	-
EECS 370, Introduction to Computer Organization	4	-	-	-	-	4	-	-	-
EECS 301, MATH 425, or STATS 412	3	-	-	-	-	-	3	-	-
TCHNCLCM 300 <sup>4</sup>	1	-	-	-	-	1	-	-	-
TCHNCLCM 496 and EECS 496 <sup>5</sup>	4	-	-	-	-	-	-	-	4
<b>Technical Electives (28 hours)<sup>6,11</sup></b>									
Flexible Technical Electives <sup>7</sup>	7	-	-	-	-	-	-	5	2
EECS Elective <sup>8</sup>	3	-	-	-	-	-	-	3	-
Core Electives <sup>9</sup>	8	-	-	-	-	-	8	-	-
Upper Level CE Electives <sup>10</sup>	10	-	-	-	-	-	-	4	6
<b>General Electives (13-16 hours)</b>	<b>13-16</b>	-	-	3	-	3	-	4	3
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>16</b>	<b>15</b>	<b>16</b>	<b>15</b>

Candidates for the Bachelor of Science in Engineering in Computer Engineering - B.S.E. in Compt. E. must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

#### Notes:

C- Rule: Among science, engineering and mathematics courses, a grade of C- or below is considered unsatisfactory.

Students are limited to attempting each of the three 200-level courses (EECS 203, EECS 280, EECS 281) at most twice. An attempt includes, but is not limited to, a notation of any letter grade (A-F), withdraw (W), pass/fail (P/F), transfer (T), or incomplete (I) posted on the U-M transcript.

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> EECS 215 must be preceded or accompanied by Physics 240.

<sup>4</sup> TCHNCLCM 300 can be taken independently of any EECS course, but it is a prerequisite for TCHNCLCM 496.

<sup>5</sup> TCHNCLCM 496 and EECS 496 must be elected concurrently with a Major Design Experience (MDE) course.

<sup>6</sup> Technical Electives: At least one of these classes must be an approved Major Design Experience Course. (See the EECS Undergraduate Advising Office for a current list.)

<sup>7</sup> Unused credits from Upper Level CE Electives or EECS Elective courses may be used to satisfy this requirement.

<sup>8</sup> Unused credits from Upper Level CE Elective courses may be used to satisfy this requirement.

<sup>9</sup> Core Electives: 8 hours from the following list: EECS 281, EECS 312, EECS 373, EECS 351.

<sup>10</sup> Upper Level CE Electives: At least 10 hours Contact the EECS Undergraduate Advising Office for the current list. Must include at least one Major Design Experience course taken concurrently with EECS 496 and TCHNCLCM 496.

<sup>11</sup> A maximum of 4 hours of EECS 499 may be applied to Technical Elective requirements and only in the area of Flexible Technical Electives. Anything beyond 4 hours will be applied toward General Electives.

## B.S.E. in Computer Science

The Computer Science program is accredited by the Computing Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <https://www.eecs.umich.edu/eecs/academics/academics.html>.

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, and 214 <sup>3</sup>	12	4	4	-	4	-	-	-	-
Mathematics 215 or 216 <sup>4</sup>	4	-	-	-	-	4	-	-	-
Engineering 100, Introduction to Engineering	4	-	4	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	4	-	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	-	4	4	-	-	-
<b>Program Subjects (24 hours)</b>									
EECS 203 Discrete Mathematics <sup>5</sup>	4	-	-	4	-	-	-	-	-
EECS 280, Programming and Elementary Data Structures	4	-	-	4	-	-	-	-	-
EECS 281, Data Structures and Algorithms	4	-	-	-	4	-	-	-	-
EECS 370, Introduction to Computer Architecture	4	-	-	-	-	4	-	-	-
STATS 250 or STATS 412 or STATS 426 or EECS 301/401 or IOE 265 <sup>6</sup>	3	-	-	-	-	-	3	-	-
EECS 376, Foundations of Computer Science	4	-	-	-	-	-	4	-	-
TCHNCLCM 300	1	-	-	-	-	-	1	-	-
<b>Major Design Experience (8 hours)</b>									
Approved CS MDE course <sup>7</sup>	4	-	-	-	-	-	-	4	-
EECS 496 Major Design Experience Professionalism	2	-	-	-	-	-	-	2	-
TCHNCLCM 497	2	-	-	-	-	-	-	2	-
<b>Technical Electives (26 hours)</b>									
Upper Level CS Technical Electives <sup>8</sup>	16	-	-	-	-	-	4	4	8
Flexible Technical Electives <sup>9,10</sup>	10	-	-	-	4	4	-	-	2
<b>General Electives (15 hours)</b>									
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>16</b>	<b>16</b>	<b>16</b>	<b>14</b>

Candidates for the Bachelor of Science in Engineering in Computer Science - B.S.E. in C.S. - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

### Notes:

C- Rule: Among science, engineering and mathematics courses, a grade of C- or below is considered unsatisfactory.

Credits from a course may only be used to fulfill a single requirement (no double counting).

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> The requirements for Math 214 can be satisfied by Math 217, 417, or 419.

<sup>4</sup> If both Math 215 and Math 216 are taken, Math 216 will be counted as a Flexible Technical Elective.

<sup>5</sup> Math 465 can be used to satisfy this requirement.

<sup>6</sup> Stats 250, EECS 301, and IOE 265 are 4 hour courses; if this is elected, the extra hour is counted toward General Electives.

<sup>7</sup> An approved Computer Science (CS) Major Design Experience (MDE) course; see the appropriate CS Program Guide for the current list. Must be taken in the same term as EECS 496 and TCHNCLCM 497. A 3-credit CS MDE course can be used if a total of 27 credits of Technical Electives are elected.

<sup>8</sup> Upper Level CS Technical Electives (ULCS): approved Computer Science courses at the 300-level or higher. See the appropriate CS Program Guide for the current list.

<sup>9</sup> Flexible Technical Electives (FTES): Approved courses at the 200 or higher level. See the appropriate CS Program Guide for the current list.

<sup>10</sup> A maximum of 4 hours of EECS 499 (or other upper-level directed/independent study) may be applied to Flexible Technical Electives. Anything beyond 4 hours will be applied toward the General Electives.

## B.S.E. in Electrical Engineering

The Electrical Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <http://www.eecs.umich.edu/eecs/undergraduate/staff.html>.

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by All Programs (55 hours)</b>									
Mathematics 115, 116, and 215 <sup>3</sup>	12	4	4	4	-	-	-	-	-
Mathematics 216	4	-	-	-	4	-	-	-	-
Engineering 100, Introduction to Engineering	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	-	4	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	4	4	-	-	-	-
<b>Program Subjects (29 hours)</b>									
EECS 215, Introduction to Circuits	4	-	-	4	-	-	-	-	-
EECS 216, Introduction to Signals and Systems	4	-	-	-	4	-	-	-	-
EECS 230, Electromagnetics I	4	-	-	-	-	4	-	-	-
EECS 280, Programming and Elementary Data Structures	4	-	-	-	4	-	-	-	-
EECS 320, Introduction to Semiconductor Device Theory	4	-	-	-	-	4	-	-	-
EECS 301, Probabilistic Methods in Engineering <sup>4</sup>	4	-	-	-	-	-	4	-	-
TCHNCLCM 300 <sup>5</sup>	1	-	-	-	1	-	-	-	-
TCHNCLCM 496 and EECS 496 <sup>5</sup>	4	-	-	-	-	-	-	-	4
<b>Technical Electives (33 hours)</b>									
Flexible Technical Electives <sup>6</sup>	10	-	-	-	-	3	-	4	3
Upper-Level EE Technical Electives <sup>7</sup>	19	-	-	-	-	4	8	7	-
Major Design Experience <sup>8</sup>	4	-	-	-	-	-	-	-	4
<b>General Electives (11 hours)</b>									
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>17</b>	<b>17</b>	<b>15</b>	<b>16</b>	<b>15</b>	<b>14</b>

Candidates for the Bachelor of Science in Engineering in Electrical Engineering - B.S.E. in E.E. - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

### Notes:

C- Rule: Among science, engineering and mathematics courses, a grade of C- or below is considered unsatisfactory.

Students are limited to attempting each of the three 200-level courses (EECS 203, EECS 280, EECS 281) at most twice. An attempt includes, but is not limited to, a notation of any letter grade (A-F), withdraw (W), pass/fail (P/F), transfer (T), or incomplete (I) posted on the U-M transcript.

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> EE students are advised to take MATH 216 before MATH 215 since EECS 216 is to be preceded or accompanied by MATH 216.

<sup>4</sup> EE students may select only EECS 301 to fulfill this requirement. No more than 4 credits of undergraduate probability may be applied toward EE program requirements. (Additional credits will appear as General Electives.)

<sup>5</sup> Technical Communications: TCHNCLCM 300 can be taken independently of any EECS course, but it is a prerequisite for TCHNCLCM 496. It is advisable to take TCHNCLCM 496 with a Major Design Experience (MDE) course.

<sup>6</sup> Flexible Technical Electives: The flexible technical elective requirement may be fulfilled by taking selected course in EECS, other engineering departments, biology, chemistry, economics, math, or physics. See the ECE Undergraduate Advising Office for the current list. All other courses must be approved by the EE Chief Program Advisor. A maximum of 4 total hours of EECS 399, EECS 499, ENGR 355 or ENGR 455 may be applied to the Flexible Technical Electives requirements. Anything beyond 4 hours will be applied towards General Electives.

<sup>7</sup> Upper-Level EE Technical Electives: Minimum 19 credits. Courses must be chosen from at least two categories; at least 7 credits must be at the 400-level or higher. See the ECE Undergraduate Advising Office for the current list. Credit hours in excess of 19 can be applied toward FTE.

<sup>8</sup> Major Design Experience: Pre-approved courses are EECS 411, 413, 425, 427, 430, 438, 452, 470, 473; other courses that are MDEs in other engineering programs may be acceptable with prior approval of the EE Chief Program Advisor. EE students pursuing a pre-approved non-EE MDE are required to complete six Upper-Level EE Technical Electives instead of the usual five. The additional credits earned through this sixth Upper-Level EE Elective will be applied toward Flexible Technical credits. Students are advised to enroll concurrently in EECS 496, TCHNCLM 496 and MDE course.

## B.S.E. in Data Science

Not an ABET accredited program. Additional information can be found on the department advising website, <https://www.eecs.umich.edu/eecs/academics/academics.html>.

	Total Credit Hours	Terms:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, and 214 <sup>4</sup>	12	4	4	-		4	-	-	-
Mathematics 215	4	-	-	-	4		-	-	-
Engineering 100, Introduction to Engineering	4	-	4	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	4	-	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211	5	5	-	-	-	-	-	-	-
Physics 140 and Lab 141	5	-	5	-	-	-	-	-	-
Physics 240 and Lab 241	5	-	-	5	-	-	-	-	-
Intellectual Breadth	16	4	4	-	4	4	-	-	-
<b>Program Core (30 hours)</b>									
EECS 203 Discrete Mathematics, or MATH 465	4	-	-	4	-	-	-	-	-
EECS 280, Programming and Elementary Data Structures	4	-	-	4	-	-	-	-	-
EECS 281, Data Structures and Algorithms	4	-	-	-	4	-	-	-	-
STATS 412	3	-	-	-	-	3	-	-	-
STATS 413	4	-	-	-	-	-	4	-	-
EECS 484 or EECS 485, Databases & Applications	4	-	-	-	-	-	4	-	-
EECS 445 or STATS 415	4	-	-	-	-	4	-	-	-
Data Science Application Course <sup>2</sup>	3	-	-	-	-	-	-	3	-
<b>Technical Electives &amp; Capstone (12 hours)</b>									
Advanced DS Technical Electives <sup>3</sup>	8	-	-	-	-	-	-	4	4
Approved DS Capstone course	4	-	-	-	-	-	-	-	4
<b>Other Requirements (16 hours)</b>									
Flexible Technical Electives <sup>4,5</sup>	11	-	-	-	4	-	4	3	-
TCHNCLCM 300	1	-	-	-	-	-	1	-	-
EECS 496, Major Design Experience Professionalism	2	-	-	-	-	-	-	2	-
TCHNCLCM 497 or STATS 404 <sup>6</sup>	2	-	-	-	-	-	-	2	-
<b>General Electives (15 hours)</b>	<b>15</b>	-	-	<b>3</b>	-	-	<b>3</b>	<b>1</b>	<b>8</b>
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>15</b>	<b>16</b>	<b>15</b>	<b>16</b>

### Notes:

C- Rule: Among science, engineering and mathematics courses, a grade of C- or below is considered unsatisfactory.

Credits from a course may only be used to fulfill a single requirement (no double counting).

- The requirements for Math 214 can be satisfied by Math 217 as an alternative.
- List of approved courses for this requirement can be found through the DS-Eng section of the EECS website.
- Advanced DS Technical Electives: 300-level or higher from a pre-approved list of courses found through the DS-Eng section of the EECS website, or with Chief Program Advisor approval prior to taking the course.
- Flexible Technical Electives (FTEs): Approved courses at the 200+ level. See the EECS Undergraduate Advising Office for the current list.
- A maximum of 4 credits of EECS 499 (or other upper-level directed/independent study) may be applied to Flexible Technical Electives. Anything beyond 4 credits will be applied toward the General Electives.

## Sequential Undergraduate/ Graduate Study (SUGS)

### **B.S.E. or B.S. in one of the EECS programs or Computer Science/ M.S.E. or M.S. in one of the Electrical Engineering and Computer Science (EECS) Programs**

There are two separate SUGS programs available through Rackham open to EECS and Computer Science undergraduates (depending on major/minor, etc.) who have completed 85 or more credit hours with a cumulative GPA of at least 3.6. Please see the individual program options and contact the respective CSE or ECE Graduate Program Coordinator for more complete program information.

### **B.S.E. in Electrical Engineering/ M.S. in Biomedical Engineering**

This SUGS program is open to all undergraduate students from Electrical Engineering who have achieved senior standing (85 credit hours or more) and have an overall cumulative GPA of 3.2 or higher. Please contact the Department of Biomedical Engineering for more complete program information.

## Graduate

### **Graduate Degrees in Computer Science and Engineering:**

- Master of Science (M.S.) in Computer Science and Engineering
- Master of Science in Engineering (M.S.E.) in Computer Science and Engineering
- Doctor of Philosophy (Ph.D.) in Computer Science and Engineering

### **Graduate Degrees in Electrical & Computer Engineering:**

- Master of Science (M.S.) in Electrical & Computer Engineering
- Master of Science in Engineering (M.S.E.) in Electrical & Computer Engineering
- Doctor of Philosophy (Ph.D.) in Electrical & Computer Engineering

Electrical Engineering and Computer Science (EECS) is one of the highest-ranking EECS departments in the country, and many of the faculty are recognized as leaders in their field. Please review Degree information in both divisions.

### **Master of Science / Master of Science in Engineering**

The M.S. (Master's of Science) and M.S.E. (Master's of Science in Engineering) degrees differ mainly in name. The degree requirements are the same. Students with a bachelor's degree in engineering can elect either degree. Students without an engineering bachelor's degree are eligible only for the M.S. The principal requirements for the specific M.S. and M.S.E. degrees are listed below. (A more complete statement on master's degree requirements is available on the Web: <http://www.eecs.umich.edu/eecs/graduate/index.html>.)

### **M.S. and M.S.E. in Computer Science and Engineering**

A student must satisfy the regulations of the Rackham School of Graduate Studies, the College of Engineering, and the regulations as specified by the program brochure(s) and the program office.

A student must earn at least 30 credit hours of graduate level coursework, of which at least 24 hours must be technical courses, at least 15 hours must be CSE coursework at the 500-level or higher (excluding credit hours earned in individual study, research or seminar

courses). The student must also satisfy course requirements in "breadth" areas of software, hardware, artificial intelligence, and theory. A maximum of six credit hours of individual study, research and seminar courses will be accepted toward the master's degree. The VLSI concentration has slightly different course requirements; please refer to the CSE Brochure available on the web for details.

The program requires that the grade point average received in CSE coursework must be at least 3.0 (based on Rackham's 4.0 scale). An individual course grade of "B-" or better is required for the credit hours received in any course to be counted towards any master's degree requirement. A master's thesis is optional. Credit hours transferred may be applied to meet any master's degree requirement except the 15 credit hours of 500-level CSE coursework required. (Rackham specifies limitations to the circumstances under which credits may be transferred. See the Rackham Student Handbook.) Courses of an insufficiently advanced level, or which substantially duplicate in level and/or content courses already completed by the student, may not be counted as meeting any master's degree requirements.

## **M.S. and M.S.E. in Electrical & Computer Engineering**

The Master's Program in Electrical & Computer Engineering covers topics such as Applied Electromagnetics & RF Circuits, Communications, Computer Vision, Control Systems, Embedded Systems, Integrated Circuits & VLSI, MEMS & Microsystems, Optics & Photonics, Power & Energy, Robotics, Signal and Image Processing & Machine Learning, and Solid State & Nanotechnology. A student must earn at least 30 credit hours of graduate-level coursework, of which at least 24 credit hours must be in technical courses, at least 12 credit hours must be EECS coursework at the 500 level or higher (excluding credit hours earned in individual study, research, or seminar courses, other departments or universities), and 9 credit hours from an ECE major area including at least 6 at the 500 level or above, and at least 6 credit hours in courses outside the major area, often outside of ECE. A maximum of 3 credit hours of S/U courses that are not directed study will be accepted

toward the degree. At most 6 credit hours of directed study will be accepted. Course grades must be "B-" or better in order to be counted towards any requirements. A grade point average of "B" or higher is required overall. A master's thesis is optional.

## **Doctor of Philosophy**

### **Ph.D. in Computer Science and Engineering**

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in her/his broad field of knowledge through completion of a prescribed set of courses and passing a comprehensive examination.

In most areas, a student must complete required coursework, pass a comprehensive examination and any other program requirements and be recommended for candidacy for the doctorate. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

Requirements regarding foreign language and non-technical courses are left to individual departments or programs and to the Graduate School. A prospective doctoral student should consult the program advisor regarding specific details.

A pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School office, 1004 Rackham Building, upon request.

## Ph.D. in Electrical & Computer Engineering

The Ph.D. Program in Electrical & Computer Engineering covers topics such as Applied Electromagnetics & RF Circuits, Communications, Computer Vision, Control Systems, Embedded Systems, Integrated Circuits & VLSI, MEMS & Microsystems, Optics & Photonics, Power & Energy, Robotics, Signal and Image Processing & Machine Learning, and Solid State & Nanotechnology. A student must earn at least 36 credit hours of graduate-level coursework, of which at least 30 credit hours must be in technical courses, at least 12 credit hours must be EECS coursework at the 500 level or higher (excluding credit hours earned in individual study, research, or seminar courses, other departments or universities), and 9 credit hours from an ECE major area including at least 6 at the 500 level or above, and at least 6 credit hours in courses outside the major area, often outside of ECE. A maximum of 3 credit hours of S/U courses that are not directed study will be accepted toward the degree. At most 6 credit hours of directed study will be accepted. Course grades must be "B-" or better in order to be counted towards any requirements. A grade point average of "B" or higher is required overall.

See the ECE Graduate Program manual for details.

## The 3.4 Program for EECS and Computer Science majors only

Students with at least a 3.4 G.P.A. in their major course work and overall G.P.A. at the time of application and graduation may apply to the ECE (not CSE) master's degree program. For more information, go to the website (<http://ece.umich.edu/eecs/undergraduate/3.4Program.html>) or contact an ECE Graduate Program Coordinator for details.

## Graduate Certificate for Data Science

The University of Michigan Graduate Data Science

Certificate Program provides graduate science, technology and skills training for data scientists. The program emphasizes the practice of modeling using modern technology to handle large, incongruent, and heterogeneous collections of data. The Graduate Certificate for Data Science is issued by the Rackham School for Graduate Studies. The Program provides interactive data-centered training and involves 9 credits of courses and 3 credits of experiential training that require a written report on data analytics. Michigan Institute for Data Science (MIDAS) faculty from different disciplines provide student mentorship and curriculum advising. MIDAS offers merit-based top-off scholarships for graduate students enrolled in the Certificate program. Completion of the program is expected in 2-4 semesters. The Data Science Certificate program aims to provide core experiences in:

- (Modeling) Understanding of core Data Science principles, assumptions & applications;
- (Technology) Data management, computation, information extraction & analytics;
- (Practice) Hands-on experience with modeling tools and technology using real data.

## Who is eligible?

University of Michigan graduate students from any field are eligible to enroll.

## Program Requirements

Below are four fundamental requirements for earning a Graduate Data Science Certificate Program.

1. Nine (9) graduate credit hours of coursework in approved courses. These courses are designated as core and elective Methods, Technology or Applications — at six (6) course hours must be from the core Modeling and Technology courses. Only one course may be double-counted with another Rackham degree program.
2. Three (3) graduate credits in Data Science related experience that is approved by the MIDAS DS Program Committee. This can take the form of non-credit activity like an internship, practicum or pro-

fessional project equivalent to a three credit hour course, or additional coursework of at least three credits from the approved course list. (This course may be double-counted with another Rackham degree program.) To satisfy this “Plus Requirement” with a data-related experience, students will have to complete and submit to the DS Certificate Program Chair a report describing their experience and results, which will be evaluated to ensure the project demonstrates Data Science content, relevance and applications.

3. Annual Graduate Research Symposium, which provides graduate students with an opportunity to present the results of their research in talks and poster sessions, will be required and will ensure the students’ interaction with MIDAS faculty. Ph.D. students will be encouraged to make an oral or poster presentation.
4. Attend the MIDAS seminar series throughout the time of enrollment in the program.

## Program Chair

Program Chair: Assoc. Prof. Ivo Dinov, <http://www.umich.edu/~dinov/>

The complete Data Science Certificate Program details are available online at <http://midas.umich.edu/certificate/>

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### EECS 101. Thriving in a Digital World

*Prerequisite: None. (4 credits)*

From mobile apps to bitmaps, this course explores computational technologies and how they impact society and our everyday lives. Topics include: social networks, creative computing, algorithms, security and digital privacy. Traditional computer programming is not a primary focus. Instead, mobile applications will be created using a novel visual programming environment.

### EECS 183. Elementary Programming Concepts

*Prerequisite: None. (Credit for only one: EECS 183, ENGR 101) (4 credits)*

Fundamental concepts and skills of programming in a high-level language. Flow of control: selection, iteration, subprograms. Data structures: strings, arrays, records, lists, tables. Algorithms using selection and iteration (decision making, finding maxima/minima, searching, sorting, simulation, etc.) Good program design, structure and style are emphasized. Testing and debugging. Not intended for Engineering students (who should take ENGR 101), nor for CS majors in LSA who qualify to enter EECS 280.

### EECS 203 (CS 203). Discrete Mathematics

*Prerequisite: MATH 115. (4 credits)*

Introduction to the mathematical foundations of computer science. Topics covered include: propositional and predicate logic, set theory, function and relations, growth of functions and asymptotic notation, introduction to algorithms, elementary combinatorics and graph theory and discrete probability theory.

### EECS 215. Introduction to Electronic Circuits

*Prerequisite: MATH 116, ENGR 101, Corequisite PHYSICS 240 (or 260). Cannot receive credit for both EECS 314 and EECS 215. (4 credits)*

Introduction to electronic circuits. Basic Concepts of voltage and current; Kirchhoff's voltage and current laws; Ohm's law; voltage and current sources; Thevenin and Norton equivalent circuits; DC and low frequency active circuits using operational amplifiers, diodes, and transistors; small signal analysis; energy and power. Time- and frequency-domain analysis of RLC circuits. Basic passive and active electronic filters. Laboratory experience with electrical signals and circuits.

### EECS 216. Introduction to Signals and Systems

*Prerequisite: EECS 215 or EECS 314 or BIOMEDE 211, preceded or accompanied by MATH 216. (4 credits)*

Theory and practice of signals and systems engineering in continuous and discrete time. Continuous-time linear time-invariant systems, impulse response, convolution. Fourier series, Fourier transforms, spectrum, frequency response and filtering. Sampling leading to basic digital

signal processing using the discrete-time Fourier and the discrete Fourier transform. Laplace transforms, transfer functions, poles and zeros, stability. Applications of Laplace transform theory to RLC circuit analysis. Introduction to communications, control and signal processing. Weekly recitations and hardware/Matlab software laboratories.

### **EECS 230. Electromagnetics I**

*Prerequisite: MATH 215, PHYS 240 (or 260), EECS 215. (4 credits)*

Vector calculus. Electrostatics. Magnetostatics. Time-varying fields: Faraday's Law and displacement current. Maxwell's equations in differential form. Traveling waves and phasors. Uniform plane waves. Reflection and transmission at normal incidence. Transmission lines. Laboratory segment may include experiments with transmission lines, the use of computer-simulation exercises, and classroom demonstrations.

### **EECS 250 (NAVARCH 202). Electronic Sensing Systems**

*Prerequisite: Preceded or accompanied by EECS 230 or PHYSICS 240. (3 credits)*

Introduction to properties and behavior of electromagnetic energy as it pertains to naval applications of communication, radar, and electro-optics. Additional topics include sound navigation and ranging (SONAR), tracking and guidance systems, and computer-controlled systems.

### **EECS 270. Introduction to Logic Design**

*Prerequisite: EECS 183 or ENGR 101 or equivalent. (4 credits)*

Binary and non-binary systems, Boolean algebra, digital design techniques, logic gates, logic minimization, standard combinational circuits, sequential circuits, flip-flops, synthesis of synchronous sequential circuits, PLAs, ROMs, RAMs, arithmetic circuits, computer-aided design. Laboratory includes design and CAD experiments.

### **EECS 280. Programming and Introductory Data Structures**

*Prerequisite: ENGR 101 or ENGR 151 or EECS 182 or EECS 183. Minimum grade of C<sup>+</sup> required for enforced prerequisites. (4 credits)*

Techniques and algorithm development and effective programming, top-down analysis, structured programming, testing and program correctness. Program language syntax and static and runtime semantics. Scope, procedure instantiation, recursion, abstract data types and parameter passing methods. Structured data types, pointers, linked data structures, stacks, queues, arrays, records and trees.

### **EECS 281. Data Structures and Algorithms**

*Prerequisite: EECS 203 or Math 465 or Math 565 and EECS 280. Minimum grade of C<sup>+</sup> required for enforced prerequisites. (4 credits)*

Introduction to algorithm analysis and O-notation; Fundamental data structures including lists, stacks, queues, priority queues, hash tables, binary trees, search trees, balanced trees and graphs; searching and sorting algorithms; recursive algorithms; basic graph algorithms; introduction to greedy algorithms and divide and conquer strategy. Several programming assignments.

### **EECS 282. Information Systems Design and Programming**

*Prerequisite: EECS 182 or EECS 183 or ENGR 101 AND Math 115. (4 credits)*

Techniques for algorithm development and programming. Learning a programming language, such as Java, which is suitable for designing enterprise-scale information systems; data structures including stacks, queues, trees and dictionaries; recursion; program complexity; object-oriented design; handling exceptions, debugging and testing; introduction to database design with JDBC and SQL.

### **EECS 285. A Programming Language or Computer System**

*Prerequisite: Some programming experience. (2 credits)*

A course covering a complex computer system or programming language. Programming problems will be assigned. Specific languages or systems to be offered will be announced in advance.

### **EECS 301. Probabilistic Methods in Engineering**

*Advised Prerequisite: Preceded or accompanied by EECS 216. (4 credits)*

Basic concepts of probability theory. Random varia-

bles: discrete, continuous and conditional probability distributions; averages; independence. Statistical inference: hypothesis testing and estimation. Introduction to discrete and continuous random processes.

### **EECS 311. Analog Circuits**

*Prerequisite: EECS 215 and EECS 216. (4 credits)*

DC and AC circuit models for diodes, bipolar junction transistors and field-effect transistors; small-signal and piecewise analysis of nonlinear circuits; analysis and design of single-stage and multi-stage transistor amplifiers: gain, biasing and frequency response; op-amp based filter design; non-ideal op-amps. Design projects. Lecture and laboratory.

### **EECS 312. Digital Integrated Circuits**

*Prerequisite: EECS 215 and Math 216. (4 credits)*

Design and analysis of static CMOS inverters and complex combinational logic gates. Dynamic logic families, pass-transistor logic, ratioed logic families. Sequential elements (latches, flip-flops). Bipolar-based logic; ECL, BiCMOS. Memories; SRAM, DRAM, EEPROM, PLA. I/O circuits and interconnect effects. Design project(s).

### **EECS 314. Electrical Circuits, Systems, and Applications**

*Prerequisite: MATH 214 or MATH 216, PHYSICS 240.*

*Credit for only one: EECS 215, or EECS 314. Not open to CE or EE students. (4 credits)*

Students will learn about electrical systems operation, specifications and interactions with other modules. Theory will be motivated by the use of examples taken from a variety of fields. Topics covered include circuit fundamentals, frequency response and transients, analog and digital electronics. In lab, students will build and analyze circuits including amplifiers, filters and temperature controllers.

### **EECS 320. Introduction to Semiconductor Devices**

*Prerequisite: EECS 215 and PHYSICS 240 or 260. (4 credits)*

Introduction to semiconductors in terms of atomic bonding and electron energy bands. Equilibrium statistics of electrons and holes. Carrier dynamics; continuity, drift and diffusion currents; generation and recombination processes, including important optical processes.

Introduction to: PN junctions, metal-semiconductor junctions, light detectors and emitters; bipolar junction transistors, junction and MOSFETs.

### **EECS 330. Electromagnetics II**

*Prerequisite: EECS 230. (4 credits)*

Time-varying electromagnetic fields and Maxwell's equations. Plane-wave propagation, reflection and transmission. Geometric optics. Radiation and antennas. System applications of electromagnetic waves. Laboratory segment consists of experiments involving microwave and optical measurements and the design of practical systems.

### **EECS 334. Principles of Optics**

*Prerequisite: PHYSICS 240. A student can receive credit for only one: EECS 334 or PHYSICS 402. (4 credits)*

Basic principles of optics: light sources and propagation of light; geometrical optics, lenses and imaging; ray tracing and lens aberrations; interference of light waves, coherent and incoherent light beams; Fresnel and Fraunhofer diffraction. Overview of modern optics with laboratory demonstrations.

### **EECS 351. Introduction to Digital Signal Processing**

*Prerequisite: EECS 216. Minimum grade of C for enforced prerequisites. (4 credits)*

DSP methods and applications. Sampling and reconstruction, difference equations, convolution, stability, z-transform, transfer function, frequency response, FIR and IIR, DTFT, DFT, FFT, windows, spectrogram, computer-aided filter design, correlation, multirate, basic image processing, discretetime wavelets, filter banks. Applications: filtering, denoising, deconvolution, classification, others.

### **EECS 370. Introduction to Computer Organization**

*Prerequisite: (EECS 203 or Math 465 or Math 565 or EECS 270) and (EECS 280 or EECS 283). (4 credits)*

Basic concepts of computer organization and hardware. Instructions executed by a processor and how to use these instructions in simple assembly-language programs. Stored-program concept. Datapath and control for multiple implementations of a processor. Performance evaluation, pipelining, caches, virtual memory, input/output.

**EECS 373. Design of Microprocessor Based Systems**

*Prerequisite: EECS 270 and EECS 370 and junior standing. (4 credits)*

The principles of hardware and software microcomputer interfacing; digital logic design and implementation. Experiments with specially designed laboratory facilities. The introduction to digital development equipment and logic analyzers. Assembly language programming.

**EECS 376. Foundations of Computer Science**

*Prerequisite: EECS 280 and (EECS 203 or Math 465 or Math 565). Minimum grade of C required for enforced prerequisites. (4 credits)*

An introduction to computation theory: finite automata, regular languages, pushdown automata, context-free languages, Turing machines, recursive languages and functions and computational complexity.

**EECS 381. Object Oriented and Advanced Programming**

*Prerequisite: EECS 281 and EECS 370. (4 credits)*

Programming techniques in Standard C++ for large-scale, complex, or high-performance software. Encapsulation, automatic memory management, exceptions, generic programming with templates and function objects, Standard Library algorithms and containers. Using single and multiple inheritance and polymorphism for code reuse and extensibility; basic design idioms, patterns, and notation.

**EECS 382. Internet-scale Computing**

*Prerequisite: EECS 281 or EECS 282. (4 credits)*

Systems-level programming techniques and concepts for the design of software systems: computer memory model; pointer safety; concurrent programming using threads; coding vulnerabilities and secure coding; network programming and remote procedure calls; reading/writing objects to disk; client-server and distributed systems. No C++ background assumed. Programming labs in C++.

**EECS 388. Introduction to Computer Security**

*Prerequisite: Enforced: EECS 281. Advisory: EECS 370. (4 credits)*

This course introduces the principles and practices of computer security as applied to software, host systems,

and networks. It covers the foundations of building, using and managing secure systems. Topics include standard cryptographic functions and protocols, threats and defenses for real-world systems, incident response and computer forensics. There will be homework exercises, programming projects and a final exam.

**EECS 398. Special Topics**

*Advised Prerequisite: Permission of instructor. (1-4 credits)*

Topics of current interest selected by the faculty. Lecture, seminar, or laboratory.

**EECS 399. Directed Study**

*Prerequisite: Sophomore or junior standing, and Permission of Instructor. (1-4 credits)*

This course provides an opportunity for undergraduate students to work on research problems in EECS or areas of special interest such as design problems.

**EECS 402. Computer Programming For Scientists and Engineers**

*Prerequisite: Senior or graduate standing (3 credits)*

Presents concepts and hands-on experience for designing and writing programs using one or more programming languages currently important in solving real-world problems. Intended for senior undergraduates and graduate students in science or engineering fields. Not available for credit to EECS majors; will not substitute for ENGR 101.

**EECS 406 (ENGR 406). High-Tech Entrepreneurship**

*Prerequisite: None. (4 credits)*

Four aspects of starting high-tech companies are discussed: opportunity and strategy, creating new ventures, functional development, and growth and financing. Also, student groups work on reviewing business books, case studies, elevator and investor pitches. Different financing models are covered, including angel or VC funding and small business (SBIR) funding.

**EECS 410 (ENGR 410) Patent Fundamentals for Engineers**

*Prerequisite: Junior or senior standing or graduate standing. (4 credits)*

This course covers the fundamentals of patents for en-

gineers. The first part of the course focuses on the rules and codes that govern patent prosecution, and the second part focuses on claim drafting and amendment writing. Other topics covered include litigation, ethics and licensing.

#### **EECS 411. Microwave Circuits I**

*Prerequisite: EECS 311 or 330, or graduate standing. (4 credits)*

Transmission-line theory, microstrip and coplanar lines, S-parameters, signal-flow graphs, matching networks, directional couplers, low-pass and band-pass filters, diode detectors. Design, fabrication and measurements (1-10GHz) of microwave-integrated circuits using CAD tools and network analyzers.

#### **EECS 413. Monolithic Amplifier Circuits**

*Prerequisite: EECS 311 and EECS 320 or graduate standing. (4 credits)*

Analysis and design of BJT and MOS multi-transistor amplifiers. Feedback theory and application to feedback amplifiers. Stability considerations, pole-zero cancellation, root locus techniques in feedback amplifiers. Detailed analysis and design of BJT and MOS integrated operational amplifiers. Lectures and laboratory.

#### **EECS 414. Introduction to MEMS**

*Prerequisite: MATH 215 and MATH 216 and PHYSICS 240 or graduate standing. (4 credits)*

Micro electro mechanical systems (MEMS), devices and technologies. Micro-machining and microfabrication techniques, including planar thin-film processing, silicon etching, wafer bonding, photolithography, deposition and etching. Transduction mechanisms and modeling in different energy domains. Analysis of micromachined capacitive, piezoresistive and thermal sensors/actuators and applications. Computer-aided design for MEMS layout, fabrication and analysis.

#### **EECS 417 (BIOMEDE 417). Electrical Biophysics**

*Prerequisite: EECS 215 and 216 or graduate standing. (4 credits)*

Electrical biophysics of nerve and muscle; electrical conduction in excitable tissue; quantitative models for nerve and muscle, including the Hodgkin Huxley equations; biopotential mapping, cardiac electrophysiology, and functional electrical stimulation; group projects.

Lecture and recitation.

#### **EECS 418. Power Electronics**

*Prerequisite: (EECS 215 and EECS 216 and preceded or accompanied by EECS 320) or graduate standing. (4 credits)*

AC-DC, DC-DC switch-mode power converter topologies. Power converter topologies. Power Semiconductor devices, inductors, capacitors. Loss mechanisms, thermal analysis. Drive, snubber circuits. Laboratory experience with power electronic circuits.

#### **EECS 419. Electric Machinery and Drives**

*Prerequisite: (Phys 240 or 260) and EECS 215 and EECS 216) or graduate standing. (4 credits)*

Generation of forces and torques in electromechanical devices. Power electronic drives, motion control. DC machines. AC machines, surface mount permanent magnet machines, induction machines. Applications examined include electric propulsion drives for electric/hybrid vehicles, generators for wind turbines, and high-speed motor/alternators for flywheel energy storage systems. Laboratory experience with electric drives.

#### **EECS 421. Properties of Transistors**

*Prerequisite: EECS 320 or graduate standing. (4 credits)*

In depth understanding of the device physics and working principle of some basic IC components: metal-semiconductor junctions, P-N junctions, metal-oxide-semiconductor junctions, MOSFETs and BJTs

#### **EECS 423. Solid-State Device Laboratory**

*Prerequisite: EECS 320 or graduate standing. (4 credits)*

Semiconductor material and device fabrication and evaluation: diodes, bipolar and field-effect transistors, passive components. Semiconductor processing techniques: oxidation, diffusion, deposition, etching, photolithography. Lecture and laboratory. Projects to design and simulate device fabrication sequence.

#### **EECS 425. Integrated Microsystems Laboratory**

*Prerequisite: EECS 311 or EECS 312 or EECS 414 or graduate standing. (4 credits)*

Development of a complete integrated microsystem, from functional definition to final test. MEMS-based

transducer design and electrical, mechanical and thermal limits. Design of MOS interface circuits. MEMS and MOS chip fabrication. Mask making, pattern transfer, oxidation, ion implantation and metallization. Packaging and testing challenges. Students work in interdisciplinary teams.

### **EECS 427. VLSI Design I**

*Prerequisite: (EECS 270 and EECS 312 and EECS 320) or graduate standing. (4 credits)*

Design techniques for rapid implementations of very large-scale integrated (VLSI) circuits, MOS technology and logic. Structured design. Design rules, layout procedures. Design aids: layout, design rule checking, logic and circuit simulation. Timing. Testability. Architectures for VLSI. Projects to develop and lay out circuits.

### **EECS 429. Semiconductor Optoelectronic Devices**

*Prerequisite: EECS 320 or graduate standing. (4 credits)*

Materials for optoelectronics, optical processes in semiconductors, absorption and radiation, transition rates and carrier lifetime. Principles of LEDs, lasers, photodetectors, modulators and solar cells. Optoelectronic integrated circuits. Designs, demonstrations and projects related to optoelectronic device phenomena.

### **EECS 430 (AOSS 431). Radiowave Propagation and Link Design**

*Prerequisite: EECS 330. (4 credits)*

Fundamentals of electromagnetic propagation and radiation; radiowave propagation in different environments (near Earth, troposphere, ionosphere, indoor and urban); antenna parameters; practical antennas; link analysis; system noise; fading and multipath interference. Course includes lectures, labs and a project in which student teams develop and implement practical wireless systems.

### **EECS 434. Principles of Photonics**

*Prerequisite: EECS 330 or EECS 334 or permission of instructor or graduate standing. (4 credits)*

Introduction to photonics, opto-electronics, lasers and fiber-optics. Topics include mirrors, interferometers, modulators and propagation in waveguides and fibers. The second half treats photons in semiconductors, including semi-conductor lasers, detectors and noise ef-

fects. System applications include fiber lightwave systems, ultra-high-peak power lasers and display technologies.

### **EECS 435. Fourier Optics**

*Prerequisite: EECS 216. (3 credits)*

Basic physical optics treated from the viewpoint of Fourier analysis. Fourier-transform relations in optical systems. Theory of image formation and Fourier transformation by lenses. Frequency response of diffraction-limited and aberrated imaging systems. Coherent and incoherent light. Comparison of imagery with coherent and with incoherent light. Resolution limitations. Optical information processing, including spatial matched filtering.

### **EECS 438. Advanced Lasers and Optics Laboratory**

*Prerequisite: EECS 334 or EECS 434 or graduate standing. (4 credits)*

Construction and design of lasers; gaussian beams; nonlinear optics; fiber optics; detectors; dispersion; Fourier optics; spectroscopy. Project requires the design and set-up of a practical optical system.

### **EECS 441. Mobile App Development for Entrepreneurs**

*Prerequisite: Senior standing, EECS 281, EECS 370, and at least four credit hours of Upper Level Electives in either Computer Science or Computer Engineering. (3 credits)*

Best practices in the software engineering of mobile applications and best practices of software entrepreneurs in the design, production and marketing of mobile apps. Students will engage in the hands-on practice of entrepreneurship by actually inventing, building and marketing their own mobile apps.

### **EECS 442. Computer Vision**

*Prerequisite: EECS 281 or graduate standing. (4 credits)*

Computational methods for the recovery, representation and application of visual information. Topics from image formation, binary images, digital geometry, similarity and dissimilarity detection, matching, curve and surface fitting, constraint propagation relaxation labeling, stereo, shading texture, object representation and

recognition, dynamic scene analysis and knowledge based techniques. Hardware, software techniques.

### **EECS 443. Senior Thesis**

*Prerequisite: Senior standing. (3 credits)*

Students develop and carry out a research plan in collaboration with a sponsoring faculty member. Students present a research proposal to be approved by both the faculty member and the chief program advisor or designate. Students submit and present a thesis to be evaluated by the sponsoring faculty member and second reader. Eligibility is limited to students who have a major GPA of 3.5 or better and are declared CS through LSA.

### **EECS 445. Introduction to Machine Learning**

*Prerequisite: EECS 281. (4 credits)*

Theory and implementation of state-of-the-art machine learning algorithms for large-scale real-world applications. Topics include supervised learning (regression, classification, kernel methods, neural networks, and regularization) and unsupervised learning (clustering, density estimation, and dimensionality reduction).

### **EECS 452. Digital Signal Processing Design Laboratory**

*Prerequisite: EECS 280, and (EECS 451 or EECS 455) or graduate standing. (4 credits)*

Architecture features of single-chip DSP processors are introduced in lecture. Laboratory exercises using two different state-of-the-art fixed-point processors include sampling, A/D and D/A conversion, digital waveform generators, real-time FIR and IIR filter implementation. The central component of this course is a 12-week team project in real-time DSP Design (including software and hardware development).

### **EECS 453. Applied Matrix Algorithms for Signal Processing, Data Analysis and Machine Learning**

*Prerequisite: Enforced: EECS 301 or MATH 425 or STATS 425 or STATS 412 or STATS 426 or IOE 265 or equivalent. Advisory: EECS 451. Credit cannot be received for both EECS 453 and EECS 551. (4 credits)*

Theory and application of matrix algorithms to signal processing, data analysis and machine learning. Theoretical topics include subspaces, eigenvalue and singular value decomposition, projection theorem, constrained, regularized and unconstrained least squares

techniques and iterative algorithms. Applications such as image deblurring, ranking of webpages, image segmentation and compression, social networks, circuit analysis, recommender systems and handwritten digit recognition. Greater emphasis on applications than in EECS 551.

### **EECS 455. Digital Communication Signals and Systems**

*Prerequisite: EECS 216 and EECS 301 or graduate standing. (4 credits)*

Digital transmission techniques in data communications, with application to computer and space communications; design and detection of digital signals for low error rate; forward and feedback transmission techniques; matched filters; modems, block and convolutional coding; Viterbi decoding. Discussion on Discrete-time LTI systems, Discrete-time Fourier Transforms (DTFT) along with homework problems.

### **EECS 458 (BIOMEDE 458). Biomedical Instrumentation and Design**

*Prerequisite: EECS 215 or EECS 314 or consent of instructor or graduate standing. (4 credits)*

Students design and construct functioning biomedical instruments. Hardware includes instrumentation amplifiers and active filters constructed using operational amplifiers. Signal acquisition, processing analysis and display are performed. Project modules include measurement of respiratory volume and flow rates, biopotentials (electrocardiogram), and optical analysis of arterial blood oxygen saturation (pulse-oximetry).

### **EECS 460. Control Systems Analysis and Design**

*Prerequisite: EECS 216 or graduate standing. (4 credits)*

Basic techniques for analysis and design of controllers applicable in any industry (e.g. automotive, aerospace, computer, communication, chemical, bioengineering, power, etc.) are discussed. Both time- and frequency-domain methods are covered. Root locus, Nyquist and Bode plot-based techniques are outlined. Computer-based experiment and discussion sessions are included in the course.

### **EECS 461. Embedded Control Systems**

*Prerequisite: EECS 216 or EECS 373 or graduate*

*standing. (4 credits)*

Basic interdisciplinary concepts needed to implement a microprocessor based control system. Sensors and actuators. Quadrature decoding. Pulse width modulation. DC motors. Force feedback algorithms for human computer interaction. Real time operating systems. Networking. Use of MATLAB to model hybrid dynamical systems. Autocode generation for rapid prototyping. Lecture and laboratory.

### **EECS 463. Power Systems Design and Operation**

*Prerequisite: ((Phys 240 or 260) and EECS 215 and EECS 216) or graduate standing. (4 credits)*

Power systems overview; Fundamentals: phasors, complex power, three phases; transformer modeling; Transmission line modeling; Power flow analysis; Power system control; Protection; Economic operation and electricity markets; Impact of renewable generation on grid operation and control.

### **EECS 467. Autonomous Robotics**

*Prerequisite: EECS 281. (4 credits)*

A theoretical and hands-on introduction to robotics from a computer science perspective. Topics: kinematics, inverse kinematics, sensors, sensor processing, motion planning, control, Kalman filters, dynamics, embedded systems, real time operating systems, state estimation and mapping and artificial intelligence methods. Emphasizes laboratory design and programming of robotic systems.

### **EECS 470. Computer Architecture**

*Prerequisite: EECS 370 and EECS 270 or graduate standing. (4 credits)*

Basic concepts of computer architecture and organization. Computer evolution. Design methodology. Performance evaluation. Elementary queuing models. CPU architecture instruction sets. ALU design. Hardware and micro-programmed control. Nanoprogramming. Memory hierarchies. Virtual memory. Cache design. Input-output architectures. Interrupts and DMA. I/O processors. Parallel processing. Pipelined processors. Multiprocessors.

### **EECS 473. Advanced Embedded Systems**

*Prerequisite: EECS 373 and EECS 215 or EECS 281 or graduate standing. 4 credits*

Design of hardware and software for modern embedded systems. Real-time operating systems. Device drivers for general operating systems. PCB design including power integrity and electromagnetic interference. Radio frequency and wireless communication. Low-power design. DC/DC converter design for PCBs. Rapid prototyping of embedded systems. Groups will design a complete embedded system.

### **EECS 475. Introduction to Cryptography**

*Prerequisite: (EECS 203 or MATH 312 or MATH 412) and (EECS 183 or EECS 280). I, alternating years (4 credits)*

Covers fundamental concepts, algorithms, and protocols in cryptography. Topics: ancient ciphers, Shannon theory, symmetric encryption, public key encryption, hash functions, digital signatures, key distribution. Highlights AES, RSA, discrete log, elliptic curves. Emphasizes rigorous mathematical study in terms of algorithmic complexity. Includes necessary background from algorithms, probability, number theory and algebra.

### **EECS 477. Introduction to Algorithms**

*Prerequisite: EECS 281 or graduate standing. (4 credits)*

Fundamental techniques for designing efficient algorithms and basic mathematical methods for analyzing their performance. Paradigms for algorithm design: divide-and-conquer, greedy methods, graph search techniques, dynamic programming. Design of efficient data structures and analysis of the running time and space requirements of algorithms in the worst and average cases.

### **EECS 478. Logic Circuit Synthesis and Optimization**

*Prerequisite: EECS 203, EECS 270, and senior standing or graduate standing. (4 credits)*

Advanced design of logic circuits. Technology constraints. Theoretical foundations. Computer-aided design algorithms. Two-level and multilevel optimization of combinational circuits. Optimization of finite-state machines. High-level synthesis techniques: modeling, scheduling and binding. Verification and testing.

### **EECS 480. Logic and Formal Verification**

*Prerequisite: EECS 281 and (EECS 376 or EECS 270). (4 credits)*

An introduction to current methodologies for verifying computer systems. Topics covered include logic and theorem proving; transition systems; temporal logic and the mu-calculus; modeling sequential and concurrent systems; model checking methods; binary decision diagrams; and controlling state explosion. Students will complete a project using current model checking technology.

### **EECS 481. Software Engineering**

*Prerequisite: EECS 281 or graduate standing. (4 credits)*

Pragmatic aspects of the production of software systems, dealing with structuring principles, design methodologies and informal analysis. Emphasis is given to development of large, complex software systems. A term project is usually required.

### **EECS 482. Introduction to Operating Systems**

*Prerequisite: EECS 281 and EECS 370 or graduate standing. (4 credits)*

Operating system design and implementation: multi-tasking; concurrency and synchronization; inter-process communication; deadlock; scheduling; resource allocation; memory and storage management; input-output; file systems; protection and security. Students write several substantial programs dealing with concurrency and synchronization in a multi-task environment, with file systems and with memory management.

### **EECS 483. Compiler Construction**

*Prerequisite: EECS 281 and EECS 370 or graduate standing. (4 credits)*

Introduction to compiling techniques including parsing algorithms, semantic processing and optimization. Students implement a compiler for a substantial programming language using a compiler generating system.

### **EECS 484. Database Management Systems**

*Prerequisite: EECS 281 or graduate standing. (4 credits)*

Concepts and methods for the design, creation, query and management of large enterprise databases. Functions and characteristics of the leading database management systems. Query languages such as SQL,

forms, embedded SQL, and application development tools. Database design, integrity, normalization, access methods, query optimization, transaction management and concurrency control and recovery.

### **EECS 485. Web Database and Information Systems**

*Prerequisites: {EECS major OR Informatics major AND (EECS 281 OR EECS 382)} OR graduate standing. (4 credits)*

Concepts surrounding Web information systems, including client/server systems, security, XML, information retrieval and search engines and data replication issues. Includes substantial final project involving development of a database-backed web site.

### **EECS 486. Informational Retrieval and Web Search**

*Prerequisites: EECS 281 or equivalent. Minimum grade for enforced prerequisite of C! (4 credits)*

Covers background and recent advances in information retrieval (IR): indexing, processing, querying, classifying data. Basic retrieval models, algorithms, and IR system implementations. Focuses on textual data, but also looks at images/videos, music/audio, and geospatial information. Web search, including Web crawling, link analysis, search engine development, social media, and crowdsourcing.

### **EECS 487. Interactive Computer Graphics**

*Prerequisite: EECS 281 or graduate standing. (4 credits)*

Computer graphics hardware, line drawing, rasterization, anti-aliasing, graphical user interface (GUI), affine geometry, projective geometry, geometric transformation, polygons, curves, splines, solid models, lighting and shading, image rendering, ray tracing, radiosity, hidden surface removal, texture mapping, animation, virtual reality and scientific visualization.

### **EECS 489. Computer Networks**

*Prerequisite: EECS 482 or graduate standing. (4 credits)*

Protocols and architectures of computer networks. Topics include client-server computing, socket programming, naming and addressing, media access protocols, routing and transport protocols, flow and congestion control, and other application-specific protocols. Emphasis is placed on understanding protocol design prin-

principles. Programming problems to explore design choices and actual implementation issues assigned.

### **EECS 490. Programming Languages**

*Prerequisite: EECS 281. (4 credits)*

Fundamental concepts in programming languages. Course covers different programming languages including functional, imperative, object-oriented, and logic programming languages; different programming language features for naming, control flow, memory management, concurrency, and modularity; as well as methodologies, techniques and tools for writing correct and maintainable programs.

### **EECS 492. Introduction to Artificial Intelligence**

*Prerequisite: EECS 281 or graduate standing. (4 credits)*

Fundamental concepts of AI, organized around the task of building computational agents. Core topics include search, logic, representation and reasoning, automated planning, decision making under uncertainty and machine learning.

### **EECS 493. User Interface Development**

*Prerequisite: EECS 281 or graduate standing. (4 credits)*

Concepts and techniques for designing computer system user interfaces to be easy to learn and use, with an introduction to their implementation. Task analysis, design of functionality, display and interaction design, and usability evaluation. Interface programming using an object-oriented application framework. Fluency in a standard object-oriented programming language is assumed.

### **EECS 494. Computer Game Design and Development**

*Prerequisite: EECS 281 or graduate standing. (4 credits)*

Concepts and methods for the design and development of computer games. Topics include: history of games, 2D graphics and animation, sprites, 3D animation, binary space partition trees, software engineering, game design, interactive fiction, user interfaces, artificial intelligence, game SDK's, networking, multi-player games, game development environments, commercialization of software.

### **EECS 496. Major Design Experience Professionalism**

*Prerequisite: Senior standing. (2 credits)*

Design principles for multidisciplinary team projects, team strategies, entrepreneurial skills, ethics, social and environmental awareness, and life long learning. Each student *must* take (simultaneously) Tech Comm 496 (2 cr.) and one of the approved 400-level team project courses in computing (4 cr.).

### **EECS 497. EECS Major Design Projects**

*Prerequisite: Senior standing, EECS 281, EECS 370, Tech Comm 300, and at least four credit hours of Upper Level Electives in either Computer Science or Computer Engineering. (4 credits)*

Professional problem-solving methods developed through intensive group studies. Normally one significant design project is chosen for entire class requiring multiple EECS disciplines and teams. Use of analytic, computer, design, and experimental techniques where applicable are used. Projects are often interdisciplinary allowing non-EECS seniors to also take the course (consult with instructor).

### **EECS 498. Special Topics**

*Prerequisite: Permission of instructor. (1-4 credits)*

Topics of current interest selected by the faculty. Lecture, seminar or laboratory.

### **EECS 499. Directed Study**

*Prerequisite: Senior standing in EECS. (1-4 credits)*

Provides an opportunity for undergraduate students to work in on substantial research problems in EECS or areas of special interest such as design problems. For each hour of credit, it is expected that the student will work an average of three or four hours per week and that the challenges will be comparable with other 400 level EECS classes. Oral presentation and/or written report due at end of term. Not open to graduate students.

### **EECS 500. Tutorial Lecture Series in System Science**

*Prerequisite: Graduate standing; mandatory satisfactory/unsatisfactory. (1 credit)*

Students are introduced to the frontiers of System Science research. Sections 01, 02 and 03 are devoted, re-

spectively, to Communications, Control, and Signal Processing. The tutorials are delivered by leaders of the respective research fields, invited from academia and industry. The presentations are self-contained and accessible to all graduate students in System Science.

### **EECS 501. Probability and Random Processes**

*Prerequisite: EECS 301 or graduate standing. (4 credits)*

Introduction to probability and random processes. Topics include probability axioms, sigma algebras, random vectors, expectation, probability distributions and densities, Poisson and Wiener processes, stationary processes, autocorrelation, spectral density, effects of filtering, linear least-squares estimation and convergence of random sequences.

### **EECS 502. Stochastic Processes**

*Prerequisite: EECS 501. (3 credits)*

Correlations and spectra. Quadratic mean calculus, including stochastic integrals and representations, wide-sense stationary processes (filtering, white noise, sampling, time averages, moving averages, autoregression). Renewal and regenerative processes, Markov chains, random walk and run, branching processes, Markov jump processes, uniformization, reversibility and queuing applications.

### **EECS 503. Introduction to Numerical Electromagnetics**

*Prerequisite: EECS 330. (3 credits)*

Introduction to numerical methods in electromagnetics including finite difference, finite element and integral equation methods for static, harmonic and time dependent fields; use of commercial software for analysis and design purposes; applications to open and shielded transmission lines, antennas, cavity resonances and scattering.

### **EECS 504. Foundations of Computer Vision**

*Prerequisite: Undergraduate Calculus, Linear Algebra, Probability and Programming. (3 credits)*

The course lays a framework for the extraction of useful information from images. Topics include representations of visual content (e.g., functions, points, graphs); visual invariance; mathematical and computational models of visual content; optimization methods

for vision. Theoretical treatment and concrete examples, e.g., feature learning, segmentation image stitching, both covered.

### **EECS 509. BioMEMS**

*Prerequisite: None. (3 credits)*

This course will cover the latest advances in bioMEMS, with specific attention to Microsystems targeting development biology and cell culture. We will use an organism's development --from genome to multicellular tissue-- as a framework for teaching bioMEMS devices: from microPCR chips to microfluidic mixers to tissue scaffolds. The aim is to provide students familiar with microfabrication and Microsystems with a context from which to view and evaluate bioMEMS devices and innovations. We will cover implantable and diagnostic microsystems in the later part of the course.

### **EECS 510. RF MEMS**

*Prerequisite: EECS 414. (4 credits)*

This course cover the principles of operation, design, fabrication and technology trends of micro-electromechanical devices for high frequency applications with a focus on communications. Micro-devices covered include resonators, switches, filters, tunable passive devices and reconfigurable modules. The physical phenomena limiting the performance and scaling of RF MEMS devices are discussed.

### **EECS 511. Integrated Analog/Digital Interface Circuits**

*Prerequisite: EECS 413 or permission of instructor. (4 credits)*

This course covers most of the well known analog to digital conversion schemes. These include the flash, folding, multi-step and pipeline Nyquist rate, architectures. Oversampling converters are also discussed. Practical design work is a significant part of this course. Students design and model complete converters.

### **EECS 512. Amorphous and Microcrystalline Semiconductor Thin Film Devices**

*Prerequisite: EECS 421 and/or permission of instructor. (3 credits)*

Introduction and fundamentals of physical, optical and

electrical properties of amorphous and microcrystalline semiconductor based devices: MIM structures, Schottky diodes, p-i-n junctions, heterojunctions, MIS structures, thin-film transistors, solar cells, threshold and memory switching devices and large area x-ray radiation detectors.

### **EECS 513. Flat Panel Displays**

*Prerequisite: EECS 423, EECS 512 and/or permission of instructor. (3 credits)*

Introduction and fundamentals to the passive, active, reflective and emissive flat panel display technologies. This course will discuss the physics, operating principles, properties and technology of the flat panel displays.

### **EECS 514. Advanced MEMS Devices and Technologies**

*Prerequisite: EECS 414. (4 credits)*

Advanced micro electro mechanical systems (MEMS) devices and technologies. Transduction techniques, including piezoelectric, electrothermal, and resonant techniques. Chemical, gas, and biological sensors, microfluidic and biomedical devices. Micromachining technologies such as laser machining and microdrilling, EDM, materials such as SiC and diamond. Sensor and actuator analysis and design through CAD.

### **EECS 515. Integrated Microsystems**

*Prerequisite: EECS 414. (4 credits)*

Review of interface electronics for sense and drive and their influence on device performance, interface standards, MEMS and circuit noise sources, packaging and assembly techniques, testing and calibration approaches and communication in integrated microsystems. Applications, including RF MEMS, optical MEMS, bioMEMS, and microfluidics. Design project using CAD and report preparation.

### **EECS 516 (BIOMEDE 516). Medical Imaging Systems**

*Prerequisite: EECS 451. (3 credits)*

Principles of modern medical imaging systems. For each modality the basic physics is described, leading to a systems model of the imager. Fundamental similarities between the imaging equations of different modalities will be stressed. Modalities covered include radiog-

raphy, x-ray computed tomography (CT), NMR imaging (MRI) and real-time ultra-sound.

### **EECS 517 (NERS 578). Physical Processes in Plasmas**

*Prerequisite: EECS 330. (3 credits)*

Plasma physics applied to electrical gas discharges used for material processing. Gas kinetics; atomic collisions; transport coefficients; drift and diffusion; sheaths; Boltzmann distribution function calculation; plasma simulation; plasma diagnostics by particle probes, spectroscopy and electromagnetic waves; analysis of commonly used plasma tools for materials processing.

### **EECS 518 (AOSS 595). Magnetosphere and Solar Wind**

*Prerequisite: Graduate standing. (3 credits)*

General principles of magnetohydrodynamics; theory of the expanding atmospheres; properties of solar wind, interaction of solar wind with the magnetosphere of the Earth and other planets; bow shock and magnetotail, trapped particles, auroras.

### **EECS 519 (NERS 575). Plasma Generation and Diagnostics Laboratory**

*Prerequisite: Preceded or accompanied by a course covering electromagnetism. (4 credits)*

Laboratory techniques for plasma ionization and diagnosis relevant to plasma processing, propulsion, vacuum electronics, and fusion. Plasma generation includes: high voltage-DC, radio frequency and electron beam sustained discharges. Diagnostics include: Langmuir probes, microwave cavity perturbation, microwave interferometry, laser schlieren and optical emission spectroscopy. Plasma parameters measured are: electron/ion density and electron temperature.

### **EECS 520. Solid State Physics**

*Prerequisite: PHYS 453 or graduate standing. (4 credits)*

Crystal structure; Phonons; Introduction to Quantum Mechanics, Free electron Fermi gas; Low dimensional conductor; Electronic structure - Energy bands; Properties of semiconductors; Dielectrics response; Light absorption and emission; Magnetic effects; Superconductivity.

**EECS 521. Solid State Devices***Prerequisite: EECS 421. (3 credits)*

Physics of operation of three terminal device structures important for high frequency analog or high speed digital applications. Emphasis on proven field-effect and bipolar-junction transistors, also including current and speculative nanoelectronic devices. Detailed study of static current-voltage characteristics and models for small and large signal behavior.

**EECS 522. Analog Integrated Circuits***Prerequisite: EECS 413. (4 credits)*

Review of integrated circuit fabrication technologies and BJT and MOS transistor models. Detailed analysis and design of analog integrated circuits, including power amplifiers, voltage references, voltage regulators, rectifiers, oscillators, multipliers, mixers, phase detectors and phase-locked loops. Design projects. Lectures and discussion.

**EECS 523. Digital Integrated Technology***Prerequisite: (EECS 423 or EECS 425) and EECS 311 and EECS 320. (4 credits)*

Integrated circuit fabrication overview, relationships between processing choices and device performance characteristics. Long-channel device I-V review, short-channel MOSFET I-V characteristics including velocity saturation, mobility degradation, hot carriers, gate depletion. MOS device scaling strategies, silicon-on-insulator, lightly-doped drain structures, on-chip interconnect parasitics and performance. Major CMOS scaling challenges. Process and circuit simulation.

**EECS 525. Advanced Solid State Microwave Circuits***Prerequisite: EECS 411 and (EECS 421 or EECS 521). (3 credits)*

General properties and design of linear and nonlinear solid state microwave circuits including: amplifier gain blocks, low-noise, broadband and power amplifiers, oscillators, mixer and multiplier circuits, packaging, system implementation for wireless communication.

**EECS 527. Layout Synthesis and Optimization***Prerequisite: EECS 281 or EECS 478 or graduate standing. (3 or 4 credits)*

Theory of circuit partitioning, floorplanning and place-

ment algorithms. Techniques for routing and clock tree design. Timing analysis and cycle time optimization. Topics in low-power design. Large-scale optimization heuristics, simulated annealing and AI techniques in CAD. Modern physical design methodologies and CAD software development.

**EECS 528. Principles of Microelectronics Process Technology***Prerequisite: EECS 421 and EECS 423. (3 credits)*

Theoretical analysis of the chemistry and physics of process technologies used in micro-electronics fabrication. Topics include: semiconductor growth, material characterization, lithography tools, photo-resist models, thin film deposition, chemical etching, plasma etching, electrical contact formation, micro-structure processing and process modeling.

**EECS 529. Semiconductor Lasers and LEDs***Prerequisite: EECS 429. (3 credits)*

Optical processes in semiconductors, spontaneous emission, absorption gain, stimulated emission. Principles of light-emitting diodes, including transient effects, spectral and spatial radiation fields. Principles of semiconducting lasers; gain-current relationships, radiation fields, optical confinement and transient effects.

**EECS 530 (APPPHYS 530). Electromagnetic Theory I***Prerequisite: EECS 330 or Physics 438. (3 credits)*

Maxwell's equations, constitutive relations and boundary conditions. Potentials and the representation of electromagnetic fields. Uniqueness, duality, equivalence, reciprocity and Babinet's theorems. Plane, cylindrical, and spherical waves. Waveguides and elementary antennas. The limiting case of electro- and magneto-statics.

**EECS 531. Antenna Theory and Design***Prerequisite: EECS 330. (3 credits)*

Theory of transmitting and receiving antennas. Reciprocity. Wire antennas: dipoles, loops and traveling-wave antennas. Analysis and synthesis of linear arrays. Phased arrays. Input impedance and method of moments. Mutual impedance. Aperture antennas: slot, Babinet's principle. Microstrip antennas. Horns, reflector and lens antennas.

**EECS 532 (AOSS 587). Microwave Remote Sensing I: Radiometry**

*Prerequisite: EECS 330, graduate standing. (3 credits)*

Radiative transfer theory: blackbody radiation; microwave radiometry; atmospheric propagation and emission; radiometer receivers; surface and volume scattering and emission; applications to meteorology, oceanography and hydrology.

**EECS 533. Microwave Measurements Laboratory**

*Prerequisite: EECS 330, Graduate Standing. (3 credits)*

Advanced topics in microwave measurements: power spectrum and noise measurement, introduction to state-of-the-art microwave test equipment, methods for measuring the dielectric constant of materials, polarimetric radar cross section measurements, near field antenna pattern measurements, electromagnetic emission measurement (EM compatibility). Followed by a project that will include design, analysis, and construction of a microwave subsystem.

**EECS 534. Design and Characterization of Microwave Devices and Monolithic Circuits**

*Prerequisite: Graduate standing EECS 421 or EECS 525. (4 credits)*

Theory and design of passive and active microwave components and monolithic integrated circuits including: microstrip, lumped inductors and capacitors, GaAs FETs, varactor and mixer diodes, monolithic phase shifters, attenuators, amplifiers and oscillators. Experimental characterization of the above components using network analyzer, spectrum analyzer, power and noise meters. Lecture and laboratory.

**EECS 535. Optical Information Processing**

*Prerequisite: EECS 334. (3 credits)*

Theory of image formation with holography; applications of holography; white light interferometry; techniques for optical digital computing; special topics of current research interest.

**EECS 536. Classical Statistical Optics**

*Prerequisite: EECS 334 or EECS 434, and EECS 301 or MATH 425. (3 credits)*

Applications of random variables to optics; statistical properties of light waves. Coherence theory, spatial and

temporal. Information retrieval; imaging through inhomogeneous media; noise processes in imaging and interferometric systems.

**EECS 537 (APPPHYS 537). Classical Optics**

*Prerequisite: EECS 330 and EECS 334. (3 credits)*

Theory of electromagnetic, physical, and geometrical optics. Classical theory of dispersion. Linear response, Kramers-Kronig relations, and pulse propagation. Light scattering. Geometrical optics and propagation in inhomogeneous media. Dielectric waveguides. Interferometry and theory of coherence. Diffraction, Fresnel and Fraunhofer. Gaussian beams and ABCD law.

**EECS 538 (APPPHYS 550) (PHYSICS 650). Optical Waves in Crystals**

*Prerequisite: EECS 434. (3 credits)*

Propagation of laser beams: Gaussian wave optics and the ABCD law. Manipulation of light by electrical, acoustical waves; crystal properties and the dielectric tensor; electro-optic, acousto-optic effects and devices. Introduction to nonlinear optics; harmonic generation, optical rectification, four-wave mixing, self-focusing and self-phase modulation.

**EECS 539 (APPPHYS 551) (PHYSICS 651). Lasers**

*Prerequisite: EECS 537 and EECS 538. (3 credits)*

Complete study of laser operation: the atom-field interaction; homogeneous and inhomogeneous broadening mechanisms; atomic rate equations; gain and saturation; laser oscillation; laser resonators, modes, and cavity equations; cavity modes; laser dynamics, Q-switching and modelocking. Special topics such as femto-seconds lasers and ultrahigh power lasers.

**EECS 540 (APPPHYS 540). Applied Quantum Mechanics I**

*Prerequisite: Permission of instructor. (3 credits)*

Introduction to nonrelativistic quantum mechanics. Summary of classical mechanics, postulates of quantum mechanics and operator formalism, stationary state problems (including quantum wells, harmonic oscillator, angular momentum theory and spin, atoms and molecules, band theory in solids), time evolution, approximation methods for time independent and time dependent interactions including electromagnetic interactions, scattering.

**EECS 541 (APPPHYS 541). Applied Quantum Mechanics II**

*Prerequisite: EECS 540. (3 credits)*

Continuation of nonrelativistic quantum mechanics. Advanced angular momentum theory, second quantization, non-relativistic quantum electrodynamics, advanced scattering theory, density matrix formalism, reservoir theory.

**EECS 542. Advanced Topics in Computer Vision**

*Prerequisite: EECS 442 or permission of instructor. (3 credits)*

The course discusses advanced topics and current research in computer vision. Topics will be selected from various subareas such as physics based vision, geometry, motion and tracking, reconstruction, grouping and segmentation, recognition, activity and scene understanding, statistical methods and learning, systems and applications.

**EECS 543. Knowledge-Based Systems**

*Prerequisite: EECS 281 and graduate standing or permission of instructor. (3 credits)*

Techniques and principles for developing application software based on explicit representation and manipulation of domain knowledge, as applied to areas such as pattern matching, problem-solving, automated planning and natural-language processing. Discussion of major programming approaches used in the design and development of knowledge-based systems.

**EECS 545. Machine Learning**

*Prerequisite: EECS 492. (3 credits)*

Survey of recent research on learning in artificial intelligence systems. Topics include learning based on examples, instructions, analogy, discovery, experimentation, observation, problem-solving and explanation. The cognitive aspects of learning will also be studied.

**EECS 546 (APPPHYS 546). Ultrafast Optics**

*Prerequisite: EECS 537. (3 credits)*

Propagation of ultrashort optical pulses in linear and nonlinear media, and through dispersive optical elements. Laser mode-locking and ultrashort pulse generation. Chirped-pulse amplification. Experimental techniques for high time resolution. Ultrafast Optoelectronics. Survey of ultrafast high field interactions.

**EECS 547 (SI 652). Electronic Commerce**

*Prerequisites: EECS 281 or SI 502 or permission of instructor. (3 credits)*

Introduction to the design and analysis of automated commerce systems, from both a technological and social perspective. Infrastructure supporting search for commerce opportunities, negotiating terms of trade and executing transactions. Issues of security, privacy, incentives and strategy.

**EECS 548 (SI 649). Information Visualization**

*Advised Prerequisites: EECS 493 or equivalent or Graduate standing. (3 credits)*

Introduction to information visualization. Topics include data and image models, multidimensional and multivariate data, design principles for visualization, hierarchical, network, textual and collaborative visualization, the visualization pipeline, data processing for visualization, visual representations, visualization system interaction design, and impact of perception. Emphasizes construction of systems using graphics application programming interfaces (APIs) and analysis tools.

**EECS 549 (SI 650). Information Retrieval**

*Advised Prerequisites: EECS 502 or equivalent. (3 credits)*

Information retrieval studies the interaction between users and large information environments. An in-depth survey of the field from classic concepts to state-of-the-art applications such as crawlers and spiders. Topics include information need, documents and queries, indexing and searching, retrieval evaluation, multimedia and hypertext search, Web search, and bibliographical databases.

**EECS 550. Information Theory**

*Prerequisite: EECS 501. (3 credits)*

Measures of information, such as entropy, conditional entropy, mutual and directed information and Kullback-Leibler divergence; fundamental limits to the performance of communication systems, including source coding (data compression) and channel coding (reliable transmission through noisy media); elementary source and channel coding techniques; information theoretic bounds on the performance of estimation/decision systems.

### **EECS 551. Matrix Methods for Signal Processing, Data Analysis and Machine Learning**

*Prerequisite: EECS 451 or graduate Standing. Credit cannot be received for both EECS 453 and 551. (4 credits)*

Theory and application of matrix methods to signal processing, data analysis and machine learning. Theoretical topics include subspaces, eigenvalue and singular value decomposition, projection theorem, constrained, regularized and unconstrained least squares techniques and iterative algorithms. Applications such as image deblurring, ranking of webpages, image segmentation and compression, social networks, circuit analysis, recommender systems and handwritten digit recognition. Applications and theory are covered in greater depth than in EECS 453.

### **EECS 552 (APPPHYS 552). Fiber Optics: Internet to Biomedical Applications**

*Prerequisite: Any one of EECS 334, EECS 429, EECS 434, EECS 529, EECS 537, EECS 538, EECS 539 or permission of instructor. (3 credits)*

This course covers the basics of fibers and applications in fields as diverse as highpower and broadband lasers, bio-medical diagnostics and therapeutics, telecommunications and internet communications. Propagation, optical amplification and nonlinearities in fibers are discussed, and examples include transmission systems and lasers. Biomedical applications include dermatology, cardiology and ophthalmology.

### **EECS 553. Theory and Practice of Data Compression**

*Prerequisite: EECS 501. (3 credits)*

Introduction to lossy and lossless source coding for data compression. Techniques: scalar and vector quantization; transform and differential coding; variable-length, Lempel-Ziv and arithmetic lossless coding. Theory: entropy for lossless coding; high-resolution theory for lossy coding. Particular attention to compression of images (JPEG), video (MPEG), speech (CELP) and audio (MP3). (A project is assigned.)

### **EECS 554. Introduction to Digital Communication and Coding**

*Prerequisite: EECS 216 and EECS 301. (3 credits)*

Digital transmission of information across discrete and

analog channels. Sampling; quantization; noiseless source codes for data compression: Huffman's algorithm and entropy; block and convolutional channel codes for error correction; channel capacity; digital modulation methods: PSK, MSK, FSK, QAM; matched filter receivers. Performance analysis: power, bandwidth, data rate and error probability.

### **EECS 555. Digital Communication Theory**

*Prerequisite: EECS 501, EECS 554. (3 credits)*

Theory of digital modulation and coding. Optimum receivers in Gaussian noise. Signal space and decision theory. Signal design. Bandwidth and dimensionality. Fundamental limits in coding and modulation. Capacity and cutoff rate. Block, convolutional and trellis coding. Continuous phase modulation. Filtered channels and intersymbol interference. Equalization. Spread-spectrum. Fading channels. Current topics.

### **EECS 556. Image Processing**

*Prerequisite: EECS 501, (EECS 453 or EECS 551). (3 credits)*

Theory and application of digital image processing. Sampling, filtering, 2D Fourier transforms, interpolation, edge detection, enhancement, denoising, restoration, segmentation, random field models of images, Bayesian methods, wavelets and sparsity models. Applications include optical imaging, biomedical images, video and image compression. Student projects based on recent image processing literature.

### **EECS 557. Communication Networks**

*Prerequisite: Graduate standing, preceded by EECS 301 or accompanied by EECS 501. (3 credits)*

System architectures. Data link control: error correction, protocol analysis, framing. Message delay: Markov processes, queuing, delays in statistical multiplexing, multiple users with reservations, limited service, priorities. Network delay: Kleinrock independence, reversibility, traffic flows, throughput analysis, Jackson networks. Multiple access networks: ALOHA and splitting protocols, carrier sensing, multi-access reservations.

### **EECS 558. Stochastic Control**

*Prerequisite: EECS 501, EECS 560. (3 credits)*

Analysis and optimization of controlled stochastic sys-

tems. Models: linear and nonlinear stochastic controlled systems, controlled Markov chains. Optimization of systems described by Markov processes; dynamic programming under perfect and imperfect information, finite and infinite horizons. System identification: off-line, recursive. Stochastic adaptive control: Markov chains, self-tuning regulators, bandit problems.

### **EECS 559. Advanced Signal Processing**

*Prerequisite: EECS 551 and EECS 501. (3 credits)*

Estimators of second order properties of random processes: nonparametric and model-based techniques of spectral estimation, characterization of output statistics for nonlinear systems, time-frequency representations. Performance evaluation using asymptotic techniques and Monte Carlo simulation. Applications include speech processing, signal extrapolation, multidimensional spectral estimation, and beamforming.

### **EECS 560 (AEROSP 550) (CEE 571) (MECHENG 564). Linear Systems Theory**

*Prerequisite: Graduate standing. (4 credits)*

Linear spaces and linear operators. Bases, subspaces, eigenvalues and eigenvectors, canonical forms. Linear differential and difference equations. Mathematical representations: state equations, transfer functions, impulse response, matrix fraction and polynomial descriptions. System-theoretic concepts: causality, controllability, observability, realizations, canonical decomposition, stability.

### **EECS 561 (MECHENG 561). Design of Digital Control Systems**

*Prerequisite: EECS 460 or MECHENG 461. (3 credits)*

Sampling and data reconstruction. Z-transforms and state variable descriptions of discrete-time systems. Modeling and identification. Analysis and design using root locus, frequency response and state space techniques. Linear quadratic optimal control and state estimation. Quantization and other nonlinearities.

### **EECS 562 (AEROSP 551). Nonlinear Systems and Control**

*Prerequisite: Graduate standing. (3 credits)*

Introduction to the analysis and design of nonlinear systems and nonlinear control systems. Stability analy-

sis using Liapunov, input-output and asymptotic methods. Design of stabilizing controllers using a variety of methods: linearization, absolute stability theory, vibrational control, sliding modes and feedback linearization.

### **EECS 564. Estimation, Filtering, and Detection**

*Prerequisite: EECS 501. (3 credits)*

Principles of estimation, linear filtering and detection. Estimation: linear and nonlinear minimum mean squared error estimation, and other strategies. Linear filtering: Wiener and Kalman filtering. Detection: simple, composite, binary and multiple hypotheses. Neyman-Pearson and Bayesian approaches.

### **EECS 565 (AEROSP 580). Linear Feedback Control Systems**

*Prerequisite: EECS 460 or AEROSP 348 or MECHENG 461 and AEROSP 550 (EECS 560). (3 credits)*

Control design concepts for linear multivariable systems. Review of single variable systems and extensions to multivariable systems. Purpose of feedback. Sensitivity, robustness, and design tradeoffs. Design formulations using both frequency domain and state space descriptions. Pole placement/observer design. Linear quadratic Gaussian based design methods. Design problems unique to multivariable systems.

### **EECS 566. Discrete Event Systems**

*Prerequisite: Graduate standing (3 credits)*

Modeling, analysis, and control of discrete event dynamical systems. Modeling formalisms considered include state machines, Petri nets, and recursive processes. Supervisory control theory; notions of controllable and observable languages. Analysis and control of Petri nets. Communicating sequential processes. Applications to database, management, manufacturing, and communication protocols.

### **EECS 567 (MFG 567) (MECHENG 567). Robot Kinematics and Dynamics**

*Prerequisite: Graduate standing or permission of instructor (3 credits)*

Geometry, kinematics, differential kinematics, dynamics, and control of robot manipulators. The mathematical tools required to describe spatial motion of a rigid

body will be presented in full. Motion planning including obstacle avoidance is also covered.

**EECS 568 (NAVARCH 568). Mobile Robotics: Methods and Algorithms**

*Prerequisite: Graduate Standing or permission of instructor. (4 credits)*

Theory and applications of probabilistic techniques for autonomous mobile robotics. This course will present and critically examine contemporary algorithms for robot perception (using a variety of modalities), state estimation, mapping, and path planning. Topics include Bayesian filtering; stochastic representations of the environment; motion and sensor models for mobile robots; algorithms for mapping, localization, planning and control in the presence of uncertainty; application to autonomous marine, ground and air vehicles.

**EECS 569. Production Systems Engineering**

*Prerequisite: None. (3 credits)*

Production systems in large volume manufacturing (e.g., automotive, semiconductor, computer, etc.) are studied. Topics include quantitative methods for analysis of production systems; analytical methods for design of lean in-process and finished goods buffering; measurement-based methods for identification and elimination of production system bottlenecks; and system-theoretic properties of production lines.

**EECS 570. Parallel Computer Architecture**

*Prerequisite: EECS 470. (4 credits)*

Architectures for explicit parallelism. Multithreaded processors, small- and large-scale multiprocessor systems. Shared-memory coherence and consistency. Effect of architecture on communication latency, bandwidth, and overhead. Latency tolerance techniques. Interconnection networks. Case studies. Term projects.

**EECS 571. Principles of Real-Time Computing**

*Prerequisite: EECS 470, EECS 482 or permission of instructor. (4 credits)*

Principles of real-time computing based on high performance, ultra reliability and environmental interface. Architectures, algorithms, operating systems and applications that deal with time as the most important resource. Real-time scheduling, communications and performance evaluation.

**EECS 573. Microarchitecture**

*Prerequisite: EECS 470 or permission of instructor. (3 credits)*

Graduate-level introduction to the foundations of high performance microprocessor implementation. Problems involving instruction supply, data supply and instruction processing. Compile-time vs. run-time tradeoffs. Aggressive branch prediction. Wide-issue processors, in-order vs. out-of-order execution, instruction retirement. Case studies taken from current microprocessors.

**EECS 574. Computational Complexity**

*Prerequisite: EECS 376 or graduate standing. (4 credits)*

Fundamentals of the theory of computation and complexity theory. Computability, undecidability, and logic. Relations between complexity classes, NP-completeness, P-completeness, and randomized computation. Applications in selected areas such as cryptography, logic programming, theorem proving, approximation of optimization problems, or parallel computing.

**EECS 575. Advanced Cryptography**

*Prerequisite: EECS 203 or equivalent (EECS 574 recommended). (4 credits)*

A rigorous introduction to the design of cryptosystems and to cryptanalysis. Topics include cryptanalysis of classical cryptosystems; theoretical analysis of one-way functions; DES and differential cryptanalysis; the RSA cryptosystem; ElGamal, elliptic, hyperelliptic and hidden monomial cryptosystems; attacks on signature schemes, identification schemes and authentication codes; secret sharing; and zero knowledge.

**EECS 578. Correct Operation for Processors and Embedded Systems**

*Prerequisite: EECS 470 or graduate standing or permission of instructor. Minimum grade required for course enforced prerequisite is C. (4 credits)*

Graduate-level introduction to topics in correctness of modern processors, embedded systems, and accelerator designs (e.g., GPUs). Robust and reliable design techniques. Hardware security assurance. Design verification: simulation, formal techniques, and post-silicon validation. Quality of services and energy management for correctness of implementation. Term projects.

**EECS 579. Digital System Testing**

*Prerequisite: Graduate standing. (4 credits)*

Overview of fault-tolerant computing. Fault sources and models. Testing process. Combinational circuit testing. D-Algorithm and PODEM. Sequential circuit testing. Checking experiments. RAM and microprocessor testing. Fault simulation. Design for testability. Testability measures. Self-testing circuits and systems.

**EECS 580. Advanced Computer Graphics**

*Prerequisite: EECS 487 (or equivalent) or graduate standing. (4 credits)*

Geometric modeling: spline curves and surfaces, subdivision surfaces, polygonal meshes, point-based and implicit surfaces. Real-time rendering: fixed and programmable pipeline, shadows. Acceleration algorithms: culling and level-of-detail. Collision detection. Delaunay triangulations and Voronoi diagrams. Non-photorealistic rendering. Pattern synthesis. Image-based rendering.

**EECS 581. Software Engineering Tools**

*Prerequisite: EECS 481 or equivalent programming experience. (3 credits)*

Fundamental areas of software engineering including life-cycle-paradigms, metrics and tools. Information hiding architecture, modular languages, design methodologies, incremental programming and very high level languages.

**EECS 582. Advanced Operating Systems**

*Prerequisite: EECS 482. (4 credits)*

Course discusses advanced topics and research issues in operating systems. Topics will be drawn from a variety of operating systems areas such as distributed systems and languages, networking, security and protection, real-time systems, modeling and analysis, etc.

**EECS 583. Advanced Compilers**

*Prerequisite: EECS 281 and 370 (EECS 483 is also recommended) (4 credits)*

In-depth study of compiler back-end design for high-performance architectures. Topics include control-flow and data-flow analysis, optimization, instruction scheduling, register allocation. Advanced topics include memory hierarchy management, instruction-level parallelism, predicated and speculative execution. The class

focus is processor-specific compilation techniques, thus familiarity with both computer architecture and compilers is recommended.

**EECS 584. Advanced Database Systems**

*Prerequisite: EECS 484 or permission of instructor. (4 credits)*

Advanced topics and research issues in database management systems. Distributed databases, advanced query optimization, query processing, transaction processing, data models and architectures. Data management for emerging application areas, including bioinformatics, the internet, OLAP and data mining. A substantial course project allows in-depth exploration of topics of interest.

**EECS 586. Design and Analysis of Algorithms**

*Prerequisite: EECS 281. (4 credits)*

Design of algorithms for nonnumeric problems involving sorting, searching, scheduling, graph theory and geometry. Design techniques such as approximation, branch-and-bound, divide-and-conquer, dynamic programming, greed and randomization applied to polynomial and NP-hard problems. Analysis of time and space utilization.

**EECS 587. Parallel Computing**

*Prerequisite: EECS 281 and graduate standing. (4 credits)*

The development of programs for parallel computers. Basic concepts such as speedup, load balancing, latency, system taxonomies. Design of algorithms for idealized models. Programming on parallel systems such as shared or distributed memory machines, networks. Grid Computing. Performance analysis. Course includes a substantial term project.

**EECS 588. Computer and Network Security**

*Prerequisite: EECS 482 or EECS 489 or graduate standing. (4 credits)*

Survey of advanced topics and research issues in computer and network security. Topics will be drawn from a variety of areas such as mandatory and discretionary security policies, secure storage, security kernels, trust management, preventing software vulnerabilities, applied cryptography, network security.

**EECS 589. Advanced Computer Networks***Prerequisite: EECS 489. (4 credits)*

Advanced topics and research issues in computer networks. Topics include routing protocols, multicast delivery, congestion control, quality of service support, network security, pricing and accounting and wireless access and mobile networking. Emphasis is placed on performance trade-offs in protocol and architecture designs. Readings assigned from research publications. A course project allows in-depth exploration of topics of interest.

**EECS 590. Advanced Programming Languages***Prerequisite: EECS 281 or equivalent. (4 credits)*

Fundamental concepts in Programming Languages (PL) as well as recent topics and trends in PL research. Topics include semantics, type systems, program verification using theorem provers, software model checking, and program analysis. Course focuses on applying PL concepts to improve software reliability. Course includes semester long individual research project.

**EECS 591. Distributed Systems***Prerequisite: EECS 482 and graduate standing. (4 credits)*

Principles and practice of distributed system design. Computations, consistency semantics and failure models. Programming paradigms including group communication, RPC, distributed shared memory, and distributed objects. Operating system kernel support; distributed system services including replication, caching, file system management, naming, clock synchronization and multicast communication. Case studies.

**EECS 592. Advanced Artificial Intelligence***Prerequisite: EECS 492 or permission of instructor. (4 credits)*

Advanced topics in artificial intelligence. Issues in knowledge representation, knowledge-based systems, problem solving, planning and other topics will be discussed. Students will work on several projects.

**EECS 594. Introduction to Adaptive Systems***Prerequisite: EECS 203, MATH 425 (Stat 425). (3 credits)*

Programs and automata that "learn" by adapting to their environment; programs that utilize genetic algorithms

for learning. Samuel's strategies, realistic neural networks, connectionist systems, classifier systems and related models of cognition. Artificial intelligence systems, such as NETL and SOAR, are examined for their impact upon machine learning and cognitive science.

**EECS 595 (LING 541) (SI 561). Natural Language Processing***Prerequisite: Senior standing. (3 credits)*

Linguistic fundamentals of natural language processing (NLP), part of speech tagging, hidden Markov models, syntax and parsing, lexical semantics, compositional semantics, word sense disambiguation, machine translation. Additional topics such as sentiment analysis, text generation, and deep learning for NLP.

**EECS 596. Master of Engineering Team Project***Prerequisite: Enrollment in the Masters of Engineering program in EECS. (1-6 credits)*

To be elected by EECS students pursuing the Master of Engineering degree. Students are expected to work in project teams. May be taken more than once up to a total of 6 credit hours.

**EECS 597 (SI 760) (LING 702). Language and Information***Prerequisite: SI 503 or EECS 281 and graduate standing or permission of instructor. (3 credits)*

A survey of techniques used in language studies and information processing. Students will learn how to explore and analyze textual data in the context of Web-based information retrieval systems. At the conclusion of the course, students will be able to work as information designers and analysts.

**EECS 598. Special Topics in Electrical Engineering and Computer Science***Prerequisite: Permission of instructor or counselor. (1-4 credits)*

Topics of current interest in electrical engineering and computer science. Lectures, seminar or laboratory. Can be taken more than once for credit.

**EECS 599. Directed Study***Prerequisite: Prior arrangement with instructor; mandatory satisfactory/unsatisfactory. (1-4 credits)*

Individual study of selected advanced topics in electri-

cal engineering and computer science. May include experimental work or reading. Primarily for graduate students. To be graded on satisfactory/unsatisfactory basis ONLY.

### **EECS 600 (IOE 600). Function Space Methods in System Theory**

*Prerequisite: Math 419. (3 credits)*

Introduction to the description and analysis of systems using function analytic methods. Metric spaces, normed linear spaces, Hilbert spaces, resolution spaces. Emphasis on using these concepts in systems problems.

### **EECS 620. Electronic and Optical Properties of Semiconductors**

*Prerequisite: EECS 520 or EECS 540. (4 credits)*

The course discusses in detail the theory behind important semiconductor-based experiments such as Hall effect and Hall mobility measurement; velocity-field measurement; photoluminescence; gain; pump-probe studies; pressure and strain-dependent studies. Theory will cover: Bandstructure in quantum wells; effect of strain on bandstructure; transport theory; Monte Carlo methods for high field transport; excitons, optical absorption, luminescence and gain.

### **EECS 627. VLSI Design II**

*Prerequisite: EECS 427. (4 credits)*

Advanced very large scale integrated (VLSI) circuit design. Design methodologies (architectural simulation, hardware description language design entry, silicon compilation, and verification), microarchitectures, interconnect, packaging, noise sources, circuit techniques, design for testability, design rules, VLSI technologies (silicon and GaAs) and yield. Projects in chip design.

### **EECS 628. Advanced High Performance VLSI Design**

*Prerequisite: EECS 627 or equivalent. (3-4 credits)*

Advanced issues in VLSI design addressing the areas of high performance, low power and reliability. Topics covered include recent approaches in leakage control, high speed on-chip communication, memory design, soft error failures, noise analysis and control, error tolerant design and new circuit families. (Students will complete an advanced project.) (A 4-credit option is

available with addition of a substantial design and simulation component to the project.)

### **EECS 631. Electromagnetic Scattering**

*Prerequisite: EECS 530 and graduate standing. (3 credits)*

Boundary conditions, field representations. Low and high frequency scattering. Scattering by half plane (Wiener-Hopf method) and wedge (Maliuzhinets method); edge diffraction. Scattering by a cylinder and sphere: Watson transformation, Airy and Fock functions, creeping waves. Geometrical and physical theories of diffraction.

### **EECS 632. Microwave Remote Sensing II - Radar**

*Prerequisite: EECS 532. (3 credits)*

Radar equation; noise statistics; resolution techniques; calibration; synthetic aperture radar; scatterometers; scattering models; surface and volume scattering; land and oceanographic applications.

### **EECS 633. Numerical Methods in Electromagnetics**

*Prerequisite: EECS 530. (3 credits)*

Numerical techniques for antennas and scattering; integral representation: solutions of integral equations: method of moments, Galerkin's technique, conjugate gradient FFT; finite element methods for 2-D and 3-D simulations; hybrid finite element/boundary integral methods; applications: wire, patch and planar arrays; scattering composite structures.

### **EECS 634 (APPPHYS 611) (Physics 611). Nonlinear Optics**

*Prerequisite: EECS 537 or EECS 538 or EECS 530. (3 credits)*

Formalism of wave propagation in nonlinear media; susceptibility tensor; second harmonic generation and three-wave mixing; phase matching; third order nonlinearities and four-wave mixing processes; stimulated Raman and Brillouin scattering. Special topics: nonlinear optics in fibers, including solitons and self-phase modulation.

### **EECS 638 (APPPHYS 609) (PHYSICS 542). Quantum Theory of Light**

*Prerequisite: Quantum mechanics, electrodynamics, atomic physics. (3 credits)*

The atom-field interaction; density matrix; quantum theory of radiation including spontaneous emission; optical Bloch equations and theory of resonance fluorescence; coherent pulse propagation; dressed atoms and squeezed states; special topics in nonlinear optics.

**EECS 643 (PSYCH 643). Theory of Neural Computation**

*Prerequisite: Graduate standing or permission of instructor. (2-4 credits)*

This is a graduate course introducing computational models of information processing in mammalian central nervous system. Following a brief overview, the course will examine: (1) Biological principles governing brain computation (e.g., population coding, computation maps, adaptive plasticity, self-organization and modularization, etc.); (2) Mechanisms underlying single neuron computation, via either passive membrane properties (equivalent cylinder model and cable equation for dendrites; integrate-and-fire or Lapique model) or active membrane properties (Hodgkins-Huxley dynamics; F-N reduced system and phase-space analysis); (3) Architectures of artificial neural network (connectionism), including models of simple perception, multi-layered feed-forward network (with supervised, back-propagated error correction learning rule), associative network (Hopfield network and Boltman machine with unsupervised, Hebbian learning rule), and reinforcement (partially supervised) learning algorithms.

**EECS 644 (PSYCH 644). Computational Modeling of Cognition**

*Prerequisite: Graduate standing or permission of instructor. (2-4 credits)*

This course will examine computational models of human cognitive processes. Course goals include learning about important computational models of specific cognitive domains and evaluating the appropriateness and utility of different computational approaches to substantive problems in cognition.

**EECS 650. Channel Coding Theory**

*Prerequisite: EECS 501 and MATH 419. (3 credits)*

The theory of channel coding for reliable communication and computer memories. Error correcting codes; linear, cyclic and convolutional codes; encoding and

decoding algorithms; performance evaluation of codes on a variety of channels.

**EECS 659. Adaptive Signal Processing**

*Prerequisite: EECS 564. (3 credits)*

Theory and applications of adaptive filtering in systems and signal processing. Iterative methods of optimization and their convergence properties: transversal filters; LMS (gradient) algorithms. Adaptive Kalman filtering and least-squares algorithms. Specialized structures for implementation: e.g., least-squares lattice filters, systolic arrays. Applications to detection, noise canceling, speech processing and beam forming.

**EECS 662 (MECHENG 662). Advanced Nonlinear Control**

*Prerequisite: EECS 562 or MECHENG 548. (3 credits)*

Geometric and algebraic approaches to the analysis and design of nonlinear control systems. Nonlinear controllability and observability, feedback stabilization and linearization, asymptotic observers, tracking problems, trajectory generation, zero dynamics and inverse systems, singular perturbations and vibrational control.

**EECS 670. Special Topics in Computer Architecture**

*Prerequisite: Permission of instructor. (3 credits)*

Current topics of interest in computer architecture. This course may be repeated for credit.

**EECS 674. Special Topics in Theoretical Computer Science**

*Prerequisite: Permission of instructor. (3 credits)*

Current topics of interest in theoretical computer science. This course may be repeated for credit.

**EECS 682. Special Topics in Software Systems**

*Prerequisite: Permission of instructor. (3 credits)*

Current topics of interest in software systems. This course may be repeated for credit.

**EECS 684. Current Topics in Databases**

*Prerequisite: EECS 484. (3 credits)*

Research issues in database systems chosen for in-depth study. Selected topics such as spatial, temporal, or real-time databases; data mining, data warehousing

or other emerging applications. Readings from recent research papers. Group projects.

### **EECS 691. Mobile Computing**

*Prerequisite: EECS 582 or EECS 589 or EECS 591 or equivalent. (3 credits)*

In-depth study of research issues in mobile and pervasive computing systems. Topics include location and context awareness, mobile data access, resource management, consistency protocols, mobile and ad hoc networking, networked sensors, security and privacy.

### **EECS 692. Special Topics in Artificial Intelligence**

*Prerequisites: Permission of instructor. (3 credits)*

Research issues in artificial intelligence chosen for in-depth study. Selected topics such as computational decision-making, knowledge representation, planning, design, multi-agent systems, cognitive architectures, AI in the arts, and rationally. Readings from recent research papers.

### **EECS 695 (PSYCH 740). Neural Models and Psychological Processes**

*Prerequisite: Permission of instructor. (3 credits)*

Consideration of adaptively and biologically oriented theories of human behavior. Emphasis on both the potential breadth of application and intuitive reasonableness of various models. There is a bias toward large theories and small simulations.

### **EECS 698. Master's Thesis**

*Prerequisite: Election of an EECS master's thesis option. (1-6 credits)*

To be elected by EE and EES students pursuing the master's thesis option. May be taken more than once up to a total of 6 credit hours. To be graded on a satisfactory/unsatisfactory basis ONLY.

### **EECS 699. Research Work in Electrical Engineering and Computer Science**

*Prerequisite: Graduate standing, permission of instructor; mandatory satisfactory/unsatisfactory. (1-6 credits)*

Students working under the supervision of a faculty member plan and execute a research project. A formal report must be submitted. May be taken for credit more than once up to a total of 6 credit hours. To be graded

satisfactory/ unsatisfactory ONLY.

### **EECS 700. Special Topics in System Theory**

*Prerequisite: Permission of instructor (to be arranged)*

### **EECS 720. Special Topics in Solid-State Devices, Integrated Circuits, and Physical Electronics**

*Prerequisite: Permission of instructor. (1-4 credits)*

Special topics of current interest in solid-state devices, integrated circuits, microwave devices, quantum devices, noise, plasmas. This course may be taken for credit more than once.

### **EECS 730. Special Topics in Electromagnetics**

*Prerequisite: Permission of instructor. (1-4 credits) (to be arranged)*

### **EECS 735. Special Topics in the Optical Sciences**

*Prerequisite: Graduate standing, permission of instructor (to be arranged) (1-4 credits)*

Key topics of current research interest in ultrafast phenomena, short wavelength lasers, atomic traps, integrated optics, nonlinear optics and spectroscopy. This course may be taken for credit more than once under different instructors.

### **EECS 750. Special Topics in Communication and Information Theory**

*Prerequisite: Permission of instructor. (to be arranged)*

### **EECS 755. Special Topics in Signal Processing**

*Prerequisite: Permission of instructor. (to be arranged) (1-4 credits)*

Advanced topics in Signal and/or image processing. The specific topics vary with each offering. This course may be taken for credit more than once.

### **EECS 760. Special Topics in Control Theory**

*Prerequisite: permission of instructor. (to be arranged)*

### **EECS 765. Special Topics in Stochastic Systems and Control**

*Prerequisite: Permission of instructor. (to be arranged) (3 credits)*

Advanced topics on stochastic systems such as stochastic calculus, nonlinear filtering, stochastic adaptive control, decentralized control and queuing networks.

**EECS 767 (SI 767). Advanced Natural Language Processing and Information Retrieval**

*Prerequisite: SI 661, SI 761, or SI 760 or permission of instructor. (3 credits)*

This course covers recent research in the areas of Computational Linguistics, Natural Language Processing and Information Retrieval. Given that a relevant textbook doesn't exist, the course reading list will include a large number of recent papers.

**EECS 770. Special Topics in Computer Systems**

*Prerequisite: Permission of instructor. (to be arranged)*

**EECS 792. Advanced AI Techniques**

*Prerequisite: EECS 492. (3 credits)*

Formulating and solving problems using artificial intelligence techniques. Projects employ advanced methods from knowledge representation, search, machine learning and other AI areas. This is a component of the Intelligent Systems qualification process.

**EECS 820. Seminar in Solid-State Electronics**

*Prerequisite: Graduate standing, permission of instructor. (1 credit)*

Advanced graduate seminar devoted to discussing current research topics in areas of solid-state electronics. Specific topics vary each time the course is offered. Course may be elected more than once.

**EECS 892. Seminar in Artificial Intelligence**

*Prerequisite: EECS 592 or equivalent. (2 credits)*

Advanced graduate seminar devoted to discussing current research papers in artificial intelligence. The specific topics vary each time the course is offered.

**EECS 990. Dissertation/Pre-Candidate**

*(2-8 credits); (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**EECS 995. Dissertation/Candidate**

*Prerequisite: Graduate School authorization for admission as a doctoral candidate. (8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Industrial and Operations Engineering

## Overview

Industrial and Operations Engineering is concerned with integrated systems of people, machines, environments and information. Drawing upon their specialized skills in mathematical, physical and social sciences (together with principles and methods of engineering analysis), industrial and operations engineers specify, predict and evaluate systems. Applications arise in industrial and manufacturing systems as well as a variety of nonindustrial settings, ranging from health care and education to financial and governmental organizations.

The wide range of tasks an industrial engineer is called upon to perform requires knowledge of operations research, ergonomics, management engineering, statistics, manufacturing engineering and computer information processing.

## Department Administration

### Department Chair

Mark Daskin

1877A Industrial and Operations Engineering Building

## Contacts

Industrial and Operations Engineering Department

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Ann Arbor, Michigan 48109-2117

**Departmental Website:**

<http://www.engin.umich.edu/ioe/>

## Mission

The Industrial and Operations Engineering Department aims to be an international leader in developing and teaching theory and methods for the design, analysis, implementation and improvement of integrated systems of people, materials, information, facilities and

technology.

## Goals

In addition, the IOE Program also has the following goals:

- To recruit, educate and support excellent, diverse students and prepare them to be leaders in the practice and further development of industrial and operations engineering.
- To have one of the leading undergraduate programs in the world in industrial and operations engineering.
- To engender the skills and desire to continually learn and grow through a lifelong professional career.

## Objectives

- Launch a successful career by effectively practicing industrial and operations engineering or be successful in advanced graduate study in engineering, scientific, business or related disciplines; practicing something other than IOE
- Assume leadership roles in their first job or graduate program;
- Contribute to the social and economic environments of their communities; and
- Have the breadth of knowledge and motivation to continue to develop their career skills through ongoing learning.

## Outcomes

1. an ability to apply knowledge of mathematics, science and engineering;
2. an ability to design and conduct experiments, as well as analyze and interpret data;
3. an ability to design and improve integrated systems of people, materials, information, facilities and technology;
4. an ability to function as a member of a multidisciplinary team;
5. an ability to identify, formulate and solve industrial

- and operations engineering problems;
6. an understanding of professional and ethical responsibility;
7. an ability to communicate effectively;
8. the broad education necessary to understand the impact of engineering solutions in a global and societal context;
9. a recognition of the need for, and an ability to engage in, life-long learning;
10. a knowledge of contemporary issues;
11. an ability to use updated techniques, skills and tools of industrial and operations engineering throughout their professional careers.

engineering disciplines, or in medicine, law or business.

## Undergraduate

<http://www.engin.umich.edu/ioe/academics/undergrad>

### Degree Program

The program in Industrial and Operations Engineering at the University of Michigan is designed to prepare students for challenges in the areas described above or for continuing their academic work to acquire an M.S.E. or Ph.D. degree. Approximately 40 percent of the courses required for the B.S.E. in I.O.E. degree are common College of Engineering core requirements, in mathematics, basic physical sciences, digital computing, humanities and social sciences, along with a broad base in engineering fundamentals. Fundamental topics in industrial engineering are provided by the nine (9) 200- and 300-level IOE courses. A solid technical foundation is obtained through 12 credits of departmental IOE electives. In addition, students gain valuable experience applying their knowledge in a senior-level design course.

The opportunity for students to tailor their studies in pursuit of individual interests is provided by an additional six (6) credits of technical electives and nine (9) credits of general electives. The goal of the technical electives is to provide a background in areas related to industrial and operations engineering. This allows students to deepen their knowledge in specific areas of industrial and operations engineering and provides an opportunity to prepare for advanced studies in other

## Sample Schedule

### B.S.E. in Industrial and Operations Engineering

The Industrial and Operations Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <http://www.engin.umich.edu/ioe/academics/undergrad>.

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects required by all programs (55 hours)</b>									
Mathematics 115, 116, 215, and 214	16	4	4	4	4	-	-	-	-
Engr 100, Intro to Engr	4	4	-	-	-	-	-	-	-
Engr 101, Intro to Computers	4	-	4	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	4	-	-	4	-	-
<b>Related Engineering Subjects (11-12 hours)</b>									
Non-IOE Engineering Courses (11-12 hours) <sup>3</sup>	12	-	-	-	4	4	-	-	4
<b>Required Program Subjects (34-35 hours**)</b>									
IOE 201, Industrial, Operations Modeling	2	-	-	2	-	-	-	-	-
IOE 202, Operations Modeling	2	-	-	2	-	-	-	-	-
IOE 265, Engr Probability and Statistics	3	-	-	-	3	-	-	-	-
IOE 310, Intro to Optim Methods	4	-	-	-	-	4	-	-	-
IOE 333, Ergonomics	3	-	-	-	3	-	-	-	-
IOE 334, Ergonomics Lab	1	-	-	-	1	-	-	-	-
IOE 316, Intro to Markov Processes	2-3**	-	-	-	-	3	-	-	-
IOE 366, Linear Statistical Models	3	-	-	-	-	3	-	-	-
IOE 373, Data Processing	4	-	-	-	-	-	4	-	-
IOE 474, Simulation	4	-	-	-	-	-	-	4	-
IOE Senior Design Course IOE 424, 481, 499 <sup>4</sup>	4	-	-	-	-	-	-	-	4
TC 380, Technical Communication in IOE	2	-	-	-	-	-	2	-	-
<b>Technical Electives (17-18 hours**)<sup>5</sup></b>	<b>17-18**</b>	-	-	-	-	3	6	6	3
<b>General Electives (9-12 hours)</b>	<b>9-12</b>	-	-	-	-	-	-	6	3
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>17</b>	<b>15</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>14</b>

Candidates for the Bachelor of Science in Engineering in Industrial and Operations Engineering - B.S.E. in I.O.E. - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

#### Notes:

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for CoE.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for CoE.

<sup>3</sup> Non-IOE Engineering Courses - Select 12 hours; 4 hours from any three different groups:

MECHENG 211 or CEE 211 or MECHENG 240

MECHENG 235 or CHE 230

MATSCIE 220 or MECHENG 382

BIOMEDE 458 or EECS 270 or EECS 314

CEE 265 or NERS 211

EECS 280

<sup>4</sup> IOE Senior Design courses are restricted to IOE undergraduate students only.

<sup>5</sup> Technical Electives - Select 11-12 hours from the following four groups; at least one course each from three of the following four groups:

A. IOE 413, 419, 440, 441, 447, 449

B. IOE 416, 460, 461\*, 465\*, 466\*

C. IOE 430, 432, 434, 436, 437, 438, 463

D. IOE 421, 422, 425, 430, 452, 453

The remaining 6 hours may be selected from any 400-level IOE courses (except IOE 490, IOE 499, IOE 424, and IOE 481) and/or from the approved list of non-IOE courses ([http://ioe.engin.umich.edu/degrees/ugrad/ugdocs/nonIOE\\_technical\\_electives.pdf](http://ioe.engin.umich.edu/degrees/ugrad/ugdocs/nonIOE_technical_electives.pdf)).

\*Maximum of 6 hours allowed from IOE 461, 465, 466.

\*\*Consult IOE academic advisor for requirements based on term of admission.

## Areas

### Operations Research

Operations research is an applied science devoted to describing, understanding, and predicting the behavior of systems, and guiding them towards better performance. Courses in this area cover the use of mathematics in constructing models to analyze and design operational systems. Students study a variety of model structures and their application to real-world processes such as production, maintenance, inspection, resource allocation, distribution and scheduling.

### Ergonomics

Ergonomics emphasizes the technical knowledge necessary to analyze and predict the performance of humans in human-machine systems. Basic courses cover the capabilities and limitations of major human subsystems including cardiovascular, muscular and cognitive (information processing) systems. Knowledge of these human subsystems is used to aid in the design of effective and safe working environments.

### Management Engineering

In the design and implementation of integrated systems, industrial engineers must be able to master the technology of new systems, to understand the technical change process, and to achieve the benefits of such systems. Management engineering courses emphasize the role of people acting as individuals, and in groups, in operating systems.

Theories of administration, group dynamics and human motivation are applied to specific managerial problems related to the establishment, clarification and modification of an organization's objectives.

They also cover the design, evaluation and improvement of human-machine systems for accomplishing these objectives.

### Production, Distribution, and Logistics

How does one add maximum value to an organization through world-class operations in the service and the manufacturing sectors? One needs highly effective production/transformation, inventory/sales and delivery/

fulfillment operations that are cost effective as well. The PDL area educates engineers and managers to lead through operational excellence. Emphasis is placed on global supply chain design, inventory management, production planning and control, facilities layout and planning, material handling, manufacturing strategy and related issues.

### Quality Engineering

Industrial and Operations Engineering graduates understand how to cope with uncertainty in the design of engineered systems. In particular, they design quality control systems and apply reliability analysis and experimental design techniques to design better products and processes.

### Computer and Information Processing

Computers and information systems are important components in most modern systems. Students are introduced to the basic terminology and concepts of information system design, construction and usage. The values and limitations of computing capabilities are explored. Emphasis is placed on the use of computer hardware and software systems in information processing and on the interface of information systems with management in helping to achieve the objectives of an organization.

## Sequential Undergraduate/ Graduate Study (SUGS)

<http://www.engin.umich.edu/ioe/academics/combined-grad>

## B.S.E in Industrial and Operations Engineering / M.S.E in Industrial and Operations Engineering

The IOE SUGS program is open to College of Engineering undergraduate students who have achieved senior standing (85 credit hours) with a minimum cumulative G.P.A. of 3.5. SUGS students are allowed to "double count" six (6) credit hours of graduate courses toward the B.S.E and M.S.E degrees. Students considering the SUGS program must "reserve" at least six (6)

undergraduate elective credit hours for courses that are eligible for credit in the IOE Masters degree program. SUGS students must enroll in Rackham for at least two (nine (9) credit) terms, paying full Rackham tuition with no other U of M registration.

## **B.S.E in Industrial and Operations Engineering / M.S. in Biomedical Engineering**

This SUGS program is open to all undergraduate students from Industrial and Operations Engineering who have achieved senior standing (85 credit hours) and have an overall cumulative G.P.A. of 3.5 or higher. Please contact the Department of Biomedical Engineering for more complete program information, <http://www.bme.umich.edu>.

## **Graduate**

### **Graduate Degrees**

- Master of Science (M.S.) in Industrial and Operations Engineering
- Master of Science in Engineering (M.S.E.) in Industrial and Operations Engineering
- Dual M.S. in Industrial and Operations Engineering/ Master of Business Administration (M.B.A.)
- Doctor of Philosophy (Ph.D.) in Industrial and Operations Engineering

### **M.S. and M.S.E. in Industrial and Operations Engineering**

The Master of Science degree in Engineering in Industrial and Operations Engineering is available to students who complete the M.S.E. course requirements and have a bachelor's degree from a recognized program in engineering. The Master of Science degree in Industrial and Operations Engineering is available to students with a bachelor's degree from a recognized program in physics, mathematics or other field related to engineering. Students who hold bachelor's degrees from other fields and who wish to receive an M.S. in

Industrial and Operations Engineering should consult with the program advisor as specialized programs (usually involving additional credit hours over basic requirements) can be developed.

The basic requirements include 30 credit hours of approved graduate courses subject to the following restrictions:

1. At least 18 credit hours of IOE courses
2. At least five (5) courses (equal or greater than 14 credit hours) must be at a 500-or greater level; with at least three (3) IOE courses (equal or greater than 8 credit hours) at a 500-or greater level. Directed study courses, courses graded S/U and one- and two-credit seminar classes may not be used to satisfy 500-level requirements.
3. At least two cognate courses (equal or greater than 4.5 credit hours) from outside the IOE Department.
4. No more than six (6) credit hours of independent study.

Students are required to make up deficiencies in their preparation in probability, statistics, computer programming, linear algebra and English. An overall grade point average of "B" or higher in graduate courses taken in the program is required.

Special options, for which recommended courses have been defined, include:

1. Operations Research
2. Ergonomics, Human Performance, and Occupational Safety
3. Production/Manufacturing/Distribution Systems
4. Quality Engineering and Applied Statistics
5. Engineering Management
6. Financial Engineering

### **Health Engineering and Patient Safety Concentration:**

The HEPS Concentration is a three semester program with its own requirements, which is conducted while simultaneously fulfilling the IOE Masters requirements. It has its own additional application procedure after admission to the Master's program.

## Requirements for Concentration in HEPS:

1. Fulfill all requirements for IOE master's program
2. Three (3) semesters (Fall, Winter, Fall)
3. Complete year long, program-designed, hands-on project (three (3) credits in the second semester, full-time in the summer, three (3) credits in the 3rd semester)
4. Satisfy the following course requirements:
  - IOE 813: Seminars in Healthcare Systems
  - Engineering — must be taken first semester (Fall):
    - Statistics/Data Analysis: 1 course
    - Intro to Healthcare: 2 courses
    - Technical Core: 2 courses
    - Methodology: 2 courses
    - Program Focus: 2 courses
5. Students may petition for special permission to count additional courses towards the HEPS requirements
6. Additional description is available at <http://cheps.engin.umich.edu/>
7. Material describing these options and other details of the graduate programs are available online at <http://www.engin.umich.edu/ioe/academics/grad>

## Ph.D. in Industrial and Operations Engineering

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. There is no general course or credit requirement for the doctorate.

At the end of the first year in the program, a student

must pass a qualifying examination to continue in the program. This exam is given in six (6) courses, chosen with the consent of the student's advisor. Most students, at the end of their second year, take a preliminary examination in their chosen area of concentration. At present there are five (5) such areas. The student must also satisfy a breadth requirement before taking the exam. After successfully passing this exam, the student is admitted to candidacy and selects a doctoral committee to supervise preparation of the dissertation. A defense of the dissertation in the presence of this committee is required.

Information that describes the general procedure leading to the doctorate is available on the Rackham Graduate School website, <http://www.rackham.umich.edu>.

## Dual M.B.A. / M.S. in Industrial and Operations Engineering

The School of Business Administration and the College of Engineering Department of Industrial and Operations Engineering offer a dual degree program enabling a student to pursue concurrent work in Business Administration and Industrial and Operations Engineering leading to the M.B.A and M.S. in I.O.E. degrees. The program is arranged so that all requirements for the degrees are completed in two and one-half years of enrollment with the required 65 credit hours completed.

Students interested in the M.B.A./M.S. in I.O.E. dual program must apply to, and be admitted by, both schools, using their respective application forms and indicating that application is being made to the joint program. Only one application fee is necessary. Students are expected to meet the prerequisites for each program. In particular, the statistics requirement for the I.O.E. program should be discussed with an advisor prior to beginning either program. This program is not open to students who have earned either the M.B.A. or M.S. in I.O.E. degrees. However, students registered in the first year of either program may apply.

Students admitted to this joint program must satisfy the following degree requirements:

1. The M.B.A 60-credit-hour degree program including:
  1. the 31.5-credit-hour M.B.A core (no credit is awarded for Business Administration core courses successfully waived; credit must be earned with Business electives);
  2. 13.5 elective hours in Business Administration (12 of the 13.5 must be approved by I.O.E.);
  3. 15 credit hours of transferable electives from the Department of Industrial and Operations Engineering.
2. The 18 hours of graduate-level I.O.E. courses, including at least eight (8) credit hours in courses numbered 500 or above. Directed study courses and seminar classes may not be counted toward the I.O.E. 500-level or above requirement.
3. A two-credit independent study in I.O.E. or the Business School which would lead to a paper integrating business and I.O.E. perspectives on a particular area of interest.

The total credit hours for the joint degree program will be at least 65.

The dual program can begin with studies in either school; however, because of the sequential nature of the core courses in the M.B.A program, most students will find it advantageous to start the first year in the Business School. Students who wish to begin with Industrial Operations Engineering should consult a counselor in the Business School to work out an appropriate plan of study.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### IOE 201. Economic Decision Making

*Prerequisite: ENGR 100 and ENGR 101. (2 credits) (7-week course)*

Overview of business operations, valuation and accounting principles. Time value of money and net present values. Practical team project experience.

### IOE 202. Operations Modeling

*Prerequisite: ENGR 100 and ENGR 101. (2 credits) (7-week course)*

Process of mathematically modeling operational decisions including the role of uncertainty in decision-making. Basic tools for solving the resulting models, particularly mathematical programs, statistical models and queueing models. Cases may come from manufacturing and service operations and ergonomics.

### IOE 265. Probability and Statistics for Engineers

*Prerequisite: Math 116 and ENGR 101, C- or better. (3 credits)*

Graphical Representation of Data; Axioms of Probability; Conditioning, Bayes Theorem; Discrete Distributions (Geometric, Binomial, Poisson); Continuous Distributions (Normal Exponential, Weibull), Covariance and Correlation. Point and Interval Estimation, Likelihood Functions, Test of Hypotheses for Means, Variances and Proportions for One and Two Populations.

### IOE 310. Introduction to Optimization Methods

*Prerequisite: Math 214, IOE 202 and ENGR 101. (4 credits)*

Introduction to deterministic models with emphasis on linear programming; simplex and transportation algorithms, engineering applications, relevant software. Introduction to integer, network and dynamic programming, critical path methods.

### IOE 316. Introduction to Markov Processes

*Prerequisite: IOE 265 and Math 214. Minimum grade of C- for enforced prerequisite. (3 credits)*

Introduction to discrete Markov Chains and continuous Markov processes, including transient and limiting behavior. Introduction to Markov Decision Processes. The Poisson/Exponential process. Applications to reliability, maintenance, inventory, production, queues and other engineering problems.

### IOE 333. Ergonomics

*Prerequisite: Preceded or accompanied by IOE 265. (3 credits)*

Introduction to human sensory, decision, control, and motor systems in the context of visual, auditory, cognitive and manual task evaluation and design. Problems with computer displays, illumination, noise, eye-hand

coordination as well as repetitive and high physical effort tasks are presented. Workplace and vehicle design strategies used to resolve these are discussed.

### **IOE 334. Ergonomics Lab**

*Prerequisite: Preceded or accompanied by IOE 333. (1 credit)*

Principles of measurement and prediction of human performance in man-machine systems. Laboratory experiments investigating human capabilities of vision, hearing, information processing, memory, motor processes, strength and endurance.

### **IOE 366. Linear Statistical Models**

*Prerequisite: IOE 265 and Math 214, C- or better. (3 credits)*

Linear statistical models and their application to engineering data analysis. Linear regression and correlation, multiple linear regression, stepwise selection, analysis of variance, introduction to design of experiments, data exploration techniques.

### **IOE 373. Data Processing**

*Prerequisite: ENGR 101. (4 credits)*

Introduction to the systems organization and programming aspects of modern digital computers. Concepts of algorithms and data structure will be discussed with practical business applications.

### **IOE 413. Optimization Modeling in Health Care**

*Prerequisite: IOE 265 and IOE 310 or equivalent. (3 credits)*

Introduction to optimization modeling in health care. Linear and integer programming models are developed for problems in health and medicine. Problems considered may include breast cancer diagnosis, radiotherapy treatment planning, fracture fixation planning and others as selected by the instructor. Emphasis is placed on model formulation, verification, validation and uncertainty quantification.

### **IOE 416. Queueing Systems**

*Prerequisite: IOE 316. (2 credits) (7-week course)*

Introduction to queueing processes and their applications. The M/M/s and M/G/1 queues. Queue length, waiting time, busy period. Examples from production, transportation, communication and public service.

### **IOE 419. Service Operations Management**

*Prerequisite: IOE 310 and IOE 316 or equivalent. (3 credits)*

Introduction to optimization, queueing, and spreadsheet-based simulation modeling applications in the service industries. Topics covered will include facility location modeling, short-term workforce management, long-term workforce planning, resource allocation, inventory applications in service systems, customer scheduling, call center design and vehicle routing.

### **IOE 421. Work Organizations**

*Prerequisite: IOE 201, 202 and senior standing. (3 credits)*

Applications of organizational theory to the analysis and design of work organizations is taught through lectures, projects in real organizations, experiential exercises and case studies. Topics include: open-systems theory, organizational structure, culture and power. A change strategy: current state analysis, future state vision and strategies for organizational transformation.

### **IOE 422. Entrepreneurship**

*Prerequisite: Senior standing. Not for graduate credit. (3 credits)*

Engineering students will explore the dynamics of turning an innovative idea into a commercial venture in an increasingly global economy. Creating a business plan originating in an international setting will: challenge students to innovate; manage risk, stress and failure; confront ethical problems; question cultural assumptions; and closely simulate the realities of life as an entrepreneur.

### **IOE 424. Practicum in Production and Service Systems**

*Prerequisite: Senior standing, IOE undergraduates only. Not for graduate credit. (4 credits)*

Student teams will work with an organization on an Industrial and Operations Engineering design project with potential benefit to the organization and the students. The final report should demonstrate a mastery of the established technical communication skills. The report will be reviewed and edited to achieve this outcome.

### **IOE 425 (MFG 426). Lean Manufacturing and Ser-**

**vices (MFG 426)**

*Prerequisite: Senior standing. (2 credits) (7-week course)*

Review of philosophies, systems, and practices utilized by world-class manufacturers and service organizations focusing on "lean management," including material and information flow, in-process quality assurance, standardized work, continuous improvement, visual management and lean leadership. Practical examples and in-class exercises bring concepts to life.

**IOE 430. Global Cultural Systems Engineering**

*Prerequisite: IOE 333 and IOE 366 or graduate standing. (3 credits)*

Selected topics of systems engineering are examined from the global cultural perspective. Topics include global cultural issues of design, marketing and communication; engineering aesthetics and ethics; individual and aggregated behavioral decision making; social networking and online communities; research and evaluation methods; applications in many systems engineering.

**IOE 432. Industrial Engineering Instrumentation Methods**

*Prerequisite: Enforced: IOE 334 or better or graduate standing. (3 credits)*

The characteristics and use of analog and digital instrumentation applicable to industrial engineering problems. Statistical methods for developing system specifications. Applications in physiological, human performance and production process measurements are considered.

**IOE 434. Human Error and Complex System Failures**

*Prerequisite: IOE 333 or IOE 536 or Permission of Instructor. (3 credits)*

Introduction to a new systems-oriented approach to safety management and the analysis of complex system failures. The course covers a wide range of factors contributing to system failures: human perceptual and cognitive abilities and limitations, the design of modern technologies and interfaces, and biases in accident investigation and error analysis. Recent concepts in the area of high reliability organizations and resilience engineering are reviewed. Students perform systems anal-

ysis of actual mishaps and disasters in various domains, including various modes of transportation, process control and health care.

**IOE 436. Human Factors in Computer Systems**

*Prerequisite: IOE 333. (3 credits)*

This course discusses how to design and evaluate computer systems for ease of use. Topics to be covered include keyboards and how people type, vision and video display design, human body size and computer furniture, regulations concerning working conditions, software issues, methods for studying user performance, documentation and information systems of the future.

**IOE 437. Automotive Human Factors**

*Prerequisite: Senior standing and IOE 333/334 or graduate standing. (3 credits)*

This course provides an overview of human factors and driving to help engineers design motor vehicles that are safe and easy to use and to provide basic knowledge for those interested in conducting automotive human factors/ergonomics research. The focus is on the total vehicle (all aspects of vehicle design) and for an international market. Key topics include design guidelines, crash investigation and statistics, driving performance measures, vehicle dynamics, occupant packaging and driver vision.

**IOE 438. Occupational Safety Management**

*Prerequisite: Enforced: IOE 333 or senior or graduate standing. (2 credits) (7-week course)*

Survey of occupational safety management methods, theories and activities. Topics include: history of safety engineering, management, and worker compensation; collection and critical analysis of accident data; safety standards, regulations and regulatory agencies; theories of self-protective behavior and accident prevention; and analysis of safety program effectiveness.

**IOE 440 (MFG 440). Operations Analysis and Management**

*Prerequisite: Enforced: IOE 310 and 316 or graduate standing. No credit granted for students who have credit for TO 605. (3 credits).*

Principles and models for analyzing, engineering and managing manufacturing and service operations as well as supply chains. Emphasis on capacity management;

queueing models of operational dynamics (including cycle time, work-in-progress, inventory, throughput and variability); operational flexibility; the math and physics of lean enterprises.

### **IOE 441 (MFG 441). Production and Inventory**

#### **Control**

*Prerequisite: IOE 310, IOE 316. (3 credits)*

Basic models and techniques for managing inventory systems and for planning production. Topics include deterministic and probabilistic inventory models; production planning and scheduling; and introduction to factory physics.

### **IOE 447 (MFG 447). Facility Planning**

*Prerequisite: IOE 310, IOE 316. (3 credits)*

Fundamentals in developing efficient layouts for single-story and multi-story production and service facilities. Manual procedures and microcomputer-based layout algorithms. Algorithms to determine the optimum location of facilities. Special considerations for multi-period, dynamic layout problems.

### **IOE 449 (MFG 449). Material Handling Systems**

*Prerequisite: IOE 310, IOE 316 with minimum grade of C- for enforced prerequisites or Graduate standing. (3 credits)*

Review of material handling equipment used in warehousing and manufacturing. Analytic models and algorithms to design and analyze the performance of discrete-flow manual and automated storage/retrieval systems, order picking centers, automated guided vehicle systems, conveyor loops, and lean manufacturing driven milkrun systems and call systems.

### **IOE 452 (MFG 455). Corporate Finance**

*Prerequisite: IOE 201, IOE 310, IOE 366. (3 credits)*

The goal of this course is to introduce a basic understanding of financial management. The course develops fundamental models of valuation and investment from first principles and applies them to problems of corporate and individual decision-making. The topics of discussion will include the net present valuation, optimal portfolio selection, risk and investment analysis, issuing securities, capital structure with debt financing and real options.

### **IOE 453 (MFG 456). Derivative Instruments**

*Prerequisite: IOE 201, IOE 310, IOE 366. (3 credits, no credit granted for students who have credit for MATH 423)*

The main objectives of the course are first, to provide the students with a thorough understanding of the theory of pricing derivatives in the absence of arbitrage, and second, to develop the mathematical and numerical tools necessary to calculate derivative security prices. We begin by exploring the implications of the absence of static arbitrage. We study, for instance, forward and futures contracts. We proceed to develop the implications of no arbitrage in dynamic trading models: the binomial and Black-Scholes models. The theory is applied to hedging and risk management.

### **IOE 460. Decision Analysis and Bounded Rationality**

*Prerequisite: IOE 265, IOE 310 with minimum grade of C- for enforced prerequisites. (3 credits)*

This course provides a rigorous introduction to prescriptive decision analysis and more descriptive bounded rationality models. The course starts from the classic axioms of rational choice and covers single-attribute and multi-attribute utility theory, decision trees, the value of information in a decision analytic context, and expert elicitation of both probabilities and utility functions. It then introduces bounded rationality and covers some of the main classes of bounded rationality and how they can be modeled.

### **IOE 461. Quality Engineering Principles and Analysis**

*Prerequisite: IOE 366. (3 credits)*

This course provides students with the analytical and management tools necessary to solve manufacturing quality problems and implement effective quality systems. Topics include voice of the customer analysis, the Six Sigma problem solving methodology, process capability analysis, measurement system analysis, design of experiments, statistical process control, failure mode and effects analysis, quality function deployment and reliability analysis.

### **IOE 463 (MFG 463). Measurement and Design of Work**

*Prerequisite: IOE 333 or MECHENG 395 or BIO-*

*MEDE 231 and IOE 265 or Stats 412. (3 credits)*

Design of lean manufacturing systems requires knowledge and skills for describing manual work, identifying value and non-value added work elements, designing efficient work equipment and methods, preventing fatigue and related worker health problems and predicting work performance.

#### **IOE 465. Design of Experiments.**

*Prerequisite: IOE 366; C- or better or graduate standing. (3 credits)*

Linear models, Multi-collinearity and Robust Regression, Comparative Experiments, Randomized Blocks and Latin Squares, Factorial Designs, Confounding, Mixed Level Fractional Factorials, Random and Mixed Models, Nesting and Split Plots, Response Surface Methods, Taguchi Contributions to Experimental Design.

#### **IOE 466 (MFG 466). Statistical Quality Control**

*Prerequisite: IOE 366 or Stats 401 or graduate standing. (3 credits)*

Quality Improvement Philosophies; Modeling Process Quality, Statistical Process Control, Control Charts for Variables and Attributes, CUSUM and EWMA, Short Production Runs, Multivariate Quality Control, Auto Correlation, Engineering Process Control, Economic Design of Charts, Fill Control, Pre-control, Adaptive Schemes, Process Capability, Specifications and Tolerances, Gage Capability Studies, Acceptance Sampling by Attributes and Variables, International Quality Standards.

#### **IOE 474. Simulation**

*Prerequisite: IOE 316, IOE 366, IOE 373. (4 credits)*

Simulation of complex discrete-event systems with applications in industrial and service organizations. Course topics include modeling and programming simulations in one or more high-level computer packages such as ProModel or GPSS/H; input distribution modeling; generating random numbers; statistical analysis of simulation output data. The course will contain a team simulation project.

#### **IOE 481. Practicum in Hospital Systems**

*Prerequisite: Senior standing, IOE undergraduates only; Not for graduate credit. (4 credits)*

Student team projects in hospital systems. Projects will

be offered from areas of industrial and operations engineering, including work measurement and control, systems and procedures, management, organization and information systems. Lectures will deal with the hospital setting and project methodologies. The final report should demonstrate a mastery of the established technical communication skills. The report will be reviewed and edited to achieve the outcome.

#### **IOE 490. Undergraduate Directed Study, Research, and Special Problems**

*Prerequisite: Permission of instructor, not for graduate credit; maximum 4 credit hours per term. (2-4 credits)*

Individual or group study, design, or laboratory research in a field of interest to the student or group. Topics may be chosen from any area of industrial and operations engineering. Student(s) must register for the individual section number of the instructor/advisor.

#### **IOE 491. Special Topics in Industrial and Operations Engineering**

*(to be arranged)*

Selected topics of current interest in industrial and operations engineering.

#### **IOE 499. Senior Design Projects**

*Prerequisite: Senior standing, permission of advisor. (4 credits)*

Selected design projects in industrial and operations engineering to be conducted for project sponsors. The final report submitted by the students should demonstrate a mastery of the established communication skills. The final project report will be reviewed to achieve this outcome.

#### **IOE 506 (Math 506). Stochastic Analysis for Finance**

*Prerequisite: Graduate standing or permission of advisor. (3 credits)*

The aim of this course is to teach the probabilistic techniques and concepts from the theory of stochastic processes required to understand the widely used financial models. In particular concepts such as martingales, stochastic integration/calculus, which are essential in computing the prices of derivative contracts, will be discussed. Pricing in complete/incomplete markets (in discrete/continuous time) will be the focus of this course

as well as some exposition of the mathematical tools that will be used such as Brownian motion, Levy processes and Markov processes.

### **IOE 510 (Math 561) (OMS 518). Linear Programming I**

*Prerequisite: Math 217, Math 417, or Math 419. (3 credits)*

Formulation of problems from the private and public sectors using the mathematical model of linear programming. Development of the simplex algorithm; duality theory and economic interpretations. Postoptimality (sensitivity) analysis application and interpretations. Introduction to transportation and assignment problems; special purpose algorithms and advanced computational techniques. Students have opportunities to formulate and solve models developed from more complex case studies and to use various computer programs.

### **IOE 511 (Math 562). Continuous Optimization Methods**

*Prerequisite: Math 217, Math 417 or Math 419. (3 credits)*

Survey of continuous optimization problems. Unconstrained optimization problems: unidirectional search techniques; gradient, conjugate direction, quasi-Newton methods. Introduction to constrained optimization using techniques of unconstrained optimization through penalty transformations, augmented Lagrangians and others. Discussion of computer programs for various algorithms.

### **IOE 512. Dynamic Programming**

*Prerequisite: IOE 510, IOE 316. (3 credits)*

The techniques of recursive optimization and their use in solving multistage decision problems, applications to various types of problems, including an introduction to Markov decision processes.

### **IOE 513. Healthcare Operations Research: Theory and Applications**

*Prerequisite: IOE 316 or IOE 515 and IOE 310 or IOE 510 and IOE 366 or IOE 474 and graduate standing or permission of instructor. (3 credits)*

This course provides an overview of the role of operations research in healthcare. It surveys and evaluates

research done in this field and addresses some of the key technical issues encountered when developing healthcare operations research models. Insights will be shared about carrying out collaborative research with healthcare professionals.

### **IOE 515. Stochastic Processes**

*Prerequisite: IOE 316 or Stats 310. (3 credits)*

Introduction to non-measure theoretic stochastic processes. Poisson processes, renewal processes and discrete time Markov chains. Applications in queueing systems, reliability, and inventory control.

### **IOE 516. Stochastic Processes II**

*Prerequisite: IOE 515. (3 credits)*

This course emphasizes the use of Markov Chains in theory and practice. General knowledge of probability theory and stochastic processes is assumed. Applications may include equipment replacement, queueing systems and production systems. Methodologies covered include invariant measures and stationary distributions for both the discrete and continuous cases.

### **IOE 518. Introduction to Integer Programming**

*Prerequisite: IOE 510. (1.5 credits) (7-week course)*

Introduction to optimization problems that fall within the framework of Integer Programming, and an overview of concepts and classical methods for their analysis and solution. Integer programming formulations, relaxations, duality and bounds, branch-and-bound and cutting plane algorithms, heuristic solution methods.

### **IOE 519. Introduction to Nonlinear Programming**

*Prerequisite: Math 217/417/419 and Math 451. (1.5 credits) (7-week course)*

Introduction to continuous nonlinear optimization problems, and an overview of concepts and classical methods for their analysis and solution. Nonlinear programming formulations. Optimality conditions for constrained and unconstrained problems. Convexity. Algorithms: steepest descent, Newton's method, barrier and penalty methods.

### **IOE 522. Theories of Administration**

*Prerequisite: IOE 421. (3 credits)*

Provide insight into leading theories concerning the administration of research and industrial organizations.

Treat the concepts needed for describing, assessing and diagnosing organizations; processes of organizational communication, motivation, and conflict management; adaptation of organization systems to the requirements of work and information technologies.

### **IOE 533 (MFG 535). Human Motor Behavior and Engineering Systems**

*Prerequisite: IOE 333 and IOE 366. (3 credits)*

This course is designed to provide a basic perspective of the major processes of human motor behavior. Emphasis will be placed on understanding motor control and man-(machine)-environment interaction. Information processing will be presented and linked to motor behavior. Application of theories to the design of the workplace, controls and tools will be underlined and illustrated by substantial examples.

### **IOE 534 (BIOMEDE 534) (MFG 534). Occupational Biomechanics**

*Prerequisite: IOE 333, IOE 334, or IOE 433. (3 credits)*

Anatomical and physiological concepts are introduced to understand and predict human motor capabilities, with particular emphasis on the evaluation and design of manual activities in various occupations. Quantitative models are developed to explain (1) muscle strength performance; (2) cumulative and acute musculoskeletal injury; (3) physical fatigue; and (4) human motion control.

### **IOE 536. Cognitive Ergonomics**

*Prerequisite: IOE 333 or IOE 433. (3 credits)*

Theories and concepts of human information processing are introduced to analyze human perceptual and cognitive performance in human machine information systems such as intelligent transportation and manufacturing systems. Conceptual and quantitative models, interface design techniques and research and evaluation methods are presented. Samples of on-going research are also discussed.

### **IOE 539 (MFG 539). Safety Engineering Methods**

*Prerequisite: IOE 265 or Biostat 503. (3 credits)*

Recognition, evaluation and control of generic safety hazards (confined spaces, electricity, fire, mechanical energy, etc.) found in contemporary workplaces, using

case studies from manufacturing, transportation and power generation. Students perform an interdisciplinary team project using systems safety engineering methods to redesign a work station, manufacturing process, or consumer product.

### **IOE 541 (MFG 541). Inventory Analysis and Control**

*Prerequisite: IOE 310, IOE 316. (3 credits)*

Models and techniques for managing inventory systems and for planning production. Topics include single item and multi-item inventory models, production planning and control and performance evaluation of manufacturing systems.

### **IOE 543 (MFG 543). Scheduling**

*Prerequisite: IOE 316, IOE 310. (3 credits)*

The problem of scheduling several tasks over time, including the topics of measures of performance, single-machine sequencing, flow shop scheduling, the job shop problem and priority dispatching. Integer programming, dynamic programming and heuristic approaches to various problems are presented.

### **IOE 545 (MFG 545). Queueing Networks**

*Prerequisite: IOE 515 or EECS 501. (3 credits)*

Introduction to queueing networks. Topics include product and non-product form networks, exact results and approximations, queueing networks with blocking and polling systems. Applications from manufacturing and service industries are given as examples.

### **IOE 547 (MFG 547). Supply Chain Facilities**

*Prerequisite: IOE 265 or equivalent, IOE 310 or equivalent with minimum grade of C- for enforced prerequisites or Graduate standing. (3 credits)*

A global supply network consists of "arcs" (transportation) and "nodes" (facilities) such as container terminals, crossdocks, distribution centers, consolidation centers, railway yards, and airfreight terminals. In this course we cover the basic functions and configuration of the above facilities, and we develop analytic design and performance evaluation models for them.

### **IOE 548. Integrated Product Development**

*Prerequisite: Graduate standing; Permission of Tauber*

*Institute. I (3 credits)*

This is a Tauber Institute-sponsored graduate elective. Students form teams of four/five, each with mixed disciplinary backgrounds spanning business, engineering and art/architecture. A product category is announced, and each team acts as an independent firm competing in that product market against other teams while working independently through an integrated exercise of market research, product design, product development and manufacture, pricing, demand forecasting and inventory control. Market share of each team is determined through both a web-based competition and a physical trade show.

**IOE 549 (MFG 549). Plant Flow Systems**

*Prerequisite: IOE 310, IOE 416. (3 credits)*

Analytical models for the design and throughput performance evaluation of material handling systems used in discrete parts flow production facilities. Analysis of design and control issues for manual and automated handling systems including lift trucks, micro-load automatic storage/retrieval systems and automated guided vehicle systems.

**IOE 551. Benchmarking, Productivity Analysis and Performance Measurement**

*Prerequisite: IOE 510. (3 credits)*

Introduction to quality engineering techniques commonly used for performance measurement, productivity analysis, and identification of best practice. Topics include balanced scorecard, activity-based costing/management, benchmarking, quality function deployment and data envelopment analysis (DEA). Significant focus of the course is on the application of DEA for identification of best practice.

**IOE 552. Financial Engineering I**

*Prerequisite: IOE 453 or Math 423 or Fin 580 or Fin 618 or Fin 855. Minimum grade required for enforced prerequisites is C-. (3 credits)*

Theory and applications of financial engineering. Designing, structuring and pricing financial engineering products (including options, futures, swaps and other derivative securities) and their applications to financial and investment risk management. Mathematical methodology that forms the basis of financial engineering, applied stochastic processes and numerical methods in

particular.

**IOE 553. Financial Engineering II**

*Prerequisite: IOE 552 or Math 542. Minimum grade required for enforced prerequisites is C-. (3 credits)*

Advanced issues in financial engineering: stochastic interest rate modeling and fixed income markets, derivative trading and arbitrage, international finance, risk management methodologies including Value-at-Risk and credit risk. Multivariate stochastic calculus methodology in finance: multivariate Ito's lemma, Ito's stochastic integrals, the Feynman-Kac theorem and Girsanov's theorem.

**IOE 562 (Stats 535). Reliability**

*Prerequisite: IOE 316 and IOE 366 or Stats 425 and Stats 426. (3 credits)*

Reliability concepts and methodology for modeling, assessing and improving product reliability: common models for component and system reliability; analysis of field and warranty data; component reliability inference; repairable systems; accelerated stress testing for reliability assessment; reliability improvement through experimental design.

**IOE 565 (MECHENG 563) (MFG 561). Time Series Modeling, Analysis, Forecasting**

*Prerequisite: IOE 366 or MECHENG 401. (3 credits)*

Time series modeling, analysis, forecasting and control, identifying parametric time series, autocovariance, spectra, Green's function, trend and seasonality. Examples from manufacturing, quality control, ergonomics, inventory and management.

**IOE 568. Statistical Learning & Applications in Quality Engineering**

*Prerequisite: IOE 466 or STATS 500. (3 credits)*

Statistical learning and data transformation methods to advance quality control techniques for variation reduction. Focus on feature extraction of waveform signals, change point detection for system monitoring, data pattern recognition for fault diagnosis and Bayes/reinforcement learning for decision making.

**IOE 570 (Stats 570). Experimental Design**

*Prerequisite: Stats 500 or background in regression (3 credits)*

Basic design principles, review of analysis of variance, block designs, two-level and three-level factorial and fractional factorial experiments, designs with complex aliasing, data analysis techniques and case studies, basic response surface methodology, variation reduction and introductory robust parameter designs.

#### **IOE 574. Simulation Analysis**

*Prerequisite: IOE 515. (3 credits)*

Underlying probabilistic aspects of simulation experiments, statistical methodology for designing simulation experiments and interpreting output. Random number generators, variate and process generation, output analysis, efficiency improvement techniques, simulation and optimization, how commercial simulation software works. Applications from telecommunications, manufacturing statistical analysis.

#### **IOE 583 (MECHENG 583) (MFG 583) (EECS 566). Scientific Basis for Reconfigurable Manufacturing**

*Prerequisite: Graduate standing or permission of instructor. (3 credits)*

Principles of reconfigurable manufacturing systems (RMS). Students will be introduced to fundamental theories applicable to RMS synthesis and analysis. Concepts of customization, integrability, modularity, diagnosability and convertibility. Reconfiguration design theory, life-cycle economics, open-architecture principles, controller configuration, system reliability, multi-sensor monitoring and stream of variations. Term projects.

#### **IOE 588 (MECHENG 588) (MFG 588). Assembly Modeling for Design and Manufacturing**

*Prerequisite: MECHENG 381 and MECHENG 401 or equivalent. (3 credits)*

Assembly on product and process. Assembly representation. Assembly sequence. Datum flow chain. Geometric Dimensioning & Tolerancing. Tolerance analysis. Tolerance synthesis. Robust design. Fixturing. Joint design and joining methods. Stream of variation. Auto body assembly case studies.

#### **IOE 590. Masters Directed Study, Research, and Special Problems**

*Prerequisite: Graduate standing and permission of instructor. (2-4 credits)*

Individual or group study, design or laboratory research in a field of interest to the student or group. Topics may be chosen from any area of industrial and operations engineering. Student(s) must register for the section number of the instructor/advisor. Maximum of six credits of IOE 590/593 may be counted toward the IOE Masters Degree.

#### **IOE 591. Special Topics**

*Prerequisite: Permission of instructor. (to be arranged)*

Selected topics of current interest in industrial and operations engineering.

#### **IOE 593. Ergonomics Professional Project**

*Prerequisite: Graduate standing, permission of instructor. (2-4 credits)*

Students work as part of a team within a production or service organization on a design project that emphasizes the application of ergonomic principles to enhance the safety, productivity, and/or quality aspects of a human-machine system. Student(s) must register for the section number of the instructor/advisor. A maximum of six credits of IOE 590/593 may be counted toward the IOE Masters Degree.

#### **IOE 600 (EECS 600). Function Space Methods in System Theory**

*Prerequisite: EECS 400 or Math 419. (3 credits)*

Introduction to the description and analysis of systems using function analytic methods. Metric spaces, normed linear spaces, Hilbert spaces, resolution spaces. Emphasis on using these concepts in systems problems.

#### **IOE 610 (Math 660). Linear Programming II**

*Prerequisite: IOE 510 (Math 561). (3 credits)*

Primal-dual algorithm. Resolution of degeneracy, upper bounding. Variants of simplex method. Geometry of the simplex method, application of adjacent vertex methods in non-linear programs, fractional linear programming. Decomposition principle, generalized linear programs. Linear programming under uncertainty. Ranking algorithms, fixed charge problem. Integer programming. Combinatorial problems.

#### **IOE 611 (Math 663). Nonlinear Programming**

*Prerequisite: IOE 510 (Math 561). (3 credits)*

Modeling, theorems of alternatives, convex sets, convex and generalized convex functions, convex inequality systems, necessary and sufficient optimality conditions, duality theory, algorithms for quadratic programming, linear complementary problems and fixed point computing. Methods of direct search, Newton and Quasi-Newton, gradient projection, feasible direction, reduced gradient; solution methods for nonlinear equations.

### **IOE 612. Network Flows**

*Prerequisite: IOE 510 (Math 561). (3 credits)*

Flow problems on networks. Maximum flow minimum cut theorem. Labeling algorithms. Circulation and feasibility theorems. Sensitivity analysis. Incidence matrices. Shortest routes. Minimum cost flows, out-of-kilter algorithm. Critical path networks, project cost curves. Multi-commodity flow problem, biflows. Matching problems in graph theory.

### **IOE 614. Integer Programming**

*Prerequisite: IOE 510 (Math 561). (3 credits)*

Modeling with integer variables, total unimodularity, cutting plane approaches, branch-and-bound methods, Lagrangian relaxation, Bender's decomposition, the knapsack and other special problems.

### **IOE 615. Advanced Stochastic Processes**

*Prerequisite: IOE 515 and Math 451. (3 credits)*

Designed for students planning to do research on stochastic models in operations research (e.g., queueing systems, stochastic scheduling, financial models, simulation, etc.) Topics covered include Martingales, Brownian motion, diffusion processes, limit theorems, and coupling.

### **IOE 616. Queueing Theory**

*Prerequisite: IOE 515. (3 credits)*

Theoretical foundations, models and techniques of queueing theory. Rigorous treatment of elementary through advanced queueing systems and queueing networks. Topics include Markov Renewal and Semi-Regenerative Processes.

### **IOE 623 (Math 623). Computational Finance**

*Prerequisite: Math 316 and Math 425/525 or IOE 552. (3 credits)*

This is a course in computational methods in finance and financial modeling. Particular emphasis will be put on interest rate models and interest rate derivatives. The specific topics include: Black-Scholes theory, no arbitrage and complete markets theory, term structure models: Hull and White models and Heath Jarrow Morton models, the stochastic differential equations and martingale approach: multinomial tree and Monte Carlo methods, the partial differential equations approach: finite difference methods.

### **IOE 635 (BIOMEDE 635). Laboratory in Biomechanics and Physiology of Work**

*Prerequisite: IOE 534 (BIOMEDE 534). (2 credits)*

This laboratory is offered in conjunction with the Occupational Biomechanics lecture course (IOE 534) to enable students to examine experimentally (1) musculoskeletal reactions to volitional acts; (2) the use of electromyography (EMGs) to evaluate muscle function and fatigue; (3) biomechanical models; (4) motion analysis system; and (5) musculoskeletal reactions to vibrations.

### **IOE 640. Mathematical Modeling of Operational Systems**

*Prerequisite: IOE 510, IOE 515. (3 credits)*

The art and science of developing, using and explicating mathematical models, presented in a studio/workshop environment. Structuring of a variety of operational "situations" so they can be reasonably represented by a mathematical model. Extensive class discussion and out-of-class investigation of potential mathematical approaches to each situation. Incorporation of data analysis.

### **IOE 641. Supply Chain Management**

*Prerequisite: IOE 510, IOE 515 and IOE 541. (3 credits)*

Structural analyses of production and inventory systems. Review of issues in supply chain management. Topics include inventory systems with stochastic lead time, multi-echelon supply systems, and coordination of material flows, information flows and financial flows in a supply chain.

### **IOE 691. Special Topics**

*Prerequisite: Permission of instructor. (to be arranged)*

Selected topics of current interest in industrial and operations engineering.

### **IOE 712. Infinite Horizon Optimization**

*Prerequisite: IOE 512. (3 credits)*

A seminar on optimization problems with an infinite time horizon. Topics include topological properties, optimality definitions, decision/forecast horizons, regenerative models and stopping rules. Applications discussed include capacity expansion, equipment replacement and production/ inventory control.

### **IOE 800. First-Year Doctoral Seminar**

*Prerequisite: Permission of instructor. (1 credit)*

Presentation by IOE faculty members of current and future research activities within the department. Discussion of procedural, philosophical and professional aspects of doctoral studies in industrial and operations engineering.

### **IOE 801. First-Year Doctoral Directed Research**

*Prerequisite: IOE Ph.D. precandidacy, permission of instructor. (1-3 credits)*

Directed research on a topic of mutual interest to the student and the instructor. Student(s) must register for the section number of the instructor/advisor.

### **IOE 802. Written and Oral Academic Presentations**

*Prerequisite: IOE 800 and IOE 801. (2 credits)*

The Dissertation Proposal is used as a platform for developing written and oral presentation skills as students prepare for the IOE Preliminary exam. Topics and assignments include: key elements of NIH and NSF proposals, writing the dissertation proposal and preparing/delivering oral presentations.

### **IOE 813. Seminars in Healthcare Systems Engineering**

*Prerequisite: Graduate standing or permission of instructor. (2 credits)*

Healthcare is critical to society and has a major impact on our economy. In this course, focused around weekly seminars by leading scholars in this important area, we provide a broad overview to ways systems engineering can improve the delivery of healthcare: decreasing costs, reducing error and developing innovations.

### **IOE 836. Seminar in Human Performance**

*Prerequisite: Graduate standing. (1 credits)*

Case studies of research techniques used in the human performance and safety fields. Speakers actively engaged in research will discuss their methods and results.

### **IOE 837. Seminar in Occupational Health and Safety Engineering**

*Prerequisite: Graduate standing. (1 credit)*

This seminar provides an opportunity for graduate students interested in occupational health and safety engineering problems to become acquainted with various related contemporary research and professional activities, as presented by both staff and guest speakers.

### **IOE 899. Seminar in Industrial and Operations Engineering**

*Prerequisite: Permission of instructor; not for master's degree; mandatory satisfactory/unsatisfactory. (1 credit)*

Presentation by IOE faculty members and outside speakers on current and future research activities in industrial and operations engineering.

### **IOE 990. Dissertation Research: Pre-Candidate**

*Prerequisite: Completion of IOE Qualifying Exam and permission of instructor. (2-8 credits); (1-4 credits)*

Dissertation work by doctoral student who has passed the IOE Qualifying Exam with Pass or Conditional Pass, but is not yet admitted to candidacy. Student must register for the section number of the instructor/advisor. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

### **IOE 995. Dissertation Research: Candidate**

*Prerequisite: Graduate School authorization for admission as a doctoral candidate and permission of the instructor. (8 credits); (4 credits)*

Dissertation research by a doctoral student who has been admitted to Candidacy. Student must register for the section number of the instructor/advisor. The defense of the dissertation (e.g., the final oral examination) must be held under a full-term candidacy enrollment.

# Materials Science and Engineering

## Overview

Materials Science and Engineering is widely recognized as one of the most promising technical fields of the 21st century.

Materials scientists and engineers specialize in the characterization, development, processing and use of metallic, ceramic, polymeric and electronic materials that are employed in all fields of technology.

Materials scientists and engineers are developing important new materials to meet the needs of our modern technological society. These include high-temperature superconductors; ultra-high-purity semiconductors for solid-state electronic devices; high-strength alloys for use at the extreme temperatures encountered in jet and rocket engines; strong, light alloys and composites for aerospace applications; specialized glasses and ceramics with high thermal, mechanical and chemical stability; and a host of polymeric materials: some with unique functional characteristics and others which replace metal, glass, wood and natural fibers in dozens of applications.

The future role of materials scientists and engineers promises to be even more important and challenging. It is widely recognized that the world is facing a critical energy shortage. Materials scientists and engineers are rising to this challenge in a variety of ways. One method is reducing the weight of automobiles and other transportation systems for fuel savings. They are also actively engaged in reducing the impact of modern society on our environment. They are at the forefront of recycling technologies and more energy-efficient ways of processing materials. New materials and processes are being developed to replace environmentally unfriendly ones currently in use. Sputtering or vapor deposition instead of plating, and biodegradable plastics are examples.

Materials science and engineering graduates are em-

ployed in research, development and manufacturing. They support the creation of new materials and processes or the improvement of old ones with the aim of tailoring properties to applications. Often the work involves cooperating with mechanical, chemical, aeronautical, automotive and other types of engineers in selecting appropriate materials in the design of various devices; evaluating the performance of materials in service; and, particularly, determining the causes and cures for in-service failures; as well as various kinds of supervisory, research, teaching and management activities. A tremendous range of materials science and engineering opportunities exists in metals, polymers, ceramics and electronic materials.

The undergraduate program in Materials Science and Engineering at the University of Michigan has been carefully designed to prepare students for the broad range of activities as described previously; or for continuing their academic work to acquire a master's or doctoral degree.

Introductory courses (either MATSCIE 220 or MATSCIE 250) and MATSCIE 242, and a second-level course (MATSCIE 350) provide a foundation of basic principles applicable to all classes of materials. Other courses include thermodynamics, transport phenomena and mechanical behavior.

Two required laboratory courses give our students a working knowledge of equipment used and methods practiced in the materials industry including processing that uses thermal, chemical and mechanical methods; characterization using mechanical testing machines, microscopy and diffraction instruments; and analysis of experimental data using statistical and digital methods.

A required course in organic chemistry (CHEM 210) may be used to satisfy the engineering chemistry requirement or the technical elective requirement. Introduction to Solid Mechanics (MECHENG 211) is also required.

Students have an opportunity to tailor their program of study to their own interests. They choose three senior-level courses from a group of six. These courses cover electrical, magnetic or optical properties of materials,

metals, polymers, ceramics, biomaterials, and materials characterization. They also choose one additional MSE course, plus 10 hours of technical electives and 12 hours of general electives.

All engineering students are required to take 16 credits of intellectual breadth to broaden their education. One of the courses must be macro- or micro-economics (ECON 101 or 102).

## Department Administration

### Department Chair

Amit Misra  
3062B HH Dow Building

Materials Science and Engineering Department  
3062 H.H. Dow  
2300 Hayward St.  
Ann Arbor, MI 48109-2136  
Phone: (734) 763-2445  
Website: <http://www.mse.engin.umich.edu>

### Mission

To provide internationally recognized leadership in education, research and service in the field of materials science and engineering. This is achieved through educational programs that produce students with a strong background in scientific and engineering problem-solving methods as well as communication and teamwork skills.

### Goals

- To provide excellent, diverse students with the knowledge and engineering skills in a quality learning environment that will enable them to become flexible, effective, life-long learners and leaders in materials-related industries, government agencies and academia.
- To have a leading undergraduate program in materials science and engineering, one that integrates a strong scientific base with engineering experience.

## Objectives

The undergraduate program in the Department of Materials Science and Engineering at the University of Michigan will graduate students who:

- possess an understanding of the structure, properties, performance and processing of materials.
- adapt to the rapidly changing scientific and technological landscape and drive the development of future technologies.
- communicate effectively with their colleagues and the general public.
- contribute substantively to science, technology, the environment, and society.

## Outcomes

All Materials Science and Engineering graduates should have:

- an ability to apply knowledge of mathematics, science and engineering within their chosen field.
- an ability to formulate engineering problems and develop practical solutions.
- an initial ability to design products and processes applicable to their chosen field.
- an ability to design, conduct, analyze and interpret the results of engineering experiments.
- an ability to work effectively in diverse teams and provide leadership to teams and organizations.
- an ability for effective oral, graphic and written communication.
- a broad education necessary to understand the impact of engineering decisions in a global/society/economic/environmental context.
- an understanding of professional and ethical responsibility.
- a recognition of the need for and an ability to engage in life-long learning.
- a broad education necessary to contribute effectively beyond their professional careers.
- a sense of responsibility to make a contribution to society.

## Sample Schedule

### B.S.E. in Materials Science and Engineering

The Materials Science and Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <http://www.mse.engin.umich.edu/undergraduate/overview>.

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, 215, and 216	16	4	4	4	4	-	-	-	-
Engineering 100, Introduction to Engineering	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	-	4	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth (Includes Econ 101 and Econ 102)	16	4	4	-	4	-	4	-	-
<b>Science and Technical Subjects (14 hours)</b>									
ME 211, Introduction to Solid Mechanics	4	-	-	-	4	-	-	-	-
Science and Technical Electives (Must include CHEM 210 - if not already taken)	10	-	-	4	-	-	3	3	-
<b>Program Subjects (47 hours)</b>									
MSE 250, Principles of Engineering Materials or MSE 220, Introduction to Materials and Manufacturing	4	-	-	4	-	-	-	-	-
MSE 242, Physics of Materials	4	-	-	-	4	-	-	-	-
MSE 330, Thermodynamics of Materials	4	-	-	-	-	4	-	-	-
MSE 335, Kinetics and Transitions in Materials Engineering	4	-	-	-	-	-	4	-	-
MSE 350, Principles of Engineering Materials II	4	-	-	-	-	4	-	-	-
MSE 360, Materials Lab I	3	-	-	-	-	3	-	-	-
MSE 365, Materials Lab II	3	-	-	-	-	-	3	-	-
MSE 420, Mechanical Behavior of Materials	3	-	-	-	-	-	-	3	-
MSE 480, Materials and Engineering Design	3	-	-	-	-	-	-	-	3
MSE 489, Materials Processing Design	3	-	-	-	-	-	-	3	-
<b>Electives</b>									
Elect 3 MSE Slectives <sup>3</sup>	9	-	-	-	-	3	3	3	-
MSE Elective	3	-	-	-	-	-	-	-	3
<b>General Electives</b>	<b>12</b>	-	-	-	-	-	-	<b>3</b>	<b>9</b>
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>14</b>	<b>17</b>	<b>15</b>	<b>15</b>

Candidates for the Bachelor of Science Degree in Engineering in Materials Science and Engineering - B.S.E. in Matl. Sci. & E. - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

#### Notes:

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or credit from another institution you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or credit from another institution you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> Elect 3 From the Following List:

- MSE 400, EMO Materials for Modern Device Technology (3 hours)
- MSE 410, Design and Applications of Biomaterials (3 hours)
- MSE 412, Polymeric Materials (3 hours)
- MSE 440, Ceramic Materials (3 hours)
- MSE 454, Computational Approaches in Materials (3 hours)
- MSE 465, Structure & Chemical Characteristics of Materials (3 hours)
- MSE 470, Physical Metallurgy (3 hours)
- MSE 514, Composite Materials (3 hours)

## Sequential Undergraduate/ Graduate Study (SUGS)

Students should apply to the program in the first term of their senior year for provisional admission into the program in order to be advised appropriately regarding planning for undergraduate and graduate course selection. No dual enrollment will be required. Other requirements include a minimum undergraduate grade point average of 3.2 for provisional admission and subsequent enrollment into the SUGS program in Materials Science and Engineering. A maximum of nine (9) credits of prior-approved course work may be double counted. Only technical electives and/or general electives may be double counted. None of the 47 required Materials Science and Engineering credits may be used for the graduate degree. A maximum of 15 credit hours that are double counted or transferred for graduate credit are allowed. Contact the prospective department for more complete program information.

## Graduate

### Graduate Degrees

- Master of Science in Engineering (M.S.E.) in Materials Science and Engineering
- Doctor of Philosophy (Ph.D.) in Materials Science and Engineering
- SUGS (M.S.E.) in Materials Science and Engineering

### Master of Science Programs

Two different types of M.S.E. degrees are offered: one with a primary focus on coursework (the Coursework M.S.E.) and one with an emphasis on research (the Research M.S.E.). Students supported with a G.S.R.A. or research fellowship, must pursue a Research M.S.E. rather than a Coursework M.S.E.

### Coursework M.S.E. Degree

Students seeking a coursework M.S.E. degree must

complete 30 credit hours of courses, which must be approved by the student's advisor. Of the 30 credit hours, up to eight (8) credit hours may be satisfied by MATSCIE 690, and at least 15 credit hours of MATSCIE department courses (excluding MATSCIE 690) must be taken. At least two (2) cognate courses (a minimum of four (4) credit hours) must be taken.

Students taking MATSCIE 690 must submit a research report commensurate with the number of MATSCIE 690 credits taken. This report must be approved by the project supervisor. It may also be used as a document for the Ph.D. oral candidacy exam.

### Research M.S.E. Degree

Students seeking a Research M.S.E. degree must complete 30 credit hours of courses, which must be approved by the student's advisor. Students must take at least nine (9) credits of MATSCIE 690. Students must take at least 12 credit hours of MATSCIE department courses. Students must take at least two (2) cognate courses (a minimum of four (4) credit hours).

Students must submit a master's thesis to an examining committee of three faculty members, two of which must be from MATSCIE. This committee will include the research advisor and two other faculty selected by the advisor in consultation with the student and approved by the Graduate Committee Chair. The thesis may also be used as a document for the Ph.D. oral candidacy exam. The thesis must be defended orally before this committee and approved by a majority of the committee and the advisor. The oral defense may also serve as the Ph.D. oral exam at the committee's discretion. This thesis should contain a critical review of background information and relevant literature, a statement of objective, a results section and a thorough scientific analysis of these results. It should have a degree of originality suitable for publication. In the event that the student is not satisfied with the results of his/her examination(s), an appeal for arbitration can be made in sequence to the graduate committee chair, the Department chair, the Rackham Graduate School or the College of Engineering Ombudsman. Graduate students who pass the Ph.D. qualifying exam but still want a Masters Degree must also satisfy the above require-

ments.

## Ph.D. Programs

### Ph.D. in Materials Science and Engineering

Advancement to candidacy in the MATSCIE doctoral program is contingent on passing the written examination and the oral examination. A master's degree is not a prerequisite. Students must complete an additional nine (9) hours of formal coursework, above that required for the M.S.E. degree. Incoming students holding an M.S.E. degree (or equivalent) from another institution must complete an additional 18 hours of formal coursework to fulfill the residency and cognate requirements set forth by the Rackham Graduate School. In general, M.S. degrees from institutions outside the U.S. or Canada will be evaluated on an individual basis to determine if they meet the criteria for equivalency as set forth by the Graduate Committee of the MATSCIE department. The criteria for such a decision will be based on the academic standards of the foreign institution, the academic performance of the student at the institution and the fulfillment of course and research requirements similar to those required in the MATSCIE department. Reports, a thesis and publications may be submitted to the Graduate Committee for consideration in reaching decisions in such cases.

The Department will furnish details of requirements upon request. Also, a pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School Office, 1004 Rackham Building, upon request.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **MATSCIE 193. Special Topics in Materials Science and Engineering**

*Prerequisite: permission of instructor. (1-4 credits)*  
Special topics of current interest to students.

### **MATSCIE 220. Introduction to Materials and Manufacturing**

*Prerequisite: Chem 130 or Chem 210. (4 credits)*

Introduction to materials engineering and materials processing in manufacturing. The engineering properties of metals, polymers, semiconductors, ceramics and composites are correlated with the internal structure of the materials and the service conditions.

### **MATSCIE 242. Physics of Materials**

*Prerequisite: Physics 240 and preceded or accompanied by Math 216. (4 credits)*

Basic principles and applications of solid state physics. Mathematical and physical description of classical and quantum mechanics, crystallography and diffraction. Applications to solid, including band structure, bonding and physical properties.

### **MATSCIE 250. Principles of Engineering Materials**

*Prerequisite: Chem 130 or Chem 210. (4 credits)*

Introductory course to engineering materials. Properties (mechanical, thermal and electrical) of metals, polymers, ceramics and electronic materials. Correlation of these properties with (1) their internal structures (atomic, molecular, crystalline, micro- and macro-), (2) service conditions (mechanical, thermal, chemical, electrical, magnetic and radiation), and (3) processing.

### **MATSCIE 280. Materials Science and Engineering Undergraduate Research Opportunity**

*Prerequisite: Open only to 1st- or 2nd-year undergraduate students with permission of instructor. (1-4 credits)*

The UROP program enables students to work one-on-one or with a small group of students with faculty members conducting research. Students receive 1 credit per 3 hours of work per week. Students participating in the program are required to attend biweekly research peer group meetings, meet monthly with a peer advisor and keep a research journal.

### **MATSCIE 330. Thermodynamics of Materials**

*Prerequisites: Chem 130 or 210, Phys 140/141, Math 215, and MATSCIE 220 or 250. (4 credits)*

The laws of thermodynamics and their consequences. Applications to solid and liquid materials. Mass and

energy balances. Gas reactions. Phase diagrams. Ellingham, Pourbaix and stability diagrams. Defects in solids. Interfaces. Statistical thermodynamics.

### **MATSCIE 335. Kinetics and Transport in Materials Engineering**

*Prerequisite: Enforced: Math 216, MATSCIE 220 or 250, and MATSCIE 330. (4 credits)*

Application of basic principles of molecular transport and mass, energy and momentum balance to the solution of heat, diffusion and fluid flow problems relevant to materials processing. Introduction to radiative heat transfer. Empirical approaches to and dimensional analysis of complex transport problems including convection, turbulence and non-Newtonian flow.

### **MATSCIE 350. Structures of Materials**

*Prerequisite: MATSCIE 220 or MATSCIE 250. (4 credits)*

Basic principles of Materials Science & Engineering; including bonding, structure and microstructure and how they are influenced by thermodynamics and kinetics.

### **MATSCIE 360. Materials Laboratory I**

*Prerequisite: Accompanied or preceded by MATSCIE 350. (3 credits)*

Laboratory experiences based on principles emphasized in Fundamentals of Materials Science including processing, properties, and structure with a focus on microstructural analysis and structure-property relationships. Continued as MATSCIE 365.

### **MATSCIE 365. Materials Laboratory II**

*Prerequisite: MATSCIE 360 and preceded or accompanied by MATSCIE 242. (3 credits)*

Laboratory experiences based on principles emphasized in Physics of Materials and Fundamentals of Materials. Processing, properties and microstructure with a focus on electronic and magnetic phenomena.

### **MATSCIE 400. Electronic, Magnetic and Optical Materials for Modern Device Technology**

*Prerequisites: MATSCIE 242 and either MATSCIE 220 or 250 or equivalents. (3 credits)*

Application of solid-state phenomena in engineering structures such as microelectronic, magnetic and opti-

cal devices. Review of quantum mechanical descriptions of crystalline solids. Microelectronic, magnetic and optical properties of devices, fabrication and process methods.

### **MATSCIE 410 (BIOMEDE 410). Design and Applications of Biomaterials**

*Prerequisite: MATSCIE 220 or 250 or permission of instructor. (3 credits)*

Biomaterials and their physiological interactions. Materials used in medicine/dentistry: metals, ceramics, polymers, composites, resorbable smart, natural materials. Material response/degradation: mechanical breakdown, corrosion, dissolution, leaching, chemical degradation, wear. Host responses: foreign body reactions, inflammation, wound healing, carcinogenicity, immunogenicity, cytotoxicity, infection, local/systemic effects.

### **MATSCIE 412 (CHE 412) (MacroSE 412). Polymeric Materials**

*Prerequisites: MATSCIE 220 or 250 and CHEM 210. (3 credits)*

The synthesis, characterization, microstructure, rheology and processing of polymeric materials. Polymers in solution and in the liquid, liquid-crystalline, crystalline and glassy states. Engineering and design properties, including viscoelasticity, yielding and fracture. Forming and processing methods. Recycling and environmental issues.

### **MATSCIE 420. Mechanical Behavior of Materials**

*Prerequisite: MECHENG 211. (3 credits)*

Macroscopic and microscopic aspects of deformation and fracture. Plasticity, general continuum approach. Microscopic hardening mechanisms. Rate and temperature dependent deformation. Deformation and fracture mechanism maps. Fracture mechanics. Fatigue behavior.

### **MATSCIE 440. Ceramic Materials**

*Prerequisites: MATSCIE 350. (3 credits)*

Chemistry, structure, processing, microstructure and property relationships and their applications in design and production of ceramic materials.

### **MATSCIE 454. Computational Approaches in MSE**

*Prerequisite: Enforced: MATSCIE 330, 335, and 365.*

(3 credits)

Computational methods and tools used in materials science and engineering, including the advantages, disadvantages, and pitfalls associated with various methods, the concepts behind the methods and the basics of numerical modeling and simulation. The hands-on laboratory sessions, home problems, and class project provide first-hand learning experience in modeling.

**MATSCIE 465. Structural and Chemical Characterization of Materials**

*Prerequisites: MATSCIE 220 or 250, MATSCIE 242, and MATSCIE 360. (3 credits)*

Study of the basic structural and chemical characterization techniques that are commonly used in materials science and engineering. X-ray, electron and neutron diffraction, a wide range of spectroscopies, microscopies and scanning probe methods will be covered. Lectures will be integrated with a laboratory where the techniques will be demonstrated and/or used by the student to study a material. Techniques will be presented in terms of the underlying physics and chemistry.

**MATSCIE 470. Physical Metallurgy**

*Prerequisite: MATSCIE 350. (3 credits)*

Phase transformations and hardening mechanisms in metallic systems. Nucleation, diffusion-controlled growth, spinodal decomposition and martensitic reactions. Strengthening mechanisms based on two-phase microstructure thermal stability.

**MATSCIE 480. Materials and Engineering Design**

*Prerequisite: Senior standing. (3 credits)*

Design concepts. Engineering economics. Various design criteria, processes and process control. Materials substitution. Competitive design. Case histories. Professional and ethical considerations. Written and oral presentations of solutions to design problems.

**MATSCIE 485 (MFG 458). Design Problems in Materials Science and Engineering**

*Prerequisite: MATSCIE 480. (1-4 credits) (to be arranged)*

The design of production and refining systems for engineering materials. Design of problems for the extraction and refining of metals, production and processing of ceramics, polymeric materials, and electronic materi-

als. Written and oral presentation of solutions to processing design problems.

**MATSCIE 489. Materials Processing Design**

*Prerequisites: MATSCIE 330 and MATSCIE 335. (3 credits)*

The design of production and refining systems for engineering materials. Design of problems for the extraction and refining of metals, production and processing of ceramics, polymeric materials and electronic materials. Written and oral presentation of solutions to processing design problems.

**MATSCIE 490. Research Problems in Materials Science and Engineering**

*Prerequisite: Not open to graduate students. (to be arranged)*

Individual or group work in a particular field or on a problem of special interest to the student. The program of work is arranged at the beginning of each term by mutual agreement between the student and a faculty member. Written and oral reports are required. Laboratory and conferences.

**MATSCIE 493. Special Topics in Materials Science and Engineering**

*Prerequisite: MATSCIE 350. (to be arranged)*

Selected topics of current interest for students entering industry.

**MATSCIE 500. Materials Physics and Chemistry**

*Prerequisite: Senior level or graduate standing. (3 credits)*

Physical properties of a wide range of materials, including crystalline and organic materials from the electronic and atomic point of view. The bonding and structure of materials will be placed in context of quantum mechanics and band theory; and the electrical, optical, thermal, mechanical and magnetic properties will be emphasized.

**MATSCIE 502. Materials Issues in Electronics**

*Prerequisites: MATSCIE 242 and MATSCIE 400 or equivalent. (3 credits)*

This course covers the key materials issues, including defects, diffusion and oxidation relevant to the conversion of a material into an electronic device.

**MATSCIE 505. Materials Science of Thin Films**

*Prerequisites: MATSCIE 242 and MATSCIE 400 or equivalent. (3 credits)*

Thermodynamics and kinetics of film nucleation, growth, structure and stability for a single crystal, polycrystalline and amorphous thin films.

**MATSCIE 510 (CHEM 511). Materials Chemistry (3 credits)**

This course presents concepts in materials chemistry. The main topics covered include structure and characterization, macroscopic properties and synthesis and processing.

**MATSCIE 511 (CHE 511) (MacroSE 511). Rheology of Polymeric Materials**

*Prerequisite: A course in fluid mechanics or permission from instructor. (3 credits)*

An introduction to the relationships between the chemical structure of polymer chains and their rheological behavior. The course will make frequent reference to synthesis, processing, characterization and use of polymers for high technology applications.

**MATSCIE 512 (CHE 512) (MacroSE 512). Polymer Physics**

*Prerequisite: Senior or graduate standing in engineering or physical science. (3 credits)*

Structure and properties of polymers as related to their composition, annealing and mechanical treatments. Topics include creep, stress relaxation, dynamic mechanical properties, viscoelasticity, transitions, fracture, impact response, dielectric properties, permeation and morphology.

**MATSCIE 514 (MacroSE 514) (MFG 514). Composite Materials**

*Prerequisite: MATSCIE 350. (3 credits)*

Behavior, processing, and design of composite materials, especially fiber composites. Emphasis is on the chemical and physical processes currently employed and expected to guide the future development of the technology.

**MATSCIE 515 (MacroSE 515). Mechanical Behavior of Solid Polymeric Materials**

*Prerequisite: MECHENG 211, MATSCIE 412. (3 credits)*

*its)*

The mechanical behavior of polymers from linear viscoelastic to yield and fracture are covered. Specific topics include dynamic-mechanical relaxations, creep, yielding, crazing, fatigue and fracture mechanics. The materials include toughened plastics, polymer alloys and blends and composite materials. Structured design with plastics is also considered.

**MATSCIE 516 (MECHENG 516). Mechanics of Thin Films and Layered Materials**

*Prerequisite: MECHENG 311 or graduate standing. (3 credits)*

Stresses and deformations in layered materials; energy-release rates and delamination; fracture mechanics of layered materials; spalling; interfacial fracture mechanics; mixed-mode fracture; buckling-driven delamination; cracking of thin films; effects of plasticity on fracture; stress-relaxation mechanisms in multi-layered materials; adhesion and fracture tests.

**MATSCIE 517 (MACROMOL 530). Advanced Function Polymers: Molecular Design and Applications**

*Prerequisite: MSE 412 or graduate standing. W/ minimum grade of C-. (3 credits)*

Development of global perspective of interdisciplinary issues involved in functional polymers. Learn how to design, synthesize, evaluate, and analyze functional polymers.

**MATSCIE 520. Advanced Mechanical Behavior**

*Prerequisite: Graduate standing. (3 credits)*

Advanced studies of deformation and failure in materials. Macroscopic and microscopic aspects of deformation. Elasticity and plasticity theories and problems in deformation processing. Fracture mechanics and composite toughening mechanisms. Mechanisms of creep deformation.

**MATSCIE 532. Advanced Thermodynamics of Materials**

*Prerequisite: MATSCIE 330 or equivalent. (3 credits)*

Classical and statistical thermochemistry with emphasis on topics important in materials science and engineering, including thermodynamics of solids, solution thermochemistry, heterogeneous equilibria of stable and

metastable phases, multicomponent systems, coherent equilibria and strain effects, interfaces and adsorption, polymer alloys and solutions.

### **MATSCIE 535. Kinetics, Phase Transformations, and Transport**

*Prerequisite: MATSCIE 330 or equivalent. (3 credits)*

Fundamentals of phase change, diffusion, heat transport, nucleation, and growth applied to solidification, ordering, spinodal decomposition, coarsening, reactions, massive transformations, diffusion-limited transformations and glass transitions.

### **MATSCIE 550. Fundamentals of Materials Science and Engineering**

*Prerequisite: Senior or graduate standing or permission of instructor. (3 credits)*

An advanced level survey of the fundamental principles underlying the structures, properties, processing and uses of engineering materials.

### **MATSCIE 554 (CHE 554). Computational Methods in MATSCIE and CHE**

*Prerequisite: Senior level or graduate standing. (3 credits)*

Broad introduction to the methods of numerical problem solving in Materials Science and Chemical Engineering. Topics include numerical techniques, computer algorithms and the formulation and use of computational approaches for the modeling and analysis of phenomena peculiar to these disciplines.

### **MATSCIE 555. Materials Energy Conversion**

*Prerequisite: Senior standing or higher. (3 credits)*

The course includes an introduction to energy conversion and storage issues. Next, the operating principles of energy conversion and storage devices are discussed. The remainder of the course focuses on the physics and chemistry of nanostructures and nanomaterial design and processing approaches to enhanced performance photovoltaics, thermoelectrics and fuel cells.

### **MATSCIE 556. Molecular Simulation of Materials**

*Prerequisite: Senior level or graduate standing. (3 credits)*

Practical and theoretical consideration in the simulation of materials on the molecular level. Molecular dynam-

ics and Monte Carlo techniques. Empirical interaction potentials for metals, ceramics and polymers. Statistical mechanics and thermodynamics of simulated systems.

### **MATSCIE 557 (CHE 557). Computational Nanoscience of Soft Matter**

*Prerequisites: Differential equations course, and a statistical thermodynamics or statistical mechanics course. (3 credits)*

Provides an understanding of strategies, methods, capabilities and limitations of computer simulation as it pertains to the modeling and simulation of soft materials at the nanoscale. The course consists of lectures and hands-on, interactive simulation labs using research codes and commercial codes. Ab initio, molecular dynamics, Monte Carlo and mesoscale methods.

### **MATSCIE 558 (CHE 558) (MacroE 558). Foundations of Nanotechnology**

*Prerequisites: Senior or graduate standing. (3 credits)*

The focus of this course is on the scientific foundations of nanotechnology. The effects of nanoscale dimensions on optical, electrical and mechanical properties are explained based on atomistic properties and related to applications in electronics, optics, structural materials and medicine. Projects and discussions include startup technological assessment and societal implications of the nanotechnology revolution.

### **MATSCIE 559 (CHE 559) (MacroE 559). Foundations of Nanotechnology II**

*Prerequisites: Senior or graduate standing. (3 credits)*

This course will cover the synthesis and processing of nano-sized metal, metal oxide and semiconductor powders. It will also include organic/inorganic and nanobiomaterials. Emphasis will be on particle properties and their use in making nonstructured materials with novel properties.

### **MATSCIE 560. Structure of Materials**

*Prerequisite: MATSCIE 550. (3 credits)*

Atomic arrangements in crystalline and noncrystalline materials. Crystallography, kinematic and dynamical theories of diffraction, applications to x-rays, electrons and neutrons. Interpretation of diffraction patterns and intensity distributions, applications to scattering in perfect and imperfect crystals and amorphous materials.

Continuum description of structure emphasizing the tensor analysis of distortions in solids.

### **MATSCIE 562. Electron Microscopy I**

*(4 credits)*

An introduction to electron optics, vacuum techniques and the operation of electron optical instruments. The theory and applications of transmission and scanning electron microscopy and electron microprobe analysis in the study of nonbiological materials.

### **MATSCIE 563 (BIOMEDE 563) (CHE 563). Biomolecular Engineering of Interfaces**

*Prerequisite: Senior or graduate standing. (3 credits)*

This class focuses on biomolecular engineering of surfaces and interfaces in contact with biological systems. Recent advances in the interfacial design of materials as well as methods that enable studying such systems will be highlighted.

### **MATSCIE 574. High-Temperature Materials**

*Prerequisite: MATSCIE 350. (3 credits)*

Principles of behavior of materials at high temperatures. Microstructure-property relationships including phase stability and corrosion resistance to high temperature materials. Fracture and fatigue at elevated temperatures. Damage accumulation behavior and engineering applications of service life techniques.

### **MATSCIE 577 (MFG 577). Failure Analysis of Materials**

*Prerequisite: MATSCIE 350. (3 credits)*

Analysis of failed structures due to tensile overload, creep, fatigue, stress corrosion, wear and abrasion, with extensive use of scanning electron microscope. Identification and role of processing defects in failure.

### **MATSCIE 583 (BIOMEDE 583) (CHE 583). Biocompatibility of Materials**

*Prerequisite: Undergraduate course in biology and/or physiology; undergraduate course in biochemistry, organic chemistry, or molecular biology. (2 credits)*

This course describes the interactions between tissue and materials and the biologic/pathologic processes involved. In addition, specifications which govern biocompatibility testing, various strengths and weaknesses of a number of approaches to testing, and future direc-

tions are discussed.

### **MATSCIE 585. Materials or Metallurgical Design Problem**

*Prerequisite: MATSCIE 480. (2 credits)*

Engineering design and economic evaluation of a specific process and/or materials application. Original and individual work and excellence of reporting emphasized. Written and oral presentation of design required.

### **MATSCIE 593. Special Topics in Materials Science & Engineering**

*Prerequisite: Permission of instructor. (1-4 credits)*

Special topics of interest to graduate students; and, possibly, undergraduate students.

### **MATSCIE 621 (NERS 621). Nuclear Waste Forms**

*Prerequisites: NERS 531 (recommended). (3 credits)*

This interdisciplinary course will review the materials science of radioactive waste remediation and disposal strategies. The main focus will be on corrosion mechanisms, radiation effects and the long-term durability of glasses and crystalline ceramics proposed for the immobilization and disposal of nuclear waste.

### **MATSCIE 622 (MFG 622) (NERS 622). Ion Beam Modification and Analysis of Materials**

*Prerequisite: NERS 421, NERS 521 or MATSCIE 350 or permission of instructor. (3 credits)*

Ion-solid interactions, ion beam mixing, compositional changes, phase changes, micro-structural changes; alteration of physical and mechanical properties such as corrosion, wear, fatigue, hardness; ion beam analysis techniques such as RBS, NRA, PIXE, ion channeling, ion microprobe; accelerator system design and operation as it relates to implantation and analysis.

### **MATSCIE 662. Electron Microscopy II**

*Prerequisite: MATSCIE 562. (3 credits)*

Advanced methods in electron microscopy such as high resolution bright field and dark field imaging, micro and convergent beam diffraction, analysis of thin film specimens and electron energy loss spectroscopy. Two lectures and one three-hour laboratory-discussion session per week.

### **MATSCIE 690. Research Problems in Materials**

**Science and Engineering***(to be arranged)*

Laboratory and conferences. Individual or group work in a particular field or on a problem of special interest to the students. The program of work is arranged at the beginning of each term by mutual agreement between the student and a member of the faculty. Any problem in the field of materials and metallurgy may be selected. The student writes a final report on this project.

**MATSCIE 693. Special Topics in Materials Science and Engineering***(to be arranged)***MATSCIE 751 (CHE 751) (Chem 751) (MacroSE 751) (Physics 751). Special Topics in Macromolecular Science***Prerequisite: Permission of instructor. (2 credits)*

Advanced topics of current interest will be stressed. The specific topics will vary with the instructor.

**MATSCIE 890. Colloquium in Materials Science and Engineering***(1 credit)*

Colloquium presentations covering a variety of topics at the forefront of research and development in materials science and engineering, including design, synthesis, fabrication, characterization and applications of metallic materials, inorganic, electronic, organic, and polymeric materials. Colloquia are delivered by renowned experts in their respective fields from academia, industry and national laboratories.

**MATSCIE 990. Dissertation/Pre-Candidate***(2-8 credits); (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**MATSCIE 995. Dissertation/Candidate***Prerequisite: Graduate School authorization for admission as a doctoral candidate (8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Mechanical Engineering

## Overview

The Department of Mechanical Engineering at the University of Michigan reflects the broad aspects of the mechanical engineering field. As exhibited by our internationally recognized leadership in traditional fields such as manufacturing and automotive engineering, to new enabling technologies of micro- and nanotechnology, biomechanics and biomaterials and environmentally friendly product design, our mechanical engineers are well positioned for the research, design, development and manufacture of a diverse set of systems and products.

The Mechanical Engineering program provides students with an excellent foundation in the core technical competencies of the discipline: thermal and fluid sciences, solid mechanics and materials and dynamics and control. Built upon these strengths is a very strong focus on application of these technical abilities through our design and manufacturing laboratory sequences. In addition, an array of technical electives is offered to enable students to tailor their mechanical engineering education to best suit their career goals.

There are numerous programs offered to enrich education, such as dual-degrees (M.E. degree and a second degree from another Engineering program), Sequential Undergraduate/Graduate Studies (SUGS), the Engineering Global Leadership Honors Program (EGL), Education Abroad (listed among CoE minors) and independent study opportunities with ME faculty. Students interested in any of these programs should contact the Mechanical Engineering Academic Services Office.

Students who do well in their undergraduate program are encouraged to consider graduate work and may take some of their electives in preparation for graduate study.

Information and assistance regarding fellowships and assistantships for graduate study may be obtained in the Academic Services Office of the Department of Mechanical Engineering.

# Department Administration

## Department Chair

Kon-Well Wang,  
Tim Manganello/BorgWarner Department Chair,  
Mechanical Engineering;  
Stephen P. Timoshenko Collegiate Professor of  
Mechanical Engineering  
2370D G.G. Brown

## Contacts

Mechanical Engineering Department  
G.G. Brown Bldg.  
2350 Hayward St.  
Ann Arbor, MI 48109-2125

**Departmental Website:** <http://me.engin.umich.edu/>

## Mission

To prepare the graduates for diverse careers in both mechanical engineering and related fields.

## Goals

To have students graduate with outstanding problem solving skills and a superb knowledge of mechanical engineering that allows them to continue their education throughout their careers and to become leaders in their fields.

## Program Educational Objectives

The Mechanical Engineering Program is designed to prepare students for continued learning and successful careers in industry, government, academia and consulting. Our alumni are expected to:

1. Apply their engineering knowledge, critical thinking and problem solving skills in professional engineering practice or in non-engineering fields, such as law, medicine or business.

2. Continue their intellectual development via graduate education or professional development courses, for example.
3. Embrace leadership roles in their careers.

## Outcomes

The outcomes that we desire our graduates demonstrate are:

- An ability to apply knowledge of mathematics, science and engineering to mechanical engineering problems.
- An ability to design and conduct experiments, as well as to analyze and interpret data.
- An ability to design systems, components or processes to meet desired needs.
- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate and solve engineering problems.
- An understanding of professional and ethical responsibility.
- An ability to effectively communicate via written, oral and visual means.
- The broad education necessary to understand the impact of engineering solutions in a global and societal context.
- A recognition of the need for and an ability to engage in life-long learning.
- A knowledge of contemporary issues.
- An ability to use modern engineering techniques, skills and computing tools necessary for engineering practice.
- An ability to work professionally in both thermal and mechanical systems areas.

# Sample Schedule

## B.S.E. in Mechanical Engineering

The Mechanical Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://abet.org>. Additional information can be found on the department advising website, <http://me.engin.umich.edu/academics/ugsh>

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by all Programs (55 hours)</b>									
Mathematics 115, 116, 215, 216+	16	4	4	4	4	-	-	-	-
Engineering 100, Introduction to Engineering+	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers+	4	-	4	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1+</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth (including one course in economics or financials <sup>4</sup> )	16	3	4	-	-	-	3	-	6
<b>Related Program Subjects (7 hours)</b>									
Advanced Mathematics <sup>3</sup>	3	-	-	-	-	-	3	-	-
EECS 314, Elect Cir, Sys, and Appl or EECS 215, Intro to Circuits	4	-	-	-	-	4	-	-	-
<b>Program Subjects (45 hours)</b>									
ME 211, Introduction to Solid Mechanics +	4	-	-	4	-	-	-	-	-
ME 235, Thermodynamics I+	3	-	-	-	3	-	-	-	-
ME 240, Introduction to Dynamics and Vibrations+	4	-	-	-	4	-	-	-	-
ME 250, Design and Manufacturing I +	4	-	-	-	4	-	-	-	-
ME 320, Fluids I+	3	-	-	-	-	3	-	-	-
ME 335, Heat Transfer	3	-	-	-	-	-	3	-	-
ME 350, Design and Manufacturing II +	4	-	-	-	-	4	-	-	-
ME 360, Systems and Controls +	4	-	-	-	-	-	4	-	-
ME 382, Engineering Materials +	4	-	-	-	-	4	-	-	-
ME 395, Laboratory I +	4	-	-	-	-	-	4	-	-
ME 450, Design and Manufacturing III	4	-	-	-	-	-	-	-	4
ME 495, Laboratory II	4	-	-	-	-	-	-	4	-
<b>Electives (Minimum 21)</b>									
Technical Electives <sup>3</sup>	9	-	-	-	-	-	-	6	3
Specialization Elective <sup>5</sup>	3								3
General Electives	9	-	-	3	-	-		6	
<b>Total</b>	<b>128</b>	<b>16</b>	<b>17</b>	<b>16</b>	<b>15</b>	<b>15</b>	<b>17</b>	<b>16</b>	<b>16</b>

Candidates for the Bachelor of Science Degree in Engineering in Mechanical Engineering - B.S.E. in Mech. E. - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

### Notes:

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 or Chemistry 210/211, you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and/or Physics 240/241 you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> Advanced Mathematics, and Technical Electives: A list of approved courses is available on the ME Department's Website & in the Academic Services Office (ASO).

<sup>4</sup> The ME department requires each student to take at least 3 credit hours economic or financial course as part of their Intellectual Breadth requirements. Any course on the supplied list within LS&A fulfills the Intellectual Breadth as a LAC. Any course on the supplied list outside of LS&A fulfills the Intellectual Breadth as a Professional & Creative Development Courses (PCDC). A list of ME approved courses is available on the ME Department's Website and in the Academic Services Office (ASO).

<sup>5</sup> A specialization elective is any 3 credit hour course that meets the requirement of either: 1) have a 300-level or higher prerequisite; or 2) be any 300-level or higher ME course.

(+) "C-" rule: Students must earn a "C-" or better in prerequisite courses indicated by the (+) symbol; anything less must be repeated prior to taking a subsequent class for which this class is required.

"D" Rule: No grade less than a "D" shall be earned in any course used for degree credit.

The Mechanical Engineering program offers several dual and joint degree programs.\* A 3.0 cumulative and math, science, and engineering grade point average is required for admissions to one of these programs. As well, minors through LS&A (see CoE Bulletin) and a Concentration in Manufacturing Systems Design or in Energy Systems is available. Refer to the ME Department's Website or consult with staff in the ASO.

\* There are dual degree programs with other Engineering Departments and Joint (MDDP) degrees with other Schools such as Music and LS&A.

## M.E. Program Specific Course Requirements

Within the M.E. program, there are five categories of program specific courses. These include M.E. Core courses, Technical Electives, Specialization Elective, Advanced Math and EECS 314/215.

### M.E. Core Courses

The M.E. Core courses consist of five categories: Design and Manufacturing, Mechanics and Materials, Dynamics and Controls, Thermal Sciences and Laboratories and Technical Communication. In total, there are 45 credits of required M.E. Core courses; and together these subjects represent the fundamental technical competencies every mechanical engineering student must learn. The list below outlines the courses from each of the core categories:

- Design and Manufacturing: ME 250, ME 350, ME 450
- Mechanics and Materials: ME 211, ME 382
- Dynamics and Controls: ME 240, ME 360
- Thermal Sciences: ME 235, ME 320, ME 335
- Labs and Technical Communication: ME 395, ME 495

### Technical Electives (T.E.s)

All M.E. students are required to take nine (9) credits of advanced technical electives (a grade of at least "D" must be obtained in each course). It is the intent of the advanced technical elective requirement that students take a number of "core technical electives" to develop a deeper technical knowledge in specific areas of mechanical engineering.

The nine (9) credits of advanced TEs required are broken down into two (2) categories. The categories are:

1. One class (at least three (3) credit hours) must be a 400-level or higher class in Mechanical Engineering. This may include 400-level classes off the core TE list but does not have to. Note that ME 490 or

ME 491 can fulfill this requirement.

2. Two (2) core TE classes (totaling at least six (6) credit hours) must come from the following list:
  - Design and Manufacturing: ME 452, ME 481, ME 483, ME 487
  - Mechanics and Materials: ME 424, ME 440, ME 461\*
  - Dynamics and Controls: ME 305, ME 311, ME 406, ME 412, ME 451
  - Thermal Sciences: ME 336, ME 420, ME 432, ME 433
  - General: ENGR 350\*\*

\*EECS 460 may be elected as a non-M.E. class, fulfilling a CORE or a Specialization Elective requirement (see guidelines below), but students may not take both EECS 460 and ME 461 for T.E. and Specialization Elective credit.

\*\*ENGR 350 is offered at Technical University of Berlin during the summer only. For ENGR 350 to be counted as an M.E. Technical Elective, the required sophomore-level M.E. courses (ME 211, ME 235, ME 240, ME 250) must be taken before ENGR 350. Otherwise, ENGR 350 counts as a general elective.

### Specialization Elective

A Specialization Elective is any course intended to allow students to explore deeply any dimension of intellectual endeavor that they elect, in both technical (including engineering) and non-technical fields (across the University). A Specialization Elective is any three (3) hour credit course that meets the requirement of either 1) have a 300-level or higher prerequisite; or 2) be any 300-level or higher M.E. course.

### Advanced Math

In addition to the CoE Core math courses, the M.E. department requires students to complete an Advanced Math course (3-4 credits). Students must earn a "D" grade or better to receive credit for the Advanced Math requirement, and it cannot be taken Pass/Fail. The approved list of Advanced Math courses recommended for ME students is provided on the department advising

website: <http://me.engin.umich.edu/academics/ugsh/courses#math>.

## Electrical Circuits

Also as part of the undergraduate ME degree, students must complete EECS 314 (4) - Electrical Circuits, Systems and Applications. Students must earn a "D" grade or better in EECS 314, and cannot take it Pass/Fail.

Students that wish to complete an Electrical Engineering minor should enroll in EECS 215 (4) - Introduction to Electronic Circuits, which counts in place of EECS 314 and follows the same grading rules. Students who are interested in the Electrical Engineering minor should contact the EE department for more information.

## Economics

The M.E. department requires each student to take at least three (3) credit hours economic or financial course as part of their Intellectual Breadth requirements. Any course on the supplied list within LSA fulfills the Intellectual Breadth as a LAC. Any course on the supplied list outside of LSA fulfills the Intellectual Breadth as a Professional & Creative Development Courses (PCDC). The approved list of economic/financial courses recommended for ME students is provided on the department advising website.

## General Electives (G.E.s)

The M.E. B.S.E. degree requires 128 credits to graduate. 119 credits are completed via the CoE Core courses, Intellectual Breadth courses, and ME Program Specific courses. General Electives complete the balance of the credits to reach the 128 total credits, which usually amounts to 9 to 12 credits of G.E. coursework.

For transfer students, students who received credit by exam, or students who transferred one or more courses from another institution, the total number of credits from the other categories may not equal 119 credits. As a result, some students will need to enroll in more or

less than 9 general elective credits, depending on how many credits are needed to reach the 128 credits required for graduation.

For the description of what courses count as General Electives, please see the CoE Bulletin: <http://www.engin.umich.edu/college/academics/bulletin/ug-ed/reqs#generalelectives>

## Sequential Undergraduate/Graduate Study (SUGS)

Students need to apply to the program at the end of the junior year for provisional admission into the respective program in order to be advised appropriately regarding planning for undergraduate and graduate course selections. This is known as the Intent Form. Requirements differ from one SUGS program to another and include: (1) a minimum undergraduate grade point average of 3.2 to 3.6, (2) a maximum of six (6) to nine (9) credits of previously approved course work may be double counted, (3) only technical electives, advanced mathematics or general electives may be double counted. Go to Departmental Contacts to find the prospective department liaison with whom to discuss complete program information.

## Joint Institute - Sequential Undergraduate/Graduate Study (JI-SUGS)

This program is designed for students who receive an undergraduate M.E. B.S.E. degree from the UM - Shanghai Jiao Tong University's Joint Institute and wish to pursue a Mechanical Engineering Master's degree at U.M. Students that participate in the joint undergraduate program and receive two undergraduate degrees from U.M. and S.J.T.U. are not eligible for this program. Students that have received only a M.E. bachelor's from S.J.T.U. and have maintained a 3.6 G.P.A. throughout their tenure may apply to the program through the Rackham Admissions Application. Requirements include: (1) a M.E. B.S.E. degree from S.J.T.U., (2) a minimum undergraduate grade point

average of 3.6, (3) a maximum of six (6) credits of previously approved course work may be double counted, and (4) only technical electives, advanced mathematics or general electives may be double counted. Go to Departmental Contacts to find the prospective department liaison with whom to discuss complete program information.

## Graduate

### Graduate Degrees

- Master of Science in Engineering (M.S.E.) in Mechanical Engineering
- Doctor of Philosophy (Ph.D.) in Mechanical Engineering

#### M.S.E. in Mechanical Engineering

The requirement for this degree is 30 credit hours of approved graduate course work. At least 18 hours must be taken in mechanical engineering, six (6) hours in mathematics, and six (6) cognate credits. Up to six (6) credit hours of research or nine (9) credit hours of thesis can be taken as part of a 30 credit hour requirement. Details of degree requirements may be found at <http://me.engin.umich.edu/academics/gsh/masters>.

#### Ph.D. in Mechanical Engineering

A doctoral committee is appointed for each applicant to supervise the investigative work of the student and election of graduate courses of instruction and passing the qualifying examination. Candidacy is achieved when the student demonstrates competence in his/her field of knowledge through completion of courses and passing the preliminary examination.

The doctoral degree is conferred after the student presents the result of their investigation in the form of a dissertation and in recognition of marked ability and scholarship in a relatively broad field of knowledge. For more information, please go to <http://me.engin.umich.edu/academics/overview/phd>.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

#### MECHENG 211. Introduction to Solid Mechanics

*Prerequisite: Physics 140, Math 116. (4 credits)*

Statics: moment and force resultants, equilibrium. Mechanics of deformable bodies: stress/strain, classification of material behavior, generalized Hooke's law. Engineering applications: axial loads, torsion of circular rods and tubes, bending and shear stresses in beams, deflection of beams, combined stresses, stress and strain transformation. Four lecture classes per week.

#### MECHENG 235. Thermodynamics

*Prerequisite: Chem 130, 125 or Chem 210, 211, and Math 116. (3 credits)*

Introduction to engineering thermodynamics. First law, second law system and control volume analyses; properties and behavior of pure substances; application to thermodynamic systems operating in a steady state and transient processes. Heat transfer mechanisms. Typical power producing cycles and refrigerators. Ideal gas mixtures and moist air applications.

#### MECHENG 240. Introduction to Dynamics and Vibrations

*Prerequisite: Physics 140, preceded or accompanied by Math 216. (4 credits)*

Vector description of force, position, velocity and acceleration in fixed and moving reference frames. Kinetics of particles, of assemblies of particles and of rigid bodies. Energy and momentum concepts. Euler's equations. Moment of inertia properties. The simple oscillator and its applications.

#### MECHENG 250. Design and Manufacturing I

*Prerequisite: Math 116, ENGR 101 or equivalent. (4 credits)*

Basics of mechanical design: visual thinking, engineering drawing and machine anatomy. Basics of manufacturing: processes, materials and thermofluid aspects. Use of computers in various phases of design and manufacturing. Exposure to CAD systems and basic machine shop techniques. Design/manufacturing project.

Three hours lecture and two hours laboratory.

**MECHENG 290. RISE 2 - Research, Innovation, Service and Entrepreneurship**

*Prerequisite: Permission of instructor. (1-3 credits)*

Individual or group project work where student(s) must apply mechanical engineering principles to research, innovation, service or entrepreneurship projects. Student(s) work under the direction of mechanical engineering faculty.

**MECHENG 305. Introduction to Finite Elements in Mechanical Engineering**

*Prerequisite: MECHENG 311. (3 credits)*

Introduction to theory and practice of the finite element method. One-dimensional, two-dimensional and three dimensional elements is studied, including structural elements. Primary fields of applications are strength of materials (deformation and stress analysis) and dynamics and vibrations. Extensive use of commercial finite element software packages, through computer labs and graded assignments. Two hour lecture and one hour lab.

**MECHENG 311. Strength of Materials**

*Prerequisite: MECHENG 211, Math 216. (3 credits)*

Energy methods; buckling of columns, including approximate methods; bending of beams of asymmetrical cross-section; shear center and torsion of thin-walled sections; membrane stresses in axisymmetric shells; elastic-plastic bending and torsion; axisymmetric bending of circular plates.

**MECHENG 320. Fluid Mechanics I**

*Prerequisite: Math 215, MECHENG 235 and MECHENG 240. (3 credits)*

Fluid statics; conservation of mass, momentum and energy in fixed and moving control volumes; steady and unsteady Bernoulli's equation; differential analysis of fluid flow; dimensional analysis and similitude; laminar and turbulent flow; boundary layers; lift and drag; introduction to commercial CFD packages; applications to mechanical, biological, environmental, and microfluidic systems

**MECHENG 335. Heat Transfer**

*Prerequisite: MECHENG 320. (3 credits)*

Heat transfer by conduction, convection, radiation; heat storage, energy conservation; steady-state/transient conduction heat transfer; thermal circuit modeling; multidimensional conduction; surface radiation properties, enclosure radiation exchange; surface convection/ fluid streams over objects, non-dimensional numbers, laminar, turbulent, thermo-buoyant flow, boiling and condensation; heat exchangers; design of thermal systems, solvers for problem solving/ design.

**MECHENG 336. Thermodynamics II**

*Prerequisite: MECHENG 235. (3 credits)*

Thermodynamic power and refrigeration systems; availability and evaluation of thermodynamic properties; general thermodynamic relations, equations of state and compressibility factors; chemical reactions; combustion; gaseous dissociation; phase equilibrium. Design and optimization of thermal systems.

**MECHENG 350. Design and Manufacturing II**

*Prerequisite: MECHENG 211, MECHENG 240, MECHENG 250, preceded or accompanied by MECHENG 382. (4 credits)*

Principles of mechanical design and manufacturing. Analysis, synthesis and selection of mechanisms, machine components and associated manufacturing processes. Design projects. Three hour lecture and one two-hour lab.

**MECHENG 360. Modeling, Analysis and Control of Dynamic Systems**

*Prerequisite: MECHENG 240 and P/A EECS 314. (4 credits)*

Developing mathematical models of dynamic systems, including mechanical, electrical, electromechanical and fluid/thermal systems and representing these models in transfer function and state space form. Analysis of dynamic system models, including time and frequency responses. Introduction to linear feedback control techniques. Synthesis and analysis by analytical and computer methods. Four hours of lecture per week.

**MECHENG 382. Mechanical Behavior of Materials**

*Prerequisite: MECHENG 211. (4 credits)*

Material microstructures, dislocations and defects; processing and mechanical properties of metals, polymers and composites; heat treatment of metals; elastic, plas-

tic, and viscoelastic behavior of materials, strain hardening; fracture, fracture mechanics, fatigue and multi-axis loading; creep and stress relaxation; materials-related design issues, materials selection, corrosion and environmental degradation of materials.

### **MECHENG 390. RISE 3 - Research, Innovation, Service, Entrepreneurship**

*Prerequisite: Permission of instructor. (2-3 credits)*  
Individual or group project work where student(s) must apply mechanical engineering principles to research, innovation, service or entrepreneurship projects. Student(s) work under the direction of Mechanical Engineering faculty. The student(s) submits proposal and presents poster at ME Undergraduate Symposium.

### **MECHENG 395. Laboratory I**

*Prerequisite: Physics 240, 241, [Physics 260,261] MECHENG 211, MECHENG 235, and MECHENG 240; preceded or accompanied by MECHENG 320, and MECHENG 382. (4 credits)*

Weekly lectures and experiments designed to introduce the student to the basics of experimentation, instrumentation, data collection and analysis, error analysis and reporting. Topics will include fluid mechanics, thermodynamics, mechanics, materials and dynamical systems. Emphasis is placed on report writing and team-building skills.

### **MECHENG 400. Mechanical Engineering Analysis**

*Prerequisite: MECHENG 211, MECHENG 240, Math 216. (3 credits)*

Exact and approximate techniques for the analysis of problems in mechanical engineering including structures, vibrations, control systems, fluids, and design. Emphasis is on application.

### **MECHENG 401 (MFG 402). Statistical Quality Control and Design**

*Prerequisite: Senior or graduate standing. (3 credits)*  
Evolution of quality methods. Fundamentals of statistics. Process behavior over time. Concept of statistical process control (SPC). Design and interpretation of control charts. Process capability study. Tolerance. Measurement system analysis. Correlation. Regression analysis. Independent t-test and paired t-test. Design and analysis of two-level factorial experiments. Frac-

tional factorial experiments. Response model building. Taguchi methods. Case studies.

### **MECHENG 406. Biomechanics for Engineering Students.**

*Prerequisites: MECHENG 320 and MECHENG 382. (3 credits)*

Fundamental properties of biological systems, followed by a quantitative, mechanical analysis. Topics include mechanics of the cytoskeleton, biological motor molecules, cell motility, muscle, tissue and bio-fluid mechanics, blood rheology, bio-viscoelasticity, biological ceramics, animal mechanics and locomotion, biomimetics and effects of scaling. Individual topics will be covered on a case by case study basis.

### **MECHENG 412. Advanced Strength of Materials**

*Prerequisite: MECHENG 311. (3 credits)*

Review of energy methods, Betti's reciprocal theorem; elastic, thermoelastic and elastoplastic analysis of axisymmetric thick cylinders and rotating discs; bending of rectangular and circular plates, including asymmetric problems; beams on elastic foundations; axisymmetric bending of cylindrical shells; torsion of prismatic bars.

### **MECHENG 420. Fluid Mechanics II**

*Prerequisite: MECHENG 320. (3 credits)*

Use of commercial CFD packages for solving realistic fluid mechanics and heat transfer problems of practical interest. Introduction to mesh generation, numerical discrimination, stability, convergence, and accuracy of numerical methods. Applications to separated, turbulent and two-phase flows, flow control and flows involving heat transfer. Open-ended design project.

### **MECHENG 424 (BME 424). Engineering Acoustics**

*Prerequisite: Math 216 or Physics 240. (3 credits)*

Vibrating systems; acoustic wave equation; plane and spherical waves in fluid media; reflection and transmission at interfaces; propagation in lossy media; radiation and reception of acoustic waves; pipes, cavities and waveguides; resonators and filters; noise; selected topics in physiological, environmental and architectural acoustics.

### **MECHENG 432. Combustion**

*Prerequisite: MECHENG 336, preceded or accompa-*

nied by *MECHENG 320*. (3 credits)

Introduction to combustion processes; combustion thermodynamics, reaction kinetics and combustion transport. Chain reactions, ignition, quenching and flammability limits, detonations, deflagrations and flame stability. Introduction to turbulent premixed combustion. Applications in IC engines, furnaces, gas turbines, and rocket engines.

**MECHENG 433 (AUTO 533). Advanced Energy Solutions**

*Prerequisite: MECHENG 235*. (3 credits)

Introduction to the challenges of power generation for a global society using the thermodynamics to understand basic principles and technology limitations. Covers current and future demands for energy; methods of power generation including fossil fuel, solar, wind and nuclear; associated detrimental by-products; and advanced strategies to improve power densities, efficiencies and emissions.

**MECHENG 438. Internal Combustion Engines**

*Prerequisite: MECHENG 235, MECHENG 336 or permission of instructor*. (4 credits)

Analytical approach to the engineering problem and performance analysis of internal combustion engines. Study of thermodynamics, combustion, heat transfer, friction and other factors affecting engine power, efficiency and emissions. Design and operating characteristics of different types of engines. Computer assignments. Engine laboratories.

**MECHENG 440. Intermediate Dynamics and Vibrations**

*Prerequisite: MECHENG 240*. (4 credits)

Newton/Euler and Lagrangian formulations for three-dimensional motion of particles and rigid bodies. Linear free and forced responses of one and two degree of freedom systems and simple continuous systems. Applications to engineering systems involving vibration isolation, rotating imbalance and vibration absorption.

**MECHENG 450. Design and Manufacturing III**

*Prerequisite: MECHENG 350, MECHENG 360, and either MECHENG 395 or AEROSP 305. May not be taken concurrently with MECHENG 455 or MECHENG 495. Not open to graduate students*. (4

credits)

A mechanical engineering design project by which the student is exposed to the design process from concept through analysis to layout and report. Projects are proposed from the different areas of study within mechanical engineering and reflect the expertise of instructional faculty and industrial representatives.

**MECHENG 451 (MFG 453). Properties of Advanced Materials for Design Engineers**

*Prerequisite: MECHENG 382*. (3 credits)

Mechanical behavior and environmental degradation of polymeric-, metal- and ceramic-matrix composites; manufacturability of advanced engineering materials; use of composite materials in novel engineering designs.

**MECHENG 452 (MFG 452). Design for Manufacturability**

*Prerequisite: MECHENG 350*. (3 credits)

Conceptual design. Design for economical production, Taguchi methods, design for assembly; case studies. Product design using advanced polymeric materials and composites; part consolidation, snap-fit assemblies; novel applications. Design projects.

**MECHENG 455. Analytical Product Design**

*Prerequisite: MECHENG 350, MECHENG 360, MECHENG 395 for MECHENG majors. PI for all others*. (3-4 credits)

Design of artifacts is addressed from a multidisciplinary perspective that includes engineering, art, psychology, marketing and economics. Using a decision-making framework, emphasis is placed on quantitative methods. Building mathematical models and accounting for interdisciplinary interactions. Students work in team design projects from concept generation to prototyping and design verification. Four credit-hour election requires prototyping of project.

**MECHENG 456 (BIOMEDE 456). Tissue Mechanics**

*Prerequisite: MECHENG 211, MECHENG 240*. (3 credits)

Definition of biological tissue and orthopedic device mechanics including elastic, viscoelastic and non-linear elastic behavior. Emphasis on structure function rela-

tionships. Overview of tissue adaptation and the interaction between tissue mechanics and physiology.

### **MECHENG 458. Automotive Engineering**

*Prerequisite: MECHENG 350. (3 credits)*

Emphasizes systems approach to automotive design. Specific topics include automotive structures, suspension steering, brakes and driveline. Basic vehicle dynamics in the performance and handling modes are discussed. A semester team-based design project is required.

### **MECHENG 461. Automatic Control**

*Prerequisite: MECHENG 360. (3 credits)*

Feedback control design and analysis for linear dynamic systems with emphasis on mechanical engineering applications; transient and frequency response; stability; system performance; control modes; state space techniques; digital control systems.

### **MECHENG 476 (BIOMEDE 476). Biofluid Mechanics**

*Prerequisite: MECHENG 320. (4 credits)*

This is an intermediate level fluid mechanics course which uses examples from biotechnology processes and physiologic applications including the cardiovascular, respiratory, ocular, renal, musculo-skeletal and gastrointestinal systems.

### **MECHENG 481. Manufacturing Processes**

*Prerequisite: MECHENG 382. (3 credits)*

Mathematical modeling of manufacturing processes used in industry to manufacture mechanical systems: machining, deformation, welding, assembly, surface treatment, and solidification processes. Process costs and limits; influence of processes on the final mechanical properties of the product. Reconfigurable manufacturing, Rapid prototyping, Direct Metal Deposition (DMD) and semiconductor manufacturing.

### **MECHENG 482 (MFG 492). Machining Processes**

*Prerequisite: MECHENG 382. (3 credits)*

Introduction to machining operations. Cutting tools and tool wear mechanisms. Cutting forces and mechanics of machining. Machining process simulation. Surface generation. Temperatures of the tool and workplace. Machining dynamics. Non-traditional machining.

### **MECHENG 483. Manufacturing System Design**

*Prerequisite: MECHENG 250. (3 credits)*

Manufacturing system design methodologies and procedures. Topics: paradigms of manufacturing; building blocks of manufacturing systems; numerical control and robotics; task allocation and line balancing; system configurations, performance of manufacturing systems including quality, productivity, and responsiveness; economic models and optimization of manufacturing systems; launch and reconfiguration of manufacturing systems; Lean manufacturing.

### **MECHENG 487 (MFG 488). Welding**

*Prerequisite: MECHENG 382. (3 credits)*

Study of the mechanism of surface bonding, welding metallurgy, effect of rate of heat input on resulting microstructures, residual stresses and distortion, economics and capabilities of the various processes.

### **MECHENG 489. Sustainable Engineering and Design**

*Prerequisite: MECHENG 235. Credit for only one: CEE 265 or MECHENG 489. Minimum Grade of "C-" required for enforced prerequisite. (3 credits)*

ME 489 covers economic, environmental and social aspects of sustainability as they pertain to engineering design. The course covers life cycle assessment, carbon/water/energy footprints, economic assessments, mass/energy balances, air/water pollutants, modeling of environmental pollutant concentrations, engineering economics, social considerations, pollution prevention, resource conservation, human and eco-toxicity, life cycle costing, and energy systems.

### **MECHENG 490. RISE 4 - Research, Innovation, Service, Entrepreneurship**

*Prerequisite: Permission of instructor. (3 credits)*

Individual or group project work where student(s) must apply mechanical engineering principles to research, innovation, service or entrepreneurship projects. Student(s) work under the direction of Mechanical Engineering faculty. (Students should work on project approximately 10 hours/week for 3 credits. The student(s) submits proposal and presents poster at ME Undergraduate Symposium.)

### **MECHENG 491. Independent Study**

*Prerequisite: MECHENG 490, permission of instructor; mandatory pass/fail. (1-3 credits)*

Individual or group experimental or theoretical research in the area of mechanical engineering. A topic in mechanical engineering under the direction of a member of the department. The student will submit a final report. Two four-hour laboratories per week. For undergraduates only.

### **MECHENG 495. Laboratory II**

*Prerequisite: MECHENG 360, MECHENG 395, preceded or accompanied by MECHENG 335 and MECHENG 350. May not elect MECHENG 450 concurrently. Not open to graduate students. (4 credits)*

Weekly lectures and extended experimental projects designed to demonstrate experimental and analytical methods as applied to complex mechanical systems. Topics will include controls, heat transfer, fluid mechanics, thermodynamics, mechanics, materials and dynamical systems. Emphasis on laboratory report writing, oral presentations and team-building skills, and the design of experiments

### **MECHENG 499. Special Topics in Mechanical Engineering**

*Prerequisite: Permission of instructor. (to be arranged)*

Selected topics pertinent to mechanical engineering.

### **MECHENG 501. Mathematical Methods in Mechanical Engineering**

*Prerequisite: Advised Math 216; Math 217 or equivalent recommended. (3 credits)*

Applied mathematics for mechanical engineering with an emphasis on mathematical principles and analytical methods. Topics include: complex analysis (functions of complex variables, contour integrals, conformal mappings), linear operator theory (vector spaces, linear algebra), ordinary differential equations (series solutions, Laplace and Fourier transforms, Green's functions).

### **MECHENG 502. Methods of Differential Equations in Mechanics**

*Prerequisite: Math 454. (3 credits)*

Applications of differential equation methods of particular use in mechanics. Boundary value and eigenvalue

problems are particularly stressed for linear and nonlinear elasticity, analytical dynamics, vibration of structures, wave propagation, fluid mechanics and other applied mechanic topics.

### **MECHENG 505. Finite Element Methods in Mechanical Engineering**

*Prerequisite: MECHENG 501 (MECHENG 311 or MECHENG 320). (3 credits)*

Theoretical and computational aspects of finite element methods. Examples from areas of thermal diffusion, potential/irrotational flows, lubrication, structural mechanics, design of machine components, linear elasticity and Navier-Stokes flows problems. Program development and modification are expected as well as learning the use of existing codes.

### **MECHENG 506 (BIOMEDE 506). Computational Modeling of Biological Tissues**

*(3 credits)*

Biological tissues have multiple scales and can adapt to their physical environment. This course focuses on visualization and modeling of tissue physics and adaptation. Examples include electrical conductivity of heart muscle and mechanics of hard and soft tissues. Homogenization theory is used for multiple scale modeling.

### **MECHENG 507. Atomistic Computer Modeling of Materials**

*Introductory quantum mechanics recommended, but not required. (3 credits)*

Describes the core methods used to simulate matter at the atomic scale. Topics include: Structure of matter and interatomic potentials; High-performance computing; Electronic structure methods; Molecular dynamics; Monte Carlo; Transition state theory; Accelerated dynamics and multi-scale modeling. Applications of these methods are illustrated in hands-on laboratories involving research-caliber simulation tools.

### **MECHENG 511. Theory of Solid Continua**

*Prerequisite: MECHENG 211, Math 450. (3 credits)*

The general theory of a continuous medium. Kinematics of large motions and deformations; stress tensors; conservation of mass, momentum and energy; constitutive equations for elasticity, viscoelasticity and plasticity; applications to simple boundary value problems.

**MECHENG 512 (CEE 509). Theory of Elasticity**

*Prerequisite: MECHENG 311 or MECHENG 412, or MECHENG 511 or equivalent. (3 credits)*

Stress, strain and displacement, equilibrium and compatibility. Use of airy stress function in rectangular and polar coordinates, asymptotic fields at discontinuities, forces and dislocations, contact and crack problems, rotating and accelerating bodies. Galerkin and Papcovich-Neuber solutions, singular solutions, spherical harmonics. Thermoelasticity. Axisymmetric contact and crack problem. Axisymmetric torsion.

**MECHENG 513 (Auto 513, MFG 513). Automotive Body Structures**

*Prerequisite: MECHENG 311. (3 credits)*

Emphasis is on body concept for design using first order modeling of thin walled structural elements. Practical application of solid/structural mechanics is considered to design automotive bodies for global bending, torsion, vibration, crashworthiness, topology, material selection, packaging and manufacturing constraints.

**MECHENG 514. Nonlinear Fracture Mechanics**

*Prerequisite: MECHENG 412. (3 credits)*

Elements of solid mechanics, historical development of fracture mechanics, energy release rate of cracked solids, linear elastic fracture mechanics and elastic-plastic fracture mechanics.

**MECHENG 515. Contact Mechanics**

*Prerequisite: MECHENG 311 or MECHENG 350. (3 credits)*

Hertzian elastic contact; elastic-plastic behavior under repeated loading; shakedown. Friction; transmission of frictional tractions in rolling; fretting; normal and oblique impact. Dynamic loading. Surface durability in rolling. Surface roughness effects. Conduction of heat and electricity across interfaces. Thermal and thermoelastic effects in sliding and static contact.

**MECHENG 516 (MATSCIE 516). Mechanics of Thin Films and Layered Materials**

*Prerequisite: MECHENG 311 or graduate standing. (3 credits)*

Stresses and deformations in layered materials; energy-release rates and delamination; fracture mechanics of layered materials; spalling; interfacial fracture mechan-

ics; mixed-mode fracture; buckling-driven delamination; cracking of thin films; effects of plasticity on fracture; stress-relaxation mechanisms in multi-layered materials; adhesion and fracture tests.

**MECHENG 517 (MacroSE 517). Mechanics of Polymers I**

*Prerequisite: MECHENG 511 or permission of instructor. (3 credits)*

Constitutive equation for linear small strain viscoelastic response; constant rate and sinusoidal responses; time and frequency dependent material properties; energy dissipation; structural applications including axial loading, bending, torsion; three dimensional response, thermo-viscoelasticity, correspondence principle, Laplace transform and numerical solution methods.

**MECHENG 518 (MFG 518). Composite Materials: Mechanics, Manufacturing, and Design**

*Prerequisite: Senior or graduate standing. (3 credits)*

Composite materials, including naturally occurring substances such as wood and bone, and engineered materials from concrete to carbon-fiber reinforced epoxies. Development of micromechanical models for a variety of constitutive laws. Link between processing and as-manufactured properties through coupled fluid and structural analyses.

**MECHENG 519. Theory of Plasticity I**

*Prerequisite: MECHENG 511. (3 credits)*

Fundamentals of plasticity; stress-strain relations, yield criteria and the general behavior of metals and nonmetals beyond proportional limit in the light of experimental evidence. Various approximate theories with emphasis on the theory of plastic flow. Application to problems of bending, torsion, plane strain and plane stress, technological problems.

**MECHENG 520. Advanced Fluid Mechanics I**

*Prerequisite: MECHENG 320. (3 credits)*

Fundamental concepts and methods of fluid mechanics; inviscid flow and Bernoulli theorems; potential flow and its application; Navier-Stokes equations and constitutive theory; exact solutions of the Navier-Stokes equations; boundary layer theory; integral momentum methods; introduction to turbulence.

**MECHENG 521. Advanced Fluid Mechanics II***Prerequisite: MECHENG 520. (3 credits)*

Viscous flow fundamentals; vorticity dynamics; solution of the Navier-Stokes equations in their approximate forms; thin shear layers and free surface flows; hydrodynamic stability and transition to turbulence; fundamental concepts of turbulence; the turbulent boundary layer; introduction to turbulence modeling.

**MECHENG 523 (AEROSP 523). Computational Fluid Dynamics I***Prerequisite: AEROSP 325 or preceded or accompanied by MECHENG 520. (3 credits)*

Physical and mathematical foundations of computational fluid mechanics with emphasis on applications. Solution methods for model equations and the Euler and the Navier-Stokes equations. The finite volume formulation of the equations. Classification of partial differential equations and solution techniques. Truncation errors, stability, conservation and monotonicity. Computer projects and homework.

**MECHENG 524. Advanced Engineering Acoustics***Prerequisite: MECHENG 424, (BIOMEDE 424). (3 credits)*

Derivation of the acoustic wave equation and development of solution techniques. Transmission and reflection from solids, plates and impedance boundaries. Radiation and scattering from non-simple geometries. Green's functions; boundary element and finite element methods. Sound in ducts and enclosures. Introduction to structural-acoustic coupling. Automotive and other applications considered.

**MECHENG 527. Multiphase Flow***Prerequisite: MECHENG 520. (3 credits)*

Selected topics in multiphase flow including nucleation and cavitation; dynamics of stationary and translating particles and bubbles; basic equations of homogeneous two-phase gas/liquid, gas/solid and vapor/liquid flows; kinematics and acoustics of bubbly flows; instabilities and shock waves in bubbly flows; stratified, annular and granular flow.

**MECHENG 530. Advanced Heat Transfer***Prerequisite: MECHENG 320 or equivalent background in fluid mechanics and heat transfer. (3 credits)**its)*

Advanced topics in conduction and convection including the presentation of several solution methods (semi-quantitative analysis, finite difference methods, superposition, separation of variables) and analysis of multi-mode heat transfer systems. Fundamentals of radiation heat transfer including; blackbody radiation, radiative properties, view factors, radiative exchange between ideal and non-ideal surfaces.

**MECHENG 532. Convection Heat Transfer***Prerequisite: MECHENG 335. (3 credits)*

Differential and integral formulations of convection. Parallel and nearly parallel laminar (boundary layer) flows. Similarity solutions. Periodic convection. Computational convection. Instability and turbulence. Kinetic and thermal scales and spectra. Flow prediction. Heat transfer prediction. Multiple scale dimensional analysis. Technological applications.

**MECHENG 533. Radiative Heat Transfer***Prerequisite: MECHENG 335. (3 credits)*

Electromagnetic, optical and quantum aspects of radiative equilibrium. Enclosure radiation including spatial, specular, and spectral distributions. Gas radiation including boundary affected thin gas and thick gas approximations. Averaged and spectral properties. Technological applications.

**MECHENG 535. Thermodynamics III***Prerequisite: MECHENG 336. (3 credits)*

Definitions and scope of thermodynamics; first and second laws. Maxwell's relations. Clapeyron relation, equation of state, thermodynamics of chemical reactions, availability.

**MECHENG 537. Advanced Combustion***Prerequisite: MECHENG 432 or equivalent. (3 credits)*

Advanced treatment of fundamental combustion processes. Conservation equations for reacting gas mixtures. The structure of one-dimensional diffusion and premixed flames; introduction to activation energy asymptotics. Two-dimensional Burke-Schumann flames and boundary layer combustion. Flame instabilities and flame stretch; turbulent combustion.

**MECHENG 538. Advanced Internal Combustion Engines**

*Prerequisite: MECHENG 438. (3 credits)*

Modern analytical approach to the design and performance analysis of advanced internal combustion engines. Study of thermodynamics, fluid flow, combustion, heat transfer and other factors affecting the design, operating and emissions characteristics of different engine types. Application of course techniques to engine research projects.

**MECHENG 539 (APPLIED PHYSICS 639). Heat Transfer Physics**

*Prerequisite: MECHENG 235, MECHENG 335. (3 credits)*

Unified treatment of thermal energy storage, transport and conversion, by principal carriers: phonon, electron, fluid particle and photon. Quantum, molecular dynamics and Boltzmann transport treatments are used, along with applications (e.g., thermoelectrics, photovoltaics, laser cooling, phonon recycling, size effects).

**MECHENG 540 (AEROSP 540). Intermediate Dynamics**

*Prerequisite: MECHENG 240. (3 credits)*

Newton/Euler and Lagrangian formulations for three dimensional motion of particles and rigid bodies. Principles of dynamics applied to various rigid-body and multi-body dynamics problems that arise in aerospace and mechanical engineering.

**MECHENG 541. Mechanical Vibrations**

*Prerequisite: MECHENG 440. (3 credits)*

Time and frequency domain mathematical techniques for linear system vibrations. Equations of motion of discrete non-conservative systems. Vibration of multi-degree-of-freedom systems. Small oscillation theory. Free vibration eigenvalue problem. Undamped system response. Viscously damped systems. Vibration of continuous systems. Modes of vibration of bars, beams, membranes, plates.

**MECHENG 542. Vehicle Dynamics**

*Prerequisite: MECHENG 440. (3 credits)*

Dynamics of the motor vehicle. Static and dynamic properties of the pneumatic tire. Mechanical models of single and double-track vehicles enabling prediction of

their response to control forces/moments and external disturbances. Directional response and stability in small disturbance maneuvers. The closed-loop driving process. Behavior of the motor vehicle in large perturbation maneuvers. Ride phenomena treated as a random process.

**MECHENG 543. Analytical and Computational Dynamics I**

*Prerequisite: MECHENG 440. (3 credits)*

Modern analytical rigid body dynamics equation formulation and computational solution techniques applied to mechanical multibody systems. Kinematics of motion generalized coordinates and speeds, analytical and computational determination of inertia properties, generalized forces, Gibb's function, Routhian, Kan's equations, Hamilton's principle, Lagrange's equations holonomic and nonholonomic constraints, constraint processing, computational simulation.

**MECHENG 548. Applied Nonlinear Dynamics**

*Prerequisite: MECHENG 360 or graduate standing. (3 credits)*

Geometrical representation of the dynamics of nonlinear systems. Stability and bifurcation theory for autonomous and periodically forced systems. Chaos and strange attractors. Introduction to pattern formation. Applications to various problems in rigid-body dynamics, flexible structural dynamics, fluid-structure interactions, fluid dynamics, and control of electromechanical systems.

**MECHENG 551 (MFG 560). Mechanisms Design**

*Prerequisite: MECHENG 350. (3 credits)*

Basic concepts. Type synthesis — creative design of mechanisms; graph theory. Precision-point Burmester theory for dimensional synthesis of linkages. Applications. Cam and follower system synthesis. Joint force analysis and dynamic analysis formulations. Analytical synthesis of programmable and compliant mechanisms. Use of software for synthesis and analysis. Design projects.

**MECHENG 552 (MFG 552). Mechatronic Systems Design**

*Advised Prerequisite: MECHENG 350, MECHENG 360, EECS 314 or equivalent (4 credits)*

Mechatronics is the synergistic integration of mechanical disciplines, controls, electronics and computers in the design of high-performance systems. Case studies, hands-on lab exercises and hardware design projects cover the practical aspects of machine design, multi-domain systems modeling, sensors, actuators, drives circuits, simulation tools, DAQ and controls implementation using microprocessors.

**MECHENG 553 (MFG 553). Microelectromechanical Systems**

*Prerequisite: Senior or graduate standing. (3 credits)*  
Basic integrated circuit (IC) manufacturing processes; electronics devices fundamentals; microelectromechanical systems fabrications including surface micromachining, bulk micromachining, LIGA and others. Introduction to micro-actuators and microsensors such as micromotors, grippers, accelerometers and pressure sensors. Mechanical and electrical issues in micromachining. IC CAD tools to design microelectromechanical structures using MCNC MUMPs service. Design projects.

**MECHENG 554 (MFG 554). Computer Aided Design Methods**

*Prerequisite: MECHENG 454. (MFG 454) or MECHENG 501. (3 credits)*  
Generalized mathematical modeling of engineering systems, methods of solution and simulation languages. Analysis methods in design; load, deformation, stress and finite element considerations; nonlinear programming. Computational geometry; definition and generation of curves and surfaces. Computer graphics; transformations; clipping and windowing; graphics systems; data structures; command languages; display processors.

**MECHENG 555 (MFG 555). Design Optimization**

*Prerequisite: Math 451 and Math 217 or equivalent. (3 credits)*  
Mathematical modeling of engineering design problems for optimization. Boundedness and monotonicity analysis of models. Differential optimization theory and selected numerical algorithms for continuous nonlinear models. Emphasis on the interaction between proper modeling and computation. Students propose design term projects from various disciplines and apply

course methodology to optimize designs.

**MECHENG 558 (MFG 558). Discrete Design Optimization**

*Prerequisite: Senior or graduate standing. (3 credits)*  
Fundamentals of discrete optimization for engineering design problems. Mathematical modeling of engineering design problems as discrete optimization problems, integer programming, dynamic programming, graph search algorithms, and introduction to NP completeness. A term project emphasizes applications to realistic engineering design problems.

**MECHENG 559 (MFG 559). Smart Materials and Structures**

*Prerequisite: EECS 314 or equivalent. (3 credits)*  
This course will cover theoretical aspects of smart materials, sensors and actuator technologies. It will also cover design, modeling and manufacturing issues involved in integrating smart materials and components with control capabilities to engineering smart structures.

**MECHENG 560 (MFG 562). Modeling Dynamic Systems**

*Prerequisite: MECHENG 360. (3 credits)*  
A unified approach to the modeling, analysis and simulation of energetic dynamic systems. Emphasis on analytical and graphical descriptions of state-determined systems using Bond Graph language. Analysis using interactive computer simulation programs. Applications to the control and design of dynamic systems such as robots, machine tools and artificial limbs.

**MECHENG 561 (EECS 561). Design of Digital Control Systems**

*Prerequisite: EECS 460 or MECHENG 461. (3 credits)*  
Sampling and data reconstruction. Z-transforms and state variable descriptions of discrete-time systems. Modeling and identification. Analysis and design using root locus, frequency response and state space techniques. Linear quadratic optimal control and state estimation. Quantization and other nonlinearities.

**MECHENG 562. Dynamic Behavior of Thermal-Fluid Processes**

*Prerequisite: MECHENG 335. (3 credits)*

Principles of transport processes and automatic control. Techniques for dynamic analysis; dynamic behavior of lumped- and distributed-parameter systems, nonlinear systems and time-varying systems; measurement of response; plant dynamics. Experimental demonstration for dynamic behavior and feedback control of several thermal and fluid systems.

**MECHENG 563 (IOE 565) (MFG 561). Time Series Modeling, Analysis, Forecasting**

*Prerequisite: IOE 366 or MECHENG 401. (3 credits)*

Time series modeling, analysis, forecasting and control, identifying parametric time series, autocovariance, spectra, Green's function, trend and seasonality. Examples from manufacturing, quality control, ergonomics, inventory and management.

**MECHENG 564 (AEROSP 550) (CEE 571) (EECS 560). Linear Systems Theory**

*Prerequisite: Graduate standing. (4 credits)*

Linear spaces and linear operators. Bases, subspaces, eigenvalues and eigenvectors, canonical forms. Linear differential and difference equations. Mathematical representations: state equations, transfer functions, impulse response, matrix fraction and polynomial descriptions. System-theoretic concepts: causality, controllability, observability, realizations, canonical decomposition, stability.

**MECHENG 565. Battery Systems and Control**

*Advised Prerequisite: MECHENG 360 or equivalent.*

*Advised Co-requisite: MECHENG 461 or equivalent. (3 credits)*

This course covers battery modeling, control and diagnostic methodologies associated to battery electric and battery hybrid electric vehicles. Emphasis is placed upon system-level modeling, model order reduction from micro-scale and surrogate models for load control, estimation, on-board identification and diagnostics for Lithium Ion batteries.

**MECHENG 566 (AUTO 566). Modeling, Analysis, and Control of Hybrid Electric Vehicles**

*Prerequisite: MECHENG 438 and MECHENG 461 or equivalent is recommended. (3 credits)*

Modeling, analysis and control of vehicles with electri-

fied propulsion systems, including electric vehicles, hybrid vehicles, plug-in and fuel cell vehicles. Introduction of the concepts and terminology, the state of the art development, energy conversion and storage options, modeling, analysis, system integration and basic principles of vehicle controls.

**MECHENG 567 (EECS 567) (MFG 567). Robot Kinematics and Dynamics**

*Prerequisite: Graduate standing or permission of instructor (3 credits)*

Geometry, kinematics, differential kinematics, dynamics, and control of robot manipulators. The mathematical tools required to describe spatial motion of a rigid body will be presented in full. Motion planning including obstacle avoidance is also covered.

**MECHENG 568. Vehicle Control Systems**

*Prerequisite: MECHENG 461 or equivalent. (3 credits)*

Design and analysis of vehicle control systems such as cruise control, traction control, active suspensions and advanced vehicle control systems for Intelligent Vehicle-Highway Systems (IVHS). Human factor considerations such as driver interfaces. This course may be used as part of the IVHS certification program.

**MECHENG 569. Control of Advanced Powertrain Systems**

*Prerequisite: MECHENG 360; preceded or accompanied by MECHENG 461. (3 credits)*

Will cover essential aspects of electronic engine control for spark ignition (gasoline) and compression ignition (diesel) engines followed by recent control developments for direct injection, camless actuation, active boosting technologies, hybrid-electric and fuel cell power generation. Will review system identification, averaging, feedforward, feedback, multivariable (multiple SISO and MIMO), estimation, dynamic programming and optimal control techniques.

**MECHENG 571 (ESENG 505). Energy Generation and Storage Using Modern Materials**

*Prerequisite: MECHENG 382 and MECHENG 335 or equivalent. (3 credits)*

Energy and power densities previously unattainable in environmentally-friendly energy technologies have

been achieved through use of novel materials. Insertion of new materials into power supplies has changed the landscape of options. Design strategies for power systems are described, in the context of growing global demand for power and energy.

**MECHENG 572 (MFG 580). Rheology and Fracture**

*Prerequisite: MECHENG 382. (3 credits)*

Mechanisms of deformation, cohesion, and fracture of matter. Unified approach to the atomic-scale origins of plastic, viscous, viscoelastic, elastic, and anelastic behavior. The influences of time and temperature on behavior. Stress field of edge and screw dislocations, dislocation interactions, and cross slip.

**MECHENG 573 (MFG 581). Friction and Wear**

*Prerequisite: Background in materials and mechanics desirable. (3 credits)*

The nature of solid surfaces, contact between solid surfaces, rolling friction, sliding friction and surface heating due to sliding; wear and other types of surface attrition are considered with reference to practical combinations of sliding materials, effect of absorbed gases, surface contaminants and other lubricants on friction, adhesion and wear; tire and brake performance.

**MECHENG 574. Nano/Micro Structure Evolution**

*Prerequisite: Graduate standing and seniors by PI. (3 credits)*

This course will focus on scientific understanding and computational techniques. Students will have the opportunity to develop a program to implement the methods to simulate nanostructure evolution. Topics covered include: configurational forces, formulation of migration, simulation of structural evolution, surface roughening, motion of thin film, composition modulation, electromigration and assembly.

**MECHENG 576 (MFG 556). Fatigue in Mechanical Design**

*Prerequisite: MECHENG 382 or equivalent. (3 credits)*

A broad treatment of stress, strain and strength with reference to engineering design and analysis. Major emphasis is placed on the analytical and experimental determination of stresses in relationship to the fatigue

strength properties of machine and structural components. Also considered are deflection, post-yield behavior, residual stresses, temperature and corrosion effects.

**MECHENG 577 (MFG 557). Use of Materials and their Selection in Design**

*Prerequisite: MECHENG 382 and senior, or graduate standing. (3 credits)*

Material properties, including physical, mechanical, thermal, electrical, economic, corrosion and environmental properties. Interaction of function, shape, choice of materials, processing, economics and environmental impact in design. Methodology for materials selection and optimization, including performance indices, multiple constraints and multiple objectives. Introduction to analysis of environmental impact of materials selection.

**MECHENG 580. Transport Phenomena in Materials Processing**

*Prerequisite: Senior or graduate standing. (3 credits)*

Proficiency in the fundamental understanding of materials processing techniques. Lectures will cover: techniques for model development and simplification with an emphasis on estimation and scaling; 'classical' analytic solutions to simple problems, physical phenomena in materials processing including non-Newtonian fluid flow, solidification, and microstructure development. Techniques for measurement of monitoring of important process variables for model verification and process control. Case studies (heat treatment; welding; polymer extrusion and molding; various metal casting processes; crystal growth).

**MECHENG 581 (MFG 574). Global Product Development**

*Prerequisite: Graduate standing. (3 credits)*

A project-based course in which each (global) student team comprising students from three universities will be responsible for development of a product for the global market. Teams will use collaboration technology tools extensively. Several case studies on global product development will be presented and follow-up lectures will focus on the issues highlighted.

**MECHENG 582 (MFG 582) (MATSCIE 523). Metal-Forming Plasticity**

*Prerequisite: MECHENG 211. (3 credits)*

Elastic and plastic stress-strain relations; yield criteria and flow rules; analyses of various plastic forming operations. Effects of hardening and friction, temperature, strain rate and anisotropy.

**MECHENG 584 (MFG 584). Advanced Mechatronics for Manufacturing**

*Prerequisite: ME 461 or equivalent. (3 credits)*

Theoretical principles and practical techniques for controlling mechatronic systems are taught in the context of advanced manufacturing applications. Specifically, the electro-mechanical design/modeling, basic/advanced control, and real-time motion generation techniques for computer-controlled manufacturing machines are studied. Hands-on labs and industrial case studies are used to re-enforce the course material.

**MECHENG 585 (MFG 585). Machining Dynamics and Mechanics**

*Prerequisite: Graduate standing or permission of instructor. (3 credits)*

Dynamic cutting process models and process stability issues. Advanced cutting process mechanics and modeling including cutting process damping, thermal energy and cutting temperature, and wear evolution. Single and multi-DOF stability analysis techniques, stability margins and stability charts. Modeling approximations for industrial applications.

**MECHENG 586 (MFG 591). Laser Materials Processing**

*Prerequisite: Senior or graduate standing. (3 credits)*

Application of lasers in materials processing and manufacturing. Laser principles and optics. Fundamental concepts of laser/material interaction. Laser welding, cutting, surface modification, forming and rapid prototyping. Modeling of processes, microstructure and mechanical properties of processed materials. Transport phenomena. Process monitoring.

**MECHENG 587 (MFG 587). Global Manufacturing**

*Prerequisite: One 400-level MFG or DES or BUS class. (3 credits)*

Globalization and manufacturing paradigms. Product-process-business integration. Product invention strategy. Customized, personalized and reconfigurable products. Mass production and lean production. Mathemati-

cal analysis of mass customization. Traditional manufacturing systems. Reconfigurable manufacturing systems. Reconfigurable machines. System configuration analysis. Responsive business models. Enterprise globalization strategies. The global integrated enterprise.

**MECHENG 588 (IOE 588) (MFG 588). Assembly Modeling for Design and Manufacturing**

*Prerequisites: MECHENG 481 and MECHENG 401 or equivalent. (3 credits)*

Assembly on product and process. Assembly representation. Assembly sequence. Datum flow chain. Geometric Dimensioning and Tolerancing. Tolerance analysis. Tolerance synthesis. Robust design. Fixturing. Joint design and joining methods. Stream of variation. Auto body assembly case studies.

**MECHENG 589. Sustainable Design of Technology Systems.**

*Prerequisite: Senior or graduate standing. (3 credits)*

Scientific perspectives on grand challenges to environment and society created by the production of energy, water, materials and emissions to support modern life styles. Integration of economic indicators with life cycle environmental and social metrics for evaluating technology systems. Case studies: sustainable design of consumer products, manufacturing and infrastructure systems.

**MECHENG 590. Study or Research in Selected Mechanical Engineering Topics**

*Prerequisite: Graduate standing; permission of the instructor who will guide the work; mandatory satisfactory/unsatisfactory. (3/6 credits)*

Individual or group study, design or laboratory research in a field of interest to the student. Topics may be chosen from any of the areas of mechanical engineering. The student will submit a report on the project at the close of the term.

**MECHENG 599. Special Topics in Mechanical Engineering**

*Prerequisite: Permission of instructor (to be arranged)*

Selected topics pertinent to mechanical engineering.

**MECHENG 605. Advanced Finite Element Methods in Mechanics**

*Prerequisite: MECHENG 505 or CEE 510, (NAVARCH 512). (3 credits)*

Recent developments in finite element methods; mixed, hybrid, mixed-hybrid, reduced integration penalty, singular, boundary integral elements. Emphasis on the methodology for developing elements by using calculus of variations. Applications selected from various branches of solid and fluid mechanics.

### **MECHENG 617. Mechanics of Polymers II**

*Prerequisite: MECHENG 511, MECHENG 517, (MacroSE 517), or permission of instructor. (3 credits)*

Selected advanced topics in the mechanics of polymeric solids and fluids, including nonlinear elasticity, nonlinear viscoelastic solids, viscoplasticity in amorphous and crystalline polymer solids, constitutive models and associated flow properties for polymer fluids, temperature dependence and solidification, applications.

### **MECHENG 619. Theory of Plasticity II**

*Prerequisite: MECHENG 519. (3 credits)*

Plastic theory for materials with isotropic hardening, kinematic hardening and time dependence. Theories based on crystal slip; variational theorems; range of validity of total deformation theories. Theory of generalized stresses applied to circular plates; behavior at finite deflection; limit analysis of shells. Plane stress, plane strain and axial symmetry. Plastic response to impact loads. Minimum weight design.

### **MECHENG 622. Inviscid Fluids**

*Prerequisite: MECHENG 520. (3 credits)*

Vorticity theorems of Helmholtz and Kelvin. Potential Flow; the complex potential; flow around bodies. Conformal mapping and free streamline theory. Rotational flow; Stability, Kelvin-Helmholtz and Rayleigh-Taylor instabilities. Motion of point vortices and vortex regions. Chaotic vortex motions. Vortex filaments and vortex sheets.

### **MECHENG 623. Hydrodynamic Stability**

*Prerequisite: MECHENG 520. (3 credits)*

An introduction to the theory of hydrodynamic stability with applications to stability of thermal flows, rotating and curved flows, wallbounded and free shear flows. Development of the asymptotic theory of the Orr-Sommerfeld equation. Review of the fundamental con-

cepts and current work in nonlinear theory of hydrodynamic stability.

### **MECHENG 624. Turbulent Flow**

*Prerequisite: MECHENG 520. (3 credits)*

Fundamentals of turbulent flows; the basic equations and the characteristic scales, statistical description of turbulence. Review of experimental results on the statistics and structure of turbulent flows. Methods for calculation of turbulent flows; the problem of closure, semi-empirical, phenomenological and analytical theories of turbulence, large-eddy and direct simulations of turbulence.

### **MECHENG 625. Nonhomogeneous Fluids**

*Prerequisite: MECHENG 520. (3 credits)*

Motion of fluids of variable density and entropy in gravitational field, including the phenomenon of blocking and selective withdrawal; waves of small finite amplitudes, including waves in the lee of mountains; stability of stratified flows; flow of Nonhomogeneous fluids in porous media. Analogy with rotating fluids.

### **MECHENG 626. Perturbation Methods for Fluids**

*Prerequisite: MECHENG 520. (3 credits)*

Application of asymptotic methods to fluid mechanics, with special emphasis on the method of matched expansions. Regular perturbation solutions; suppression of secular terms; method of multiple scales; boundary layer and low Reynolds number flows by inner and outer expansions; phenomena in rotating flows. Applications to computational fluid mechanics.

### **MECHENG 627 (NAVARCH 627). Wave Motion in Fluids**

*Prerequisite: MECHENG 520 or NAVARCH 520 or equivalent. (3 credits)*

Surface waves in liquids; group velocity and dispersion; water waves created by and wave resistance to a moving body; Korteweg de Vries equation; conoidal and solitary waves in water; wave reflection and diffraction; shallow-water waves by the method of characteristics; statistical approach and spectral analysis; wave generation.

### **MECHENG 631. Statistical Thermodynamics**

*Prerequisite: MECHENG 230 or MECHENG 336. (3*

*credits)*

Introduction to statistical methods for evaluating thermodynamic and transport properties. Elements of quantum mechanics, statistical mechanics and kinetic theory, as applied to engineering thermodynamics.

### **MECHENG 635. Thermodynamics IV**

*Prerequisite: MECHENG 535. (3 credits)*

Discussion of thermodynamic systems including surface phenomena, external fields and relativistic effects. Study of complex equilibrium calculations including effect of heterogeneous reactions and real substance behavior. Introduction to the thermo-dynamics of irreversible processes with applications to heat and mass transfer, relaxation phenomena and chemical reactions.

### **MECHENG 641. Advanced Vibrations of Structures**

*Prerequisite: MECHENG 541. (3 credits)*

Energy formulation for nonconservative gyroscopic systems. Spectral methods for free and forced vibrations. Eigenvalue and boundary value problems. Non self-adjoint systems. Variational methods of approximation: Bubnov-Galerkin. Perturbation theory for the eigenvalue problem. Dynamics of rotating systems. Dynamics of constrained dynamical systems.

### **MECHENG 643. Analytical and Computational Dynamics II**

*Prerequisite: MECHENG 543. (3 credits)*

Kinematical and dynamical equation formulation for rigid and flexible mechanical multi-body systems undergoing large overall motion and small elastic deformation. Energy principles, higher and lower pair joint parameterizations, space and dense equation formulation and solution techniques, numerical integration, generalized impulse and momentum, collisions and computational elastodynamics. Course project.

### **MECHENG 645. Wave Propagation in Elastic Solids**

*Prerequisite: MECHENG 541. (3 credits)*

Elastodynamic equations, isotropic and anisotropic materials; vector/scalar potentials, reflection and transmission at interfaces, mode conversion, surface waves, Rayleigh-Lamb equation. Green's tensor; variational, Galerkin and Hamilton's equations. Kirchhoff-Love

and Reissner-Mindlin kinematic hypotheses for beam, plate and shell theories. Fourier and Laplace transform, modal and state-vector solution techniques.

### **MECHENG 646 (BIOMEDE 646). Mechanics of Human Movement**

*Prerequisite: MECHENG 540, (AEROSP 540) or MECHENG 543, or equivalent. (3 credits)*

Dynamics of muscle and tendon, models of muscle contraction. Kinematics and dynamics of the human body, methods for generating equations of motion. Mechanics of proprioceptors and other sensors. Analysis of human movement, including gait, running and balance. Computer simulations and discussion of experimental measurement techniques.

### **MECHENG 648. Nonlinear Oscillations and Stability of Mechanical Systems**

*Prerequisite: MECHENG 541. (3 credits)*

Large amplitude mechanical vibrations; phase-plane analysis and stability; global stability, theorems of Liapunov and Chetayev; asymptotic and perturbation methods of Lindstedt-Poincare, multiple scales, Krylov-Bogoliubov-Mitropolsky; external excitation, primary and secondary resonances; parametric excitation, Mathieu/Hill equations, Floquet theory; multi-degree of freedom systems and modal interaction.

### **MECHENG 649 (AEROSP 615) (CEE 617). Random Vibrations**

*Prerequisite: Math 425 or equivalent, CEE 513 or MECHENG 541, or AEROSP 543 or equivalent. (3 credits)*

Introduction to concepts of random vibration with applications in civil, mechanical and aerospace engineering. Topics include: characterization of random processes and random fields, calculus of random processes, applications of random vibrations to linear dynamical systems, brief discussion on applications to nonlinear dynamical systems.

### **MECHENG 661. Adaptive Control Systems**

*Prerequisite: MECHENG 561. (3 credits)*

Introduction to control of systems with undetermined or time varying parameters. Theory and application of self-tuning and model reference adaptive control for continuous and discrete-time deterministic systems.

Model based methods for estimation and control, stability of nonlinear systems, adaptation laws and design and application of adaptive control systems.

**MECHENG 662 (AEROSP 672) (EECS 662). Advanced Nonlinear Control**

*Prerequisite: EECS 562 or MECHENG 548. (3 credits)*

Geometric and algebraic approaches to the analysis and design of nonlinear control systems. Nonlinear controllability and observability, feedback stabilization and linearization, asymptotic observers, tracking problems, trajectory generation, zero dynamics and inverse systems, singular perturbations and vibrational control.

**MECHENG 663. Estimation of Stochastic Signals and Systems**

*Prerequisite: MECHENG 563 or IOE 565 or MFG. 561 equivalent. (3 credits)*

Estimation and prediction methods for vector stochastic signals and systems. Topics include characteristics of stochastic signals and systems; principles of estimation theory; linear regression models; description of signals and systems within a time series framework; prediction, prediction-error and correlation-type estimation methods; recursive estimation methods; asymptotic properties; model validation.

**MECHENG 695. Master's Thesis Research**

*Prerequisite: MECHENG 595; mandatory satisfactory/unsatisfactory. (3 credits)*

Student must complete a dissertation and defend his/her thesis in front of a committee of at least 2 faculty members.

**MECHENG 699. Advanced Special Topics in Mechanical Engineering**

*Prerequisite: Permission of instructor. (to be arranged)*

Advanced selected topics pertinent to mechanical engineering.

**MECHENG 790. Mechanical Sciences Seminar**

*Prerequisite: Candidate status in the mechanical sciences. (1 credit)*

Every Ph.D. student in the field of mechanical sciences is asked to present a one-hour seminar about his/her

research, and lead a one-hour follow-up discussion.

Active participation in the discussions that follow all presentations is also required for a grade. In addition, each student will participate as a panelist in a panel discussion of the future trends in his/her field. Graded S-U.

**MECHENG 990. Dissertation/Pre-Candidate**

*(1-8 credits); (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**MECHENG 995. Dissertation/Candidate**

*Prerequisite: Graduate School authorization for admission as a doctoral candidate. (8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Naval Architecture and Marine Engineering

## Overview

More than 70 percent of the surface of our planet is covered by water. Engineering for the marine environment covers the design and production of all types of systems to operate successfully in this often harsh and demanding environment. In addition to traditional naval architecture and marine engineering, instruction is offered in offshore engineering, coastal engineering and marine environmental engineering.

Recent graduates are active in design and research related to offshore oil and gas exploration and production platforms. Others are involved in overcoming waterborne pollution transport in the Great Lakes and the oceans, and coastal erosion predictions, as well as the design of traditional ships, submersibles, high-speed vessels and recreational craft.

Since the design of modern marine systems encompasses many engineering fields, graduates of this department are called upon to handle diverse professional responsibilities; therefore the program includes study in the fundamentals of the physical sciences and mathematics as well as a broad range of engineering aspects that constitute design for the marine environment. To provide the appropriate educational breadth, students are required to complete at least 16 credits of Intellectual Breadth requirements from an approved list of courses. It is recognized that the undergraduate program cannot, in the time available, treat all important aspects of engineering for the marine environment that may be desired by the student; therefore, graduate work is encouraged.

Ship and offshore platform analysis and design require knowledge of hull geometry, vessel arrangements, hydrostatic stability, structures, resistance, propulsion, maneuvering and seakeeping. Other areas of concern are the economic aspects of design and operation, production, model testing, propeller and control theory, vibration problems, and piping and electrical system

analysis and design.

The undergraduate degree program is arranged to give the student a broad engineering mechanics education by requiring basic courses in the areas of structural mechanics, hydrodynamics, marine power systems and marine dynamics. These courses cover engineering fundamentals and their application to the design and construction of marine vehicles and systems. Courses in marine structures deal with the design and analysis of marine vehicles and platforms including static strength, fatigue, dynamic response, safety and production. Resistance, maneuvering and seakeeping characteristics of vessels in the marine environment are the subject matter for courses in marine hydrodynamics. Marine power systems involve all the mechanical systems on a marine vehicle with particular emphasis on the selection and arrangement of the main propulsion system. In marine dynamics, the student studies the vibrations of marine structures and engines and the responses of the vessel to wind and waves. Through the use of technical and general electives, students may decide to focus their education in areas such as:

- Marine Structures
- Ship Production and Management
- Sailing Yachts
- High Speed Craft
- Marine Power Systems

An integration and demonstrations of the material covered in earlier courses takes place in the junior and senior laboratory courses and in the two-semester, final design sequence. In the first course of the design sequence, the student works on a class design project using state-of-the-art computer-aided design tools. In the second semester, the students form design teams and work on projects of their choosing. Recent final design projects have included a mega yacht, an offshore wind farm repair vessel, a cruise ship rescue vessel, an offshore well intervention vessel, a neo-Panamax containership, a naval vessel for high-energy weapons, and an offshore racing trimaran.

The department works closely with the marine industry and is able to assist graduates in obtaining positions in the field. The department is in regular contact with the

country's marine design offices, shipyards, ship operators, government agencies and other organizations concerned with naval architecture and marine engineering. A successful summer internship program allows students to work in the industry.

Students who meet the academic requirements of both departments may earn an additional B.S.E. degree in another engineering program, or in combined programs with other engineering departments. The combined programs allow substantial substitution of courses required in one regular program for those required in the other, and typically can be completed in two extra terms.

## Department Administration

### Department Chair

Steven Louis Ceccio  
212 Naval Architecture & Marine Engineering  
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### Contacts

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**Departmental Website:** <http://name.engin.umich.edu/>

## Mission

The mission of the Naval Architecture and Marine Engineering (NA&M.E.) Department, University of Michigan, is to be a world leader in the education of engineers in the application of engineering principles for the marine environment by:

- providing the leading bachelor's program in naval architecture and marine engineering, with emphasis on the conceptual design, engineering, manufacture and life cycle management of marine vehicles, structures and complex systems;

- providing the leading graduate education and research program in engineering for the marine environment, one which spans a broad range of inquiry;
- providing leadership and service to the state, national and international marine community.

## Goals

In addition, the N.A.&M.E. Program also has the following goals:

- to recruit, educate and support exceptional, diverse students and engage them in lifelong learning and achievement while preparing them for a sustained career of engineering leadership in the marine related industries, government service and academia.
- to maintain and enhance the leading undergraduate program in the world in naval architecture and marine engineering; one which provides a rigorous and effective preparation for a lifelong career of engineering leadership and service.

## Objectives

The Educational Objectives of the N.A.&M.E. Program are to produce graduates that, in 3-5 years' time, are:

1. designing and manufacturing vehicles and structures that operate in the marine environment
2. working effectively in teams
3. practicing professionally in the marine industries, enrolling in graduate study, and engaging in lifelong learning.

## Outcomes

The student outcomes of the N.A.&M.E. Program are:

- an ability to apply knowledge of mathematics, science and engineering within naval architecture and marine engineering; [ABET: 3A]
- an ability to formulate engineering problems and develop practical solutions; [ABET: 3e, 3k]
- an ability to design products and processes applica-

ble to naval architecture and marine engineering; [ABET: 3c]

- an ability to design, conduct, analyze and interpret the results of engineering experiments in a laboratory; [ABET: 3c]
- an ability to work effectively in diverse teams and provide leadership to teams and organizations; [ABET: 3d]
- an ability for effective oral, graphic and written communication; [ABET: 3g]
- a broad education necessary to understand the impact of engineering decisions in a global/societal/economic/environmental context; [ABET: 3h]
- an understanding of professional and ethical responsibility; [ABET: 3f]
- a recognition of the need for and an ability to engage in life-long learning; [ABET: 3i]
- a broad education necessary to contribute effectively beyond their professional careers; [ABET: 3j]
- a sense of responsibility to make a contribution to society; [ABET: 3f]
- an ability to apply probability and statistical methods to naval architecture and marine engineering problems; [ABET: 3a, Program: i]
- an ability to apply basic knowledge in fluid mechanics, dynamics, structural mechanics, material properties, hydrostatics, stochastic mechanics and energy/propulsion systems in the context of marine vehicles, and/or ocean structures; [ABET: 3a, Program: ii]
- a familiarity and experience with instrumentation appropriate to naval architecture and marine engineering including experiment design, data collection, data analysis and formal laboratory report writing; [ABET: 3b, Program: iii]
- an understanding of the organization, methods and techniques of marine system manufacture and the use of concurrent marine design; [ABET: 3k]
- an understanding of and experience in marine system conceptual and preliminary design using industrial capability design software, including a team design experience with formal written and oral presentation. [ABET: 3c, 3g]

## Undergraduate

### Degree Program

The undergraduate degree program is arranged to give the student a broad engineering mechanics education by requiring basic courses in the areas of structural mechanics, hydrodynamics, marine power systems and marine dynamics. These courses cover engineering fundamentals and their application to the design and construction of marine vehicles and systems. Courses in marine structures deal with the design and analysis of marine vehicles and platforms including static strength, fatigue, dynamic response, safety and production. Resistance, maneuvering and seakeeping characteristics of vessels in the marine environment are the subject matter for courses in marine hydrodynamics. Marine power systems involve all the mechanical systems on a marine vehicle with particular emphasis on the selection and arrangement of the main propulsion system. In marine dynamics, the student studies the vibrations of marine structures and engines and the rigid body responses of the vessel to the wind and waves.

## Sample Schedule

### B.S.E. in Naval Architecture and Marine Engineering

The Naval Architecture and Marine Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department's undergraduate advising website, <http://name.engin.umich.edu/academics/undergraduateprogram/>

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects Required by All Programs (55 hours)</b>									
Mathematics 115, 116, 215, and 216	16	4	4	4	4	-	-	-	-
Engineering 100, Introduction to Engineering	4	4	-	-	-	-	-	-	-
Engineering 101, Introduction to Computers	4	-	4	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	-	-	2	-	4	4
<b>Related Technical Core Subjects (11 hours)</b>									
ME 211, Introduction to Solid Mechanics	4	-	-	-	4	-	-	-	-
ME 240, Introduction to Dynamics	4	-	-	-	4	-	-	-	-
ME 235, Thermodynamics I	3	-	-	3	-	-	-	-	-
<b>Program Subjects (46 hours)</b>									
NA 270, Marine Design	4	-	-	4	-	-	-	-	-
NA 260, Marine Systems Manufacturing	2	-	-	-	2	-	-	-	-
NA 280, Probability for Marine Engineers	2	-	-	-	2	-	-	-	-
NA 310, Marine Structures I	4	-	-	-	-	4	-	-	-
NA 320, Marine Hydrodynamics I	4	-	-	-	-	4	-	-	-
NA 321, Marine Hydrodynamics II	4	-	-	-	-	-	4	-	-
NA 331, Marine Engineering I	3	-	-	-	-	3	-	-	-
NA 332, Marine Electrical Engineering	3	-	-	-	-	-	3	-	-
NA 340, Marine Dynamics I	4	-	-	-	-	-	4	-	-
NA 391, Marine Engineering Laboratory I	3	-	-	-	-	-	3	-	-
NA 461, Marine Structures Construction	3	-	-	-	-	-	-	-	3
NA 470, Foundations of Ship Design	4	-	-	-	-	-	-	4	-
NA 475, Marine Design Team Project	4	-	-	-	-	-	-	-	4
NA 492, Marine Engineering Laboratory II	2	-	-	-	-	-	-	2	-
<b>Electives (15 - 18 hours)</b>									
Technical Electives <sup>3</sup>	7	-	-	-	-	-	-	4	3
General Electives	9	-	-	-	-	3	2	1	1
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>16</b>	<b>16</b>	<b>15</b>	<b>15</b>

Candidates for the Bachelor of Science Degree in Engineering in Naval Architecture and Marine Engineering - B.S.E. in N.A.M.E. - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

#### Notes:

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 125/126/130 you will have met the Chemistry Core Requirement for the College of Engineering.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and Physics 240/241 you will have met the Physics Core Requirement for the College of Engineering.

<sup>3</sup> Technical Electives - Choose 2 from the following lists. At least one must come from Group 1:

#### Group 1

- NA 410, Marine Structure II
- NA 420, Environmental Ocean Dynamics
- NA 423, Introduction to Numerical Hydrodynamics
- NA 431, Marine Engineering II
- NA 440, Marine Dynamics II

#### Group 2

- NA 401, Small Craft Design
- NA 403, Sailing Craft Design Principles
- NA 416, Theory of Plates and Shells
- NA 483 Marine Control Systems
- NA 525 Drag Reduction Techniques
- NA 562, Marine Systems Production Strategy Operations Management
- Advanced Mathematics: Math 450, Math 454, or Math 471
- Other courses as approved by the department.

## Focus of Study

In the fourth year, students are required to select two (2) technical electives from an approved list. These electives allow students to focus their education in specific areas. Example focus areas and possible courses are as follows:

- Marine Structures: NA 410 and NA 440
- High Speed Craft Design: NA 401 and NA 431 or NA 440
- Marine Power Systems: NA 431 and NA 401
- Marine Manufacturing: NA 410 and NA 562
- Sailing Yachts: NA 403 and NA 410, NA 431, or NA 440

These and other combinations of general and technical electives should be selected in consultation with the Undergraduate Program Advisor.

Students are strongly encouraged to review the possible options prior to their senior year.

## Sequential Undergraduate/ Graduate Study (SUGS)

### B.S.E./M.S.E. in Naval Architecture and Marine Engineering

This program permits outstanding Naval Architecture and Marine Engineering students to receive the B.S.E. and M.S.E. degrees. The student benefits from the continuity of study and the inefficiencies of transferring from an undergraduate to a graduate program are eliminated. The program allows students with a 3.2 or better G.P.A., to apply early in the first semester of their senior year (once 85 credit hours have been completed), for a Sequential Undergraduate/Graduate program, which allows them to double count up to nine (9) credits and transfer up to six (6) credits of technical or general electives. In consultation with their advisor, students select technical electives that will be relevant to the master's program of study. Students are admitted using the normal department graduate admission pro-

cess, with the admission standards required for expected successful completion of the program. Please contact the Naval Architecture and Marine Engineering department for more complete program information.

## Graduate

### Graduate Degrees

- Master of Science (M.S.) in Naval Architecture and Marine Engineering
- Master of Science in Engineering (M.S.E.) in Naval Architecture and Marine Engineering
- Joint Master of Science in Engineering (M.S.E.)/Master of Business Administration (M.B.A.) in Naval Architecture and Marine Engineering
- Doctor of Philosophy (Ph.D.) in Naval Architecture and Marine Engineering

### Masters Programs

#### M.S. and M.S.E. in Naval Architecture and Marine Engineering

Applicants for the M.S. or M.S.E. degrees normally hold a Bachelor of Science degree in naval architecture and marine engineering with an average grade of 3.5 on a 4.0 scale. However, the graduate program has been structured so that students with a bachelor's degree in other engineering disciplines that require knowledge of basic mechanics—such as mechanical engineering, applied mechanics, aerospace or civil engineering—may also start directly on their master's program. Students with a bachelor's degree from another field without knowledge of basic mechanics and only want to pursue a master's degree will be required to take NA 470 (Foundation of Ship Design).

#### Joint M.S.E. / M.B.A. in Naval Architecture and Marine Engineering

The Department of Naval Architecture and Marine Engineering and the School of Business Administration offer a joint degree program for qualified persons to

pursue concurrent work in business administration and naval architecture and marine engineering studies leading to the M.B.A. and M.S.E. degrees. The program is arranged so that all requirements for both degrees can be completed in two years of enrollment, depending on the undergraduate's NAME background and the specialty area of the NAME master's program. The degrees are awarded simultaneously.

The program can begin with studies in either school. However, because of the sequential nature of the core courses in the M.B.A. program, most students will find it advantageous to start with year one in the Business School. During the remainder of the program, courses might be taken in both schools. Students who wish to begin in NAME should consult a counselor in the Business School to formulate an appropriate plan of study. Interested students must file separate applications and be admitted to both schools. Students admitted to this joint program must satisfy the following degree requirements:

1. The MBA 57 credit hour degree program including:
  - 45 Business Administration Credits, made up of:
    - Roughly 30 credit hours M.B.A. core
    - Roughly 15 elective hours in business administration
  - MBA communication requirement
    - Up to 12 credit hours of transferable electives from the Department of Naval Architecture and Marine Engineering
  
2. The N.A.&ME 30 credit hour degree program including:
  - 18 hours of graduate-level N.A.&M.E. courses 15 of the 18 N.A.&M.E. credits required need to be 500 level N.A.&M.E. courses or higher.
  - 2 cognate courses must include one (1) Mathematics course

## Ph.D. Programs

### Doctor of Philosophy (Ph.D.) in Naval Architecture and Marine Engineering

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must conduct an independent investigation in a subdivision of the selected field, and must present the results of the investigation in the form of a dissertation.

A student becomes a pre-candidate for the doctorate when admitted to the Horace H. Rackham School of Graduate Studies and accepted in a field of specialization. Candidacy is achieved when the student demonstrates competence in her/his broad field of knowledge through the completion of course work, passing comprehensive exams and successful presentation of a Ph.D. prospectus.

There is no general course requirement for the doctorate. However, during the course of a student's graduate study, three (3) math classes and 50 total classroom credit hours are expected as a minimum (with an approved M.S. degree earned before admission to the Ph.D. program, the total classroom credit hours could be reduced to 20). The comprehensive exam consists of a Part I, written exam covering general mechanics; and a Part II, oral exam and prospectus presentation describing the proposed Ph.D. dissertation. A special doctoral committee is appointed for each applicant to supervise the work of the student both in election of courses and in the preparation of the dissertation.

A pamphlet describing the general procedure leading to the doctorate is available from the Rackham Graduate School upon request.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **NAVARCH 102 (NS 201). Introduction to Ship Systems**

*Prerequisite: None. (3 credits) (Not open for credit to students in NAME.)*

Types, structures and purposes of ships. Ship compartmentation, propulsion systems, auxiliary power systems, interior communications and ship control. Elements of ship design to achieve safe operations and ship stability characteristics.

### **NAVARCH 260. Marine Systems Manufacturing**

*Prerequisite: NAVARCH 270 or concurrent with NAVARCH 270. (2 credits)*

The marine industry and its environment as it relates to all aspects that impact the production and operations of maritime products. Industrial and operations aspects of shipping/shipbuilding. Topics include industry characteristics; product types/components; shipbuilding, boatbuilding, offshore equipment manufacturing methods; design; production engineering; planning; contracts/specifications; cost estimating; production and material control.

### **NAVARCH 270. Marine Design**

*Prerequisite: Math 116. (4 credits)*

Introduction to the marine industries, ships and platforms. Engineering economics as applied in marine design decision making. Overview of preliminary ship design with brief team design project. Hydrostatics, stability and trim of ships, boats, and marine platforms.

### **NAVARCH 280. Introduction to Probability for Marine Engineers**

*Prerequisite: Math 116. (2 credits)*

Introduction to the fundamentals of probability theory, with marine applications. Events, Probabilities, Combinatorics, Independence, Bayes Theorem; Discrete and Continuous Random Variables, Central Limit Theorem, Elements of Engineering Statistics, goodness of fit, regression, correlation.

### **NAVARCH 310. Marine Structures I**

*Prerequisite: MECHENG 211, NAVARCH 270. (4 credits)*

Structural analysis of ship hulls and offshore structures. Loading, material and fabrication considerations. Hull primary bending and midship section analysis. Framing systems. Secondary and tertiary stresses in stiffened plate components. Energy methods. Introduction to Finite Element Analysis. Failure theories for buckling; combined stress states; brittle fracture and fatigue.

### **NAVARCH 320. Marine Hydrodynamics I**

*Prerequisite: Math 215 and MECHENG 211 or MECHENG 240, or permission of instructor. (4 credits)*

Concepts and basic equations of marine hydrodynamics. Similitude and dimensional analysis, basic equations in integral form, continuity and Navier-Stokes equations. Ideal fluid flow, Euler's equations, Bernoulli equation, free surface boundary value problems. Laminar and turbulent flows in pipes and around bodies.

### **NAVARCH 321. Marine Hydrodynamics II**

*Prerequisite: NAVARCH 320. (4 credits)*

Ideal and viscous fluid theory applied to marine systems. Ship resistance components. Resistance prediction from model testing and standard series. Two-dimensional and three-dimensional airfoil theory. Propeller geometry, design and matching. Hull-propeller interaction, propeller charts, powering prediction. Unsteady marine hydrodynamics: wave loads, seakeeping and transport of pollutants.

### **NAVARCH 331. Marine Engineering I**

*Prerequisites: MECHENG 235, co-requisite NAVARCH 320. (3 credits)*

Diesel engines, steam turbines and gas turbines as marine prime movers. Thermodynamic cycles, ratings, matching to loads. Engine-propeller matching. Mechanical transmission of power to marine loads. Principles of fluid system design. Introduction to heat transfer and heat exchangers.

### **NAVARCH 332. Marine Electrical Engineering**

*Prerequisites: NAVARCH 331, Phys 240. (3 credits)*

Electrical circuit analysis. Electromagnetic interactions. Principles, characteristics, and properties of transform-

ers, and DC and AC motors. Power electronics, integrated marine electrical plants. Electrical power distribution and control. Circuit protection. Introduction to fuel cells.

### **NAVARCH 340. Marine Dynamics I**

*Prerequisites: MECHENG 240. Co-requisite: NAVARCH 321. (4 credits)*

Structural vibration; one and multi-degree of freedom models. Forced steady state response. Fourier series; definition and application to frequency response. Introduction to random processes and applications in linear systems. Rigid body motion of floating structures. Sea wave excitation. Hydrodynamic added mass and damping; anti-roll tanks. Ship maneuvering; directional stability and steady turning.

### **NAVARCH 391. Marine Laboratory I**

*Prerequisites: NAVARCH 320 and NAVARCH 310 and NAVARCH 331; Concurrent enrollment with NAVARCH 321 advised. Minimum grade for enforced prerequisite is C-. (3 credits)*

This course is the first in a two-part capstone laboratory class. It provides experimental foundation for the Engineering Mechanics part of the curriculum. Instruction includes laboratory techniques and instrumentation, as well as error analysis. Investigations include fluid dynamics and structural mechanics. Technical report writing is stressed.

### **NAVARCH 401. Small Craft Design**

*Prerequisite: Preceded or accompanied by NAVARCH 321 and NAVARCH 340. (4 credits)*

Hydrodynamics of small high-speed craft including planing hulls, air cushion vehicles, surface effect ships and catamarans. Theoretical and empirical methods for resistance propulsion and attitude prediction. Nonlinear dynamics and stability of high-speed marine vehicles. Effect of hull form on resistance and dynamic performance. Structural design considerations including bottom plating strength and frame loading. Discussion of various types of framing. Material choices.

### **NAVARCH 403. Sailing Craft Design Principles**

*Prerequisite: Preceded or accompanied by NAVARCH 321. (3 credits)*

Forces and moments acting on a sailing yacht. Speed

polar diagrams. Two- and three-dimensional airfoil theory. Application to keel and rudder design. Yacht model testing. Delft Standard Series for prediction of hydrodynamic performance. Aerodynamics of yacht sails. Sail force coefficients. Velocity Prediction Program. Rigging design and analysis. Yacht racing rules.

### **NAVARCH 410 (MFG 410). Marine Structures II**

*Prerequisite: NAVARCH 310 advised.*

Structural modeling and analysis techniques applied to ship and marine structure components. Equilibrium and energy methods applied to elastic beam theory; static bi-axial bending, torsion and buckling. Shear flow in multicell cross sections. Stiffened and composite plates. Plastic analysis of beams and plates. Structural limit states and introduction to structural reliability.

### **NAVARCH 416 (AEROSP 416). Theory of Plates and Shells**

*Prerequisite: NAVARCH 310 or AEROSP 315. (3 credits)*

Linear elastic plates. Membrane and bending theory of axisymmetric and non-axisymmetric shells. Variational formulation of governing equations boundary conditions. Finite element techniques for plate and shell problems.

### **NAVARCH 420 (AOSS 420). Environmental Ocean Dynamics**

*Prerequisites: NAVARCH 320 or AOSS 305 or CEE 325. (4 credits)*

Physical conditions and physical processes of the oceans; integration of observations into comprehensive descriptions and explanations of oceanic phenomena. Emphasis on wave and current prediction, optical and acoustical properties of sea water, currents, tides, waves and pollutant transport.

### **NAVARCH 423. Introduction to Numerical Hydrodynamics**

*Prerequisite: NAVARCH 320, NAVARCH 321. (4 credits)*

Numerical integration, uncertainty analysis and solution of PDE's using finite differences and finite volume methods. Turbulence modeling and algorithms for solving the Navier-Stokes equations and introduction to solution of air-water flows. Computer lab sessions in-

roduce the student to the computing environment for source-code development, mesh generation, simulation and post-processing.

#### **NAVARCH 424. Hydrofoils, Propellers and Turbines**

*Advised Prerequisite: NAVARCH 320 or equivalent. (4 credits)*

Introduction to the fundamentals of lifting surfaces related to the selection, design, experimental and numerical modeling, as well as optimization of hydrofoils, propellers, and turbines.

#### **NAVARCH 431. Marine Engineering II**

*Prerequisite: NAVARCH 310, NAVARCH 331, NAVARCH 332, NAVARCH 340. (3 credits)*

Integrated treatment of the statics and dynamics of marine power transmission systems. Shafting design and alignment. Bearing selection and lubrication. Propeller excitation, added mass, and damping. Vibration modeling, analysis and evaluations of shafting systems: torsional, longitudinal and lateral vibrations.

#### **NAVARCH 440. Marine Dynamics II**

*Prerequisite: NAVARCH 321, NAVARCH 340. (4 credits)*

Dynamic analysis in a fluid environment. Rayleigh's principle for continuous systems. Equations of motion for ship rigid body dynamics. Wave excitation. Response Amplitude Operator (RAO). Random processes and probability. Motion in irregular seas. Introduction to time series analysis.

#### **NAVARCH 461 (MFG 462). Marine Structures Construction**

*Prerequisite: NAVARCH 260 and NAVARCH 310. (3 credits)*

Principles and applications of modular construction and assembly, major manufacturing processes, thermo-mechanical interactions and contributions to quality and dimensional accuracy, accuracy control methods and practices.

#### **NAVARCH 470 (MFG 470). Foundations of Ship Design**

*Prerequisite: NAVARCH 321, NAVARCH 332, NAVARCH 340. Co-requisites: NAVARCH 310. I (4*

*credits)*

Organization of ship design. Preliminary design methods for sizing and form; powering, maneuvering, sea-keeping estimation; arranging; propulsion; structural synthesis; and safety and environmental risk of ships. Extensive use of design computer environment. Given owner's requirements, students individually create and report the conceptual/preliminary design for a displacement ship.

#### **NAVARCH 471. Advanced Ship Design**

*Prerequisite: Must be minoring in NAME. (3 credits)*

Individual or team-based design course for non-NAME majors. Students create, develop and document original marine designs. Projects typically involve a ship, yacht, submersible, or offshore system. Involves project planning and weekly progress reporting. Written and oral presentation of the project.

#### **NAVARCH 475. Marine Design Team Project**

*Prerequisite: NAVARCH 470. (4 credits)*

Small teams of 4 or more students create, develop, and document original marine designs to contract design level. Projects typically involve a ship, yacht, submersible, or offshore system. Involves extensive project planning and weekly progress reporting. Extensive written and oral presentation of the project. Significant design CAD effort.

#### **NAVARCH 483. Marine Control Systems**

*Prerequisite: NAVARCH 331, NAVARCH 332 or permission of instructor. (3 credits)*

This course covers the theoretical foundation and practical design aspects of marine control systems. Students will be exposed to important system concepts and available analysis and design tools. Fundamental concepts of dynamic behavior and feedback design will be emphasized in the context marine control system applications.

#### **NAVARCH 490. Directed Study, Research and Special Problems**

*Prerequisite: Undergraduate only and permission. (to be arranged)*

Individual or team project, experimental work or study of selected topics in naval architecture or marine engineering. Intended primarily for students with senior

standing.

#### **NAVARCH 491. Marine Engineering Laboratory I**

*Prerequisite: NAVARCH 310, NAVARCH 320, NAVARCH 321, NAVARCH 331, NAVARCH 332, NAVARCH 340. (3 credits)*

Instruction in laboratory techniques and instrumentation. Use of computers in data analysis that includes Fast Fourier transforms. Technical report writing. Investigation of fluid concepts, hydro-elasticity, marine dynamics, propeller forces, wave mechanics, ship hydrodynamics and extrapolation of model tests to full scale.

#### **NAVARCH 492. Marine Engineering Laboratory II**

*Prerequisite: NAVARCH 310, NAVARCH 320, NAVARCH 321, NAVARCH 331, NAVARCH 332, NAVARCH 340, NAVARCH 491. (2 credits)*

Instruction in laboratory techniques and instrumentation. Use of computers in data analysis and understanding the fast Fourier transform and frequency domain. Technical report writing. Investigation of fluid concepts, hydro-elasticity, marine of dynamics, propeller forces, wave mechanics, ship hydrodynamics, and extrapolation of model tests to full scale. Use of the frequency domain.

#### **NAVARCH 499. Special Topics in Naval Architecture and Marine Engineering**

*(1-6 credits)*

Special topics in Naval Architecture and Marine Engineering for Undergraduates.

#### **NAVARCH 510. Marine Structural Mechanics**

*Prerequisite: NAVARCH 410. (4 credits)*

Failure modes encountered in ship and offshore structures. Von Karman plate equations. Geometric and material nonlinear analyses of beams and stiffened plates. Calculus of variations. Effective width and breadth of stiffened plates. Introduction to structural reliability theory with applications to marine structural design.

#### **NAVARCH 511. Special Topics in Ship Structure**

*Prerequisite: Prior arrangement with instructor. (to be arranged)*

Individual or team project, experimental work, research or directed study of selected advanced topics in ship

structure. Primarily for graduate students.

#### **NAVARCH 512 (CEE 510). Finite Element Methods in Solid and Structural Mechanics**

*Prerequisite: Graduate standing. (3 credits)*

Basic equations of three dimensional elasticity. Derivation of relevant variational principles. Finite element approximation. Convergence requirements. Isoparametric elements in two and three dimensions. Implementational considerations. Locking phenomena. Problems involving non-linear material behavior.

#### **NAVARCH 513. Defect Assessment for Marine Structures**

*Prerequisite: NAVARCH 461 or permission of instructor. (3 credits)*

Engineering-Critical-Assessment (ECA) is about providing a quantitative evaluation of a structure's fitness for service (FFS) when a flaw or damage is detected either in service or during construction. This course discusses basic mechanics principles and the state of the art methodologies for establishing the integrity of a structure containing crack-like defects.

#### **NAVARCH 514 (MFG 515). Fatigue of Structures**

*Prerequisite: None. (3 credits)*

Fundamental concepts associated with fatigue damage and failure in engineering structures and contemporary design and analysis procedures with an emphasis on fatigue of welded structures, including most recent developments in finite element based fatigue design and analysis procedures, e.g., mesh-insensitive structural stress method and master S-N curve approach.

#### **NAVARCH 520. Intermediate Hydrodynamics**

*Prerequisite: None. (4 credits)*

Computation of wave loads on marine vehicles and offshore structures including resistance, diffraction, viscous and radiation forces. Linear theory using panel methods and Green functions. Forces on cylindrical bodies. Morison's Equation. Nonlinear computation using desingularized method for inviscid flow and Reynold's averaged Navier-Stokes equation (RANS) for viscous flow.

#### **NAVARCH 523. Numerical Marine Hydrodynamics**

*Prerequisite: NAVARCH 423. (3 credits)*

Develop the necessary skills to numerically predict the hydrodynamic performance of bodies that move in the marine environment. Topics include numerical uncertainty analysis, panel methods for the free-surface Green function and Michell's integral, discretization fundamentals for unstructured finite-volume methods, interface capturing methods and turbulence modeling for ship flows.

### **NAVARCH 525. Drag Reduction Techniques**

*Prerequisite: NAVARCH 320. (3 credits)*

Course addresses active and passive techniques of friction drag reduction. Active methods discussed include air layers and cavities, polymer and gas/bubble injection, and super-hydrophobic and other coating technologies. Passive techniques covered include hull form optimization and appendages such as stern flaps, lifting bodies and bulbous bows.

### **NAVARCH 540. Marine Dynamics II**

*Prerequisite: NAVARCH 340. (4 credits)*

Fundamental analysis of marine dynamical systems. Normal mode analysis. Matrix representation of frequency domain seakeeping equations. Properties of linear gravity waves. Wave forces on marine structures. Linear and non-linear time domain seakeeping and maneuvering simulations. Nonlinear stability and bifurcation theory applied to mooring and capsizing. Shock mitigation.

### **NAVARCH 551. Offshore Engineering I**

*Prerequisite: Graduate student standing or permission of instructor. (3 credits)*

Offshore engineering structures. Introduction to hydrodynamic loads on offshore platforms. Detailed study of forces on slender bodies - risers, pipelines, cables. Morison's equation. Flow induced motions, vortex induced vibrations, galloping. Two-cylinder flows. Mathematical modeling, experiments, data processing. Marine hydrokinetic energy harnessing.

### **NAVARCH 552. Offshore Engineering II**

*Advised Prerequisite: NAVARCH 551. (3 credits)*

Design and analysis requirements of offshore engineering structures. Hydrodynamic loads on offshore platforms. Wave theories applied in offshore engineer-

ing. Marine riser mechanics: dynamics and structural stability. Mooring dynamics: nonlinear stability and design.

### **NAVARCH 562 (MFG 563). Marine Systems Production Business Strategy and Operations Management**

*Prerequisite: NAVARCH 260 or permission of instructor or graduate standing. (4 credits)*

Examination of business strategy development, operations management principles and methods and design-production integration methods applied to the production of complex marine systems such as ships, offshore structures, and yachts. Addresses shipyard and boat yard business and product strategy definition, operations planning and scheduling, performance measurement, process control and improvement.

### **NAVARCH 568 (EECS 568). Mobile Robotics: Methods and Algorithms**

*Prerequisite: Graduate standing or permission of instructor. (4 credits)*

Theory and applications of probabilistic techniques for autonomous mobile robotics. This course will present and critically examine contemporary algorithms for robot perception (using a variety of modalities), state estimation, mapping and path planning. Topics include Bayesian filtering; stochastic representations of the environment; motion and sensor models for mobile robots; algorithms for mapping, localization, planning and control in the presence of uncertainty; application to autonomous marine, ground and air vehicles.

### **NAVARCH 570 (MFG 572). Advanced Marine Design**

*Prerequisite: Graduate standing required. (4 credits)*

Organization of marine product development; concurrent marine design. Shipbuilding policy and build strategy development. Group behaviors; leadership and facilitation of design teams. General theories and approaches to design. Conceptual design of ships and offshore projects. Nonlinear programming, multicriteria optimization, and genetic algorithms applied to marine design.

### **NAVARCH 580 (MFG 580). Optimization and Management of Marine Systems**

*Prerequisites: None. (4 credits)*

Optimization methods (linear, integer, nonlinear, deterministic and stochastic sequential optimization concepts and applications in the operations of marine systems. Elements of maritime management. Risk analysis and utility theory. Fleet deployment optimization for major ocean shipping segments. Forecasting concepts and applications to shipping and shipbuilding decisions.

### **NAVARCH 582 (MFG 579). Reliability, Risk and Safety Analysis**

*Prerequisite: EECS 401 or Math 425 or STATS 412. (3 credits)*

Brief review of probability and statistics. Mathematical methods of reliability analysis for systems with or without repairs. Reliability, availability, maintenance, replacement, and repair decisions. Safety and risk analysis. Risk assessment methods and case Studies. FMEA, fault tree and event tree analysis. Marine, Automotive, Manufacturing, Health Care and other applications.

### **NAVARCH 583. Adaptive Control**

*Prerequisite: Graduate standing or permission of instructor. Not Offered On Regular Basis (3 credits)*

Models of systems with unknown or time-varying parameters. Theory and algorithm for online parameter identification. Adaptive observers. Direct and indirect adaptive control. Model reference adaptive control. Robustness and convergence of adaptive systems. Design and analysis of nonlinear adaptive control. Application and implementation of adaptive systems.

### **NAVARCH 590. Directed Study, Research and Special Problems**

*Prerequisite: Permission of instructor. (1-6 credits)*

Individual or group study, design, or laboratory research in a field of interest to the student. Topics may be chosen from any of the areas of Naval Architecture and Marine Engineering.

### **NAVARCH 592. Master's Thesis**

*Prerequisite: Graduate standing. (1-6 credits)*

To be elected by Naval Architecture and Marine Engineering students pursuing the master's thesis option. May be taken more than once up to a total of 6 credit hours.

### **NAVARCH 599. Special Topics in Naval Architecture and Marine Engineering**

*Prerequisite: Graduate standing or permission of instructor. (1-6 credits)*

Special topics in Naval Architecture and Marine Engineering.

### **NAVARCH 615. Special Topics in Ship Structure Analysis II**

*Prerequisite: NAVARCH 510, prior arrangement with instructor. (to be arranged)*

Advances in specific areas of ship structure analysis as revealed by recent research. Lectures, discussions and assigned readings.

### **NAVARCH 620. Computational Fluid Dynamics for Ship Design**

*Advised Co-requisite: NAVARCH 500. (3 credits)*

Development of the necessary skills for the hydrodynamic design of hull shapes based on available Computational Fluid dynamic (CFD) tools. Topics: Potential Flows (Deeply submerged, Free-surface treatments, Status of CFD solvers), Viscous flows (Basics, Turbulence modeling, Grid generation, Discretization, Numerical methodologies (Strategies for Wave Resistance, Viscous flows, Total resistance and Optimization work).

### **NAVARCH 792. Professional Degree Thesis**

*(2-8 credits); (1-4 credits)*

### **NAVARCH 990. Dissertation/Pre-Candidate**

*(2-8 credits); (1-8 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

### **NAVARCH 995. Dissertation/Candidate**

*Prerequisite: Graduate School authorization for admission as a doctoral candidate. (1-8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Nuclear Engineering and Radiological Sciences

1919 Cooley  
tvfount@umich.edu  
(734) 936-3130

## Overview

Nuclear engineering and radiological sciences are concerned with the direct technological use of atomic and subatomic particles. These applications have become an inseparable part of much of modern technological life: smoke detectors, nuclear power reactors, nondestructive evaluation of turbine blades, hardening of artificial hip joints, treatment of radioactive waste, medical CT and PET imaging, treatment of cancer using radiotherapy—all of these rely on the direct manipulation and measurements of parts of atoms or their emitted energy. These are the kinds of technologies that nuclear engineering and radiological sciences encompasses. The Undergraduate Program in Nuclear Engineering and Radiological Sciences leads to the Bachelor of Science in Engineering (B.S.E.) in N.E.R.S..

## Department Administration

### Department Chair

Ronald M. Gilgenbach, Chair and Chihiro Kikuchi  
Collegiate Professor

Nuclear Engineering and Radiological Sciences Department

1906 Cooley Memorial Laboratory

2355 Bonisteel Blvd.

Ann Arbor, MI 48109-2104

Email: [rongilg@umich.edu](mailto:rongilg@umich.edu)

Phone: (734) 764-4260

Fax: (734) 763-4540

## Contacts

**Departmental Website:** <http://www.engin.umich.edu/ners>

**Student Advisor / Counselor**

Trisha Fountain

## Mission

To provide a superior education for engineers and scientists in nuclear engineering and radiological sciences and to develop future leaders in industry, government and education.

## Goals

The program provides students with:

- skills and tools necessary for industrial, medical, governmental and environmental applications of nuclear processes and radiation; and
- insights and skills that will prepare them to be leaders in research and the practice of nuclear engineering and radiological sciences.

## Objectives

Our alumni:

- are expected to engage in entry-level professional practice in industry, government or health care practice, where, within the initial phase (few years) of employment, they will be performing analysis and measurements related to radiation and radiation interactions with matter, including nuclear power system and health physics and analysis; or,
- enter graduate studies and earn M.S. or Ph.D. degrees in nuclear engineering and related fields;
- are expected to have successful careers and assume leadership roles building upon their strong background in fundamental engineering analysis, teamwork and communication skills and ability to engage in life-long learning for their continual improvement of their skills and knowledge.

## Outcomes

Graduates of the program will have:

- an ability to apply mathematics, science and engineering, including atomic and nuclear physics, to the study of radiation interactions with matter and nuclear processes;
- an ability to use the techniques, skills and modern engineering tools necessary for engineering practice;
- an ability to identify, formulate and solve engineering problems and develop practical solutions;
- an ability to design a system, component, or process applicable to nuclear engineering and radiological science, to meet desired needs with realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability;
- an ability to design and conduct engineering experiments, as well as to analyze and interpret data, including the characteristic attributes of nuclear processes and radiation;
- an ability to function effectively on diverse multidisciplinary teams and provide leadership to teams and organizations;
- an ability to communicate effectively in oral, graphic and written communication;
- the broad education necessary to understand the impact of engineering solutions and biological effects of radiation in a global, economic, environmental and societal context;
- an understanding of professional and ethical responsibility;
- a recognition of the need for, and an ability to engage in life-long learning;
- a knowledge of contemporary issues.

## Engineering Physics

### Overview

Basic physics is an integral part of every engineering curriculum. However, in many areas of engineering the sophistication of the field, coupled with the staggering rate of technological advance, has created a need for engineers with much stronger backgrounds in math and physics—people who can work in an engineering environment and who are capable of applying advanced physics concepts to bring innovations to the market-

place. For example, the development of the computer closely followed the invention of the transistor. Consider the number of other recently discovered physical phenomena (lasers, nuclear reactors, particle accelerators, etc.) that have been successfully brought to fruition by engineers.

Engineering Physics is particularly attractive to those students who may attend graduate school, even if they have not decided on a particular field. An advanced physics and mathematics background coupled with an engineering curriculum is excellent preparation for most graduate engineering programs and for traditional physics or applied physics programs.

Engineering Physics meets the stated needs by providing a thorough curriculum in basic and advanced engineering courses combined with sufficient physics and mathematics to be equivalent to a traditional degree in physics. A unique feature of the curriculum is the elective sequence of engineering courses that the student may select in a specialized field of engineering. This sequence of courses can be chosen by the student (with the faculty advisor's approval) in any field of interest, such as microprocessor design, plasma processing, electro-optics, radiological health, computational methods or bioengineering, to name just a few. With 46 credit hours of electives in math, engineering and physics, the student has a high degree of flexibility and opportunity for exploring or specializing in fields of interest.

Engineering Physics is Administered by the Nuclear Engineering and Radiological Sciences Department.

### Program Administration

#### Contacts

Nuclear Engineering and Radiological Sciences  
Department  
1906 Cooley Memorial Laboratory  
2355 Bonisteel Blvd.  
Ann Arbor, MI 48109-2104  
Email: [rongilg@umich.edu](mailto:rongilg@umich.edu)  
Phone: (734) 764-4260  
Fax: (734) 763-4540

## **Undergraduate Contacts**

### **Faculty Program Advisor**

Michael Atzmon  
2933 Cooley  
atzmon@umich.edu  
(734) 764-6888

### **Student Advisor/Counselor**

Trisha Fountain  
1919 Cooley  
tvfount@umich.edu  
(734) 936-3130

## **Mission**

To provide students with a high-quality education that prepares them for careers in engineering and science.

## **Goals**

To educate students in the scientific fundamentals as well as in an engineering discipline of their choice, to provide the depth and breadth required to adapt to changes in technology.

## Sample Schedule

### B.S.E. in Nuclear Engineering and Radiological Sciences

The Nuclear Engineering and Radiological Sciences program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org>. Additional information can be found on the department advising website, <http://www.engin.umich.edu/ners/academics/undergrad>

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects required by all programs (55 hours)</b>									
Mathematics 115, 116, 215, and 216	16	4	4	4	4	-	-	-	-
Engr 100, Intro to Engr	4	4	-	-	-	-	-	-	-
Engr 101, Intro to Computers	4	-	4	-	-	-	-	-	-
Chemistry 12 5/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	4	-	-	4	-	-
<b>Related Technical Subjects (11 hours)</b>									
MATSCIE 250, Princ of Eng Materials or MSE 220, Intro to Materials and Manf	4	-	-	-	4	-	-	-	-
EECS 215, Intro to Circuits or EECS 314, Electrical Circuits, Systems, and Applications	4	-	-	-	-	4	-	-	-
MECHENG 235, Thermodynamics I	3	-	-	-	-	3	-	-	-
<b>Program Subjects (45 hours)</b>									
NERS 250, Fundamentals of Nuclear Eng and Rad Sci	4	-	-	-	4	-	-	-	-
NERS 311, Ele of Nuc Eng & Rad Sci I	3	-	-	-	-	3	-	-	-
NERS 312, Ele of Nuc Eng & Rad Sci II	3	-	-	-	-	-	3	-	-
NERS 315, Nuclear Instr Lab	4	-	-	-	-	-	4	-	-
NERS 320, Prob in nucl Engr & Rad Sci	4	-	-	-	-	4	-	-	-
NERS 344, Fluid Mech Nucl Eng	3	-	-	-	-	-	3	-	-
NERS 441, Nuclear Reactor Theory I	4	-	-	-	-	-	-	4	-
NERS 444, Therm-hyd Nucl Sys	3	-	-	-	-	-	-	3	-
Laboratory Course (above NERS 315) <sup>3</sup>	4	-	-	-	-	-	-	-	4
Design Course <sup>4</sup>	4	-	-	-	-	-	-	-	4
NERS Electives <sup>5</sup>	9	-	-	-	-	-	-	6	3
<b>Technical Electives (5 hours)<sup>6</sup></b>	<b>5</b>	-	-	-	-	2	-	-	3
<b>General Electives (12 hours)</b>	<b>12</b>	-	-	3	3	-	3	3	-
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>16</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>16</b>	<b>14</b>

Candidates for the Bachelor of Science Degree in Engineering in Nuclear Engineering and Radiological Sciences - B.S.E. in N.E.R.S. - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

#### Notes:

- <sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 12 5/126/130 you will have met the Chemistry Core Requirement for the College of Engineering.
- <sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and Physics 240/241 you will have met the Physics Core Requirement for the College of Engineering.
- <sup>3</sup> Laboratory Course, (above NERS 315) select one from the following: NERS 425, 535, 575, 586. (NERS 535 and 575 require program advisor's consent.)
- <sup>4</sup> Design Course, select one: NERS 442, 554.
- <sup>5</sup> One course must be selected from the following: NERS 421, NERS 471 and NERS 484. A maximum of 3 credit hours of independent study (NERS 499) can count as a NERS elective. All additional NERS 499 credits beyond those 3 can only be counted as a general elective.
- <sup>6</sup> Technical electives are defined as: 300-level and above Mathematics, Physics or non-NERS Engineering courses. Course content must be technical. All substitutions must be approved by the faculty advisor.

## B.S.E. in Engineering Physics

Not an ABET accredited program. Additional information can be found on the department advising website,  
<http://eng.physics.engin.umich.edu/>

	Total Credit Hours	Term:							
		1	2	3	4	5	6	7	8
<b>Subjects required by all programs (55 hours)</b>									
Mathematics 115, 116, 215, and 216	16	4	4	4	4	-	-	-	-
Engr 100, Intro to Engr	4	4	-	-	-	-	-	-	-
Engr 101, Intro to Computers	4	-	4	-	-	-	-	-	-
Chemistry 125/126 and 130 or Chemistry 210 and 211 <sup>1</sup>	5	5	-	-	-	-	-	-	-
Physics 140 with Lab 141; Physics 240 with Lab 241 <sup>2</sup>	10	-	5	5	-	-	-	-	-
Intellectual Breadth	16	4	4	4	4	-	-	-	-
<b>Advanced Mathematics (6 hours)</b>									
Mathematics Electives <sup>3</sup>	6	-	-	-	-	-	3	3	-
<b>Related Technical Subjects (8 hours)</b>									
MATSCIE 250, Princ of Eng Materials or MATSCIE 220, Intro to Materials and Manf	4	-	-	4	-	-	-	-	-
EECS 314, Elect Cir, Sys, and Appl or EECS 215, Intro to Circuits	4	-	-	-	4	-	-	-	-
<b>Physics Technical Subjects (20 hours)</b>									
Physics 340, Waves, Heat and Light	3	-	-	-	3	-	-	-	-
Physics 390, Intro to Modern Physics or NERS 311, Ele of Nuc Engr & Rad Sci I	3	-	-	-	-	3	-	-	-
Physics 401, Int Mech <sup>4</sup>	3	-	-	-	-	-	3	-	-
Physics 405, Int Elect and Mag	3	-	-	-	-	-	-	3	-
Physics 406, Stat/thermal Physics	3	-	-	-	-	-	-	-	3
Physics Elective (300-level +)	3	-	-	-	-	-	-	-	3
Physics Lab Elective or Directed Study with Research Lab Component	2	-	-	-	-	2	-	-	-
<b>Engr Technical Electives (20 hours)</b>									
Engineering Electives <sup>5</sup>	16	-	-	-	-	4	4	4	4
Engineering Laboratory Elective (400-level or higher)	4	-	-	-	-	-	-	-	4
<b>Technical Electives (7 hours)<sup>6</sup></b>									
Mathematics, Physics or Engr Courses (300-level or higher)	7	-	-	-	-	3	4	-	-
<b>General Electives (12 hours)<sup>7</sup></b>									
<b>Total</b>	<b>128</b>	<b>17</b>	<b>17</b>	<b>17</b>	<b>15</b>	<b>15</b>	<b>17</b>	<b>13</b>	<b>17</b>

Candidates for the Bachelor of Science in Engineering in Engineering Physics - B.S.E. in Eng Physics - must complete the program listed above. This sample schedule is an example of one leading to graduation in eight terms.

### Notes:

<sup>1</sup> If you have a satisfactory score or grade in Chemistry AP, A-Level, IB Exams or transfer credit from another institution for Chemistry 130/125/126 you will have met the Chemistry Core Requirement for CoE.

<sup>2</sup> If you have a satisfactory score or grade in Physics AP, A-Level, IB Exams or transfer credit from another institution for Physics 140/141 and 240/241 you will have met the Physics Core Requirement for CoE.

<sup>3</sup> Math Electives must be 300-level or higher.

<sup>4</sup> For students pursuing ME in Engr Technical Elecives, CEE 211 or ME 240 will be advised as a stutitute for Physics 401.

<sup>5</sup> Engineering Electives are to be chosen in consultation with the faculty advisor to form a coherent sequence that clearly defines professional goals for the student. Sample elective sequences for a number of different subject areas are available from the academic or faculty advisors.

<sup>6</sup> For students pursuing ME in Engr Tech Elective, students will be advised to take ME 235 and ME 320 as Flexible Tech Electives.

<sup>7</sup> Students contemplating graduate studies in Physics should elect Physics 453, Quantum Mech and Physics 463, Solid State for a complete background.

## Sequential Undergraduate/ Graduate Study (SUGS)

The five-year Sequential Undergraduate/Graduate Study (SUGS) Program permits students who enter the program in the first term of their senior year to receive the B.S.E. and M.S.E. degrees (or the B.S.E. and M.Eng. degrees) upon completion of a minimum of 149 credit hours. Students should speak with the department advising office to learn more about the SUGS application process and procedures. SUGS admissions requirements will vary. Please go to our website for more information: <http://www.engin.umich.edu/ners>

Available programs include:

- B.S.E in Nuclear Engineering and Radiological Sciences/M.S. in Nuclear Engineering and Radiological Sciences
- B.S.E in Nuclear Engineering and Radiological Sciences/M.S. in Biomedical Engineering

## Graduate

### M.S. and M.S.E. Programs

#### M.S. in Nuclear Science and M.S.E. in Nuclear Engineering and Radiological Sciences

- **Undergraduate Preparation:** Entrance requirements are NERS 311, 312, and Math 454 (or their equivalents) and may NOT be applied towards the 30 hours for the Master's Degree.
- **Bachelor of Science (B.S.):** Apply for the Master's of Science (M.S.) diploma
- **Bachelor of Science in Engineering (BSE):** Apply for the Master's of Science in Engineering (M.S.E.) diploma

Please review the "Checklist for Master's Degree Requirements" available in the department office and online.

### Nuclear Engineering and Radiological Sciences, M.S.E.

Students entering the program must have a bachelor's degree from an accredited engineering program.

### Nuclear Science, M.S.

The nuclear science program is available to those with bachelor's degrees from recognized programs in physics, chemistry or mathematics who wish to work in the field of nuclear engineering and radiological sciences.

## Master's Graduation Requirements

The Master's degree in Nuclear Engineering and Radiological Sciences requires 30 hours of coursework at the graduate level, including 20 hours from N.E.R.S. (of which four (4) courses must be at the 500-level or above). Rackham requires a minimum of four (4) credit hours of cognate graduate-level coursework. N.E.R.S. requires that the cognate courses be related to the student's degree program and should be chosen with the advice of the student's graduate advisor. A student must also take at least one 400-level or higher laboratory course for the M.S. degree while a graduate student. The average grade in N.E.R.S. courses must be a "B" (a grade point of 3.0/4.0) or better, and the average grade for all courses must also be a "B" or higher. Undergraduates who earned the following degrees should apply for the corresponding diplomas.

### Master's Project: (Optional)

The student, with approval of the student's graduate advisor, may substitute a master's project report for two (2) to six (6) credit hours of graduate coursework (NERS 599). In addition to a written final report, the student will be required to make a seminar presentation on the master's project.

Minimum Number of Credits Required: 30 credit hours.

## Ph.D. Programs

### Nuclear Engineering and Radiological Sciences, Ph.D. Nuclear Science, Ph.D.

The doctoral degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly scheduled graduate courses of instruction in the chosen field and in such cognate subjects as may be required by Rackham and the advisor. In addition, the student must pursue independent investigation in a subdivision of the selected field and must present the result of the investigation in the form of a dissertation. The selected fields (options) are:

- Fission Systems and Radiation Transport
- Materials
- Plasmas and Fusion
- Radiation Measurements and Imaging

### Ph.D. Candidacy and Graduation Requirements

- Laboratory course requirement
- Breadth course requirements
- NERS candidacy requirements
- Thesis prospectus
- Dissertation and dissertation defense

#### Laboratory Course Requirement

All Ph.D. students must take NERS 515, Nuclear Measurements Laboratory, and obtain a grade of “B” (5.00) or better. Students who have taken NERS 315 or an equivalent as an undergraduate must instead take one of NERS 425, NERS 535, NERS 575, or NERS 586. The student’s advisor and graduate program chair must approve in writing any variances and substitutions.

#### Breadth Course Requirements

All Ph.D. students must take and obtain a grade of “B” (3.0/4.0) or better in six (6) credit hours of N.E.R.S. courses selected from outside the student’s option, as defined by the following lists of courses.

Courses not listed do not satisfy this requirement; the student’s advisor and graduate chair must approve any variances in writing. The purpose of this requirement is to ensure the breadth of nuclear engineering and radiological science education of our Ph.D. students and to ensure that the student is exposed to the quantitative analytical methods used in other specialties in the field. A laboratory course used to satisfy this breadth requirement cannot be used to satisfy the laboratory requirement (above). Breadth courses are not required for candidacy; however, they are required for final degree approval.

#### Breadth Requirement Courses and Option Classification:

Fission Systems and Radiation Transport: NERS 441, 442, 444, 462, 543, 544\*, 546, 551, 554\*, 561, 590\*\*, 644

Materials: NERS 521, 522, 524, 531, 622

Measurements: NERS 481, 484, 518, 535, 580, 582, 583, 585, 586, 587

Plasmas and Fusion: NERS 471, 571, 572, 573, 574, 575, 576, 577, 578

\*Students in the Measurements Option cannot elect these courses as breadth courses

\*\*590 Computational Fluid Dynamics (CFD) for Nuclear Applications

\*\*590 Computational Transport Methods

\*\*590 Solvers for Nuclear Applications

#### NERS and Rackham Candidacy Requirements

- Time to Candidacy - A student must achieve candidacy within 2.0 years after the first enrollment in the N.E.R.S. Ph.D. program.
- Coursework In Residence - A precandidate must complete at least 18 credit hours of graded (including the grade of “S” for Satisfactory) graduate course work registered as a Rackham student while in residence on the Ann Arbor campus.
- Courses elected as visit (audit) do not meet this requirement, nor do any doctoral courses (those designated as 990, etc.).
- Cognate Requirement - Before advancing to candidacy, students must complete four (4) credit hours of cognate coursework with a grade of B or better according to the NERS graduation requirements.

Additional Rackham requirements can be found at:

<http://www.rackham.umich.edu/current-students/policies/academic-policies/section5#52>

- All courses in Responsible Conduct of Research and Scholarship (RCRS) for Ph.D. students must be completed. <http://rcrs.engin.umich.edu/>

## Advancement to Candidacy

The entire NERS faculty will decide a student's advancement to candidacy based on a broad assessment of the student's performance on a written examination, the student's academic and research record, and the recommendation of the student's advisor.

The written examination is a six-hour test in a specific option: 1) Fission Systems and Radiation Transport; 2) Plasmas and Fusion; 3) Materials; 4) Measurements; or 5) an alternative area approved in advance by the NERS Executive Committee. The exam will cover topics at the graduate level. Students are encouraged to access the NERS CTOOLS website for copies of old examinations, and to discuss with their research advisor specific topics covered and relevant courses. The written exam is prepared by the examination committee in each Option and is given twice a year, in January and May.

To take the written exam, a student must be a doctoral precandidate in good standing with the graduate school, have identified a thesis advisor, and have a minimum graduate G.P.A. of 3.3 (B+) at the time of the exam. Exceptions will be considered by petition to the Departmental Graduate Committee. Also, a student must receive the written approval of their advisor and the NERS Graduate Chair.

The written exam will be graded anonymously, and the scores will be communicated to the student within two (2) weeks of the exam. The student will be considered by the Option Faculty for advancement to candidacy within a month of the written exam, taking into account the score on the written exam, the student's academic and research record, and the input of the student's advisor. A recommendation on advancement to candidacy will be prepared by the Option Faculty for the full N.E.R.S. faculty, who will decide each case. If the fac-

ulty decision is not to advance the student to candidacy, the student will be informed of the reasons for the decision and the specific recommendations of the faculty. A student may be considered for candidacy a second time, but attempts beyond the second will require approval of the department faculty.

Note on advancement to candidacy: before the student advances to candidacy, the department will audit the student's Ph.D. checklist to ensure that all candidacy requirements have been met. The breadth courses are not required for candidacy, but they must be taken before completion of the doctoral degree.

## Dissertation Prospectus

A thesis prospectus exam is required for completion of the Ph.D. degree. This exam must be taken within 12 months of achieving candidacy status, and after the candidate has formed a dissertation committee.

The exam will consist of a presentation by the candidate on his or her proposed research program, lasting about 30 minutes, followed by questioning. After questions covering the presentation material, questions of a more fundamental but related nature may be introduced. These questions may cover material found in standard undergraduate or introductory graduate N.E.R.S. courses. This question period is nominally expected to last 60 minutes.

This examining committee will consist of at least three (3) members of the student's dissertation committee (the full committee will be invited), and one randomly selected N.E.R.S. faculty member from outside the candidate's dissertation committee. The chair of the examining committee will be the student's dissertation committee chair. Following the questioning the examining committee will discuss the proposed research and prospectus, and vote on passing or failing the student; their decision will be communicated to the student as soon afterwards as practicable, generally along with suggestions for the direction of the research, and to the N.E.R.S. faculty as a whole at the next faculty meeting.

This exam may be attempted twice; the second attempt must occur within 12 months of the first. Additional

attempts beyond the second will require approval of the N.E.R.S. faculty.

The thesis prospectus will be scheduled at the advisor's request. The student should then submit his or her name, option, research topic and an abstract to the departmental Graduate Coordinator, along with some dates that both the advisor and student find convenient. The Graduate Coordinator will then set the committee, schedule the exam, and reserve the room for the exam. Additionally, the student is required to send an electronic abstract to the full examining committee and departmental graduate coordinator. After consulting with the student's advisor, a paper, publication, report, and/or slides are encouraged in addition to the abstract.

## Dissertation and Dissertation Defense

Ph.D. students must complete a written dissertation describing an original, substantive, and scholarly contribution to their field of study. A dissertation committee, chaired by the student's research advisor(s), will read this dissertation and its abstract and judge their adequacy. The committee may require changes to the dissertation. Each student must also present and successfully defend the dissertation work at a public meeting.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **NERS 211 (ENSCEN 211). Introduction to Nuclear Engineering and Radiological Sciences**

*Prerequisite: Preceded or accompanied by Math 216. (4 credits)*

This course will discuss different forms of energy, the history of nuclear energy, the fundamentals of fission and fusion nuclear power, radiological health applications and electromagnetic radiation in the environment. Current topics in the media such as radon, radioactive waste and nuclear proliferation will also be covered.

### **NERS 250. Fundamentals of Nuclear Engineering and Radiological Sciences**

*Prerequisite: Preceded or accompanied by Math 216 and Physics 240. (4 credits)*

Technological, industrial and medical applications of radiation, radioactive materials and fundamental particles. Special relativity, basic nuclear physics, interactions of radiation with matter. Fission reactors and the fuel cycle.

### **NERS 290. Special Topics for Nuclear Engineering and Radiological Sciences**

*Prerequisite: Permission of instructor. (1-3 credits)*

Special topics offered at the first and second year level. The subject matter may change from term to term.

### **NERS 299. Directed Study in Nuclear Engineering and Radiological Sciences**

*Prerequisite: None. (1-3 credits)*

Offers a direct study experience to 1st and 2nd year students in an area of interest to the student and faculty member. (Each hour of credit requires 3 - 4 hours of work per week. An oral presentation and/or written report is due at the end of the term.)

### **NERS 311. Elements of Nuclear Engineering and Radiological Sciences I**

*Prerequisite: NERS 250, Physics 240, preceded or accompanied by Math 454. (3 credits)*

Photons, electrons, neutrons and protons. Particle and wave properties of radiation. Introduction to quantum mechanics. Properties and structure of atoms.

### **NERS 312. Elements of Nuclear Engineering and Radiological Sciences II**

*Prerequisite: NERS 311. (3 credits)*

Nuclear properties. Radioactive decay. Alpha-, beta- and gamma- decays of nuclei. Nuclear fission and fusion. Radiation interactions and reaction cross-sections.

### **NERS 315. Nuclear Instrumentation Laboratory**

*Prerequisites: EECS 215 or EECS 314, preceded or accompanied by NERS 312. (4 credits)*

An introduction to the devices and techniques most common in nuclear measurements. Topics include the principles of operation of gas-filled, solid state and scintillation detectors for charged particle, gamma ray and neutron radiations. Techniques of pulse shaping, counting and analysis for radiation spectroscopy. Tim-

ing and coincidence measurements.

### **NERS 320: Problems in Nuclear Engineering and Radiological Sciences**

*Prerequisites: Concurrent enrollment in NERS 311. (4 credits)*

This course introduces students to several basic problems in nuclear engineering and radiological sciences, together with mathematical and numerical methods for solving the problems. The course is meant to prepare students for more advanced senior-level NERS courses.

### **NERS 344. Fluid Mechanics for Nuclear Engineers**

*Prerequisite: NERS 311 and MECHENG 235. (3 credits)*

Mass, Momentum, and energy balance in lumped-parameter and differential forms. Hydrostatics. Laminar and turbulent flow in pipes. Application of fluid mechanics to nuclear components and systems.

### **NERS 421. Nuclear Engineering Materials**

*Prerequisites: MATSCIE 220 or MATSCIE 250, NERS 312. (3 credits)*

An introduction to materials used in nuclear systems and radiation effects in materials (metals, ceramics, semiconductors, organics) due to neutrons, charged particles, electrons and photons.

### **NERS 425. Application of Radiation**

*Prerequisite: NERS 312. (4 credits)*

Applications of radiation interaction with matter using various forms (neutrons, ions, electrons, photons) of radiation, including activation analysis, neutron radiography, nuclear reaction analysis, Rutherford backscattering analysis, proton-induced x-ray emission, plasma-solid interactions and wave-solid interactions. Lectures and laboratory.

### **NERS 441. Nuclear Reactor Theory I**

*Prerequisite: NERS 312, Math 454. (4 credits)*

An introduction to the theory of nuclear fission reactors including neutron transport theory, the P1 approximation, diffusion theory, criticality calculations, reactor kinetics, neutron slowing down theory and numerical solution of the diffusion equation.

### **NERS 442. Nuclear Power Reactors**

*Prerequisite: NERS 441, CEE 325 or MECHENG 320 or equivalent. (4 credits)*

Analysis of nuclear fission power systems including an introduction to nuclear reactor design, reactivity control, steady-state thermal-hydraulics and reactivity feedback, fuel cycle analysis and fuel management, environmental impact and plant siting and transient analysis of nuclear systems. A semester-long design project of the student's choice.

### **NERS 444. Thermal-hydraulics for Nuclear Systems**

*Prerequisite: Enforced: NERS 344 or graduate standing. (3 credits)*

Mass, momentum, and energy balance in lumped-parameter and differential forms for two-phase flows. Heat conduction, convective heat transfer, heat transfer by radiation. Flow regime maps and thermal hydraulics phenomena in nuclear applications, e.g. counter-current flow limitation and critical heat flux. Best-estimate thermal hydraulic systems codes for nuclear power plant transients.

### **NERS 462. Reactor Safety Analysis**

*Prerequisite: Preceded or accompanied by NERS 441. (3 credits)*

Analysis of design and operational features of nuclear reactor systems that are relevant to safety. Topics include radiation sources and exposure, engineered safety features, system reliability, transient and accident analysis, reactor containment and radionuclide source term, and NRC regulations and licensing. Emphasis will be placed on probabilistic risk assessment for representative nuclear power plants.

### **NERS 471. Introduction to Plasmas**

*Prerequisite: Preceded or accompanied by Physics 240 or equivalent. (3 credits)*

Single particle orbits in electric and magnetic fields, moments of Boltzmann equation and introduction to fluid theory. Wave phenomena in plasmas. Diffusion of plasma in electric and magnetic fields. Analysis of laboratory plasmas and magnetic confinement devices. Introduction to plasma kinetic theory.

### **NERS 472. Fusion Reactor Technology**

*Prerequisite: NERS 471. (3 credits)*

Study of technological topics relevant to the engineer-

ing feasibility of fusion reactors as power sources. Basic magnetic fusion and inertial fusion reactor design. Problems of plasma confinement. Energy and particle balances in fusion reactors, neutronics and tritium breeding, and environmental aspects. Engineering considerations for ITER and NIF.

**NERS 481 (BIOMEDE 481). Engineering Principles of Radiation Imaging**

*(2 credits)*

Analytic description of radiation production, transport and detection in radiation imaging systems. Measurements methods for image quality and statistical performance of observers. Systems for radiographic and radioisotope imaging, including film/screen, storage phosphor, and electronic radiography, fluoroscopy, computed tomography, Anger camera and PET systems. Emphasis on impact of random process on observer detection.

**NERS 484 (BIOMEDE 484, ENSCEN 484). Radiological Health Engineering Fundamentals**

*Prerequisite: NERS 312 or equivalent or permission of instructor. (4 credits)*

Fundamental physics behind radiological health engineering and topics in quantitative radiation protection. Radiation quantities and measurement, regulations and enforcement, external and internal dose estimation, radiation biology, radioactive waste issues, radon gas, emergencies and wide variety of radiation sources from health physics perspective.

**NERS 490. Special Topics in Nuclear Engineering and Radiological Sciences**

*Prerequisite: Permission of instructor. (1-4 credits)*

Selected topics offered at the senior or first-year graduate level. The subject matter may change from term to term.

**NERS 499. Research in Nuclear Engineering and Radiological Sciences**

*Prerequisite: Permission of instructor. Junior or senior status required. (1-3 credits)*

This course offers research or directed study experience to 3rd or 4th year students in an area of interest to the student and faculty member.

**NERS 511. Quantum Mechanics in Neutron-Nuclear Reactions**

*Prerequisite: NERS 312, Math 454. (3 credits)*

An introduction to quantum mechanics with applications to nuclear science and nuclear engineering. Topics covered include the Schroedinger equation and neutron-wave equations, neutron absorption, neutron scattering, details of neutron-nuclear reactions, cross sections, the Breit-Wigner formula, neutron diffraction, nuclear fission, transuranic elements, the deuteron problem, masers and lasers.

**NERS 512. Interaction of Radiation and Matter**

*Prerequisite: NERS 511. (3 credits)*

Classical and quantum-mechanical analysis of the processes by which radiation interacts with matter. Review of nuclear structure and properties. Nuclear models. Nuclei as sources of radiation. Interaction of electromagnetic radiation with matter. Interaction of charged particles with matter. Radiative collisions and theory of Bremsstrahlung. Interaction of neutrons with matter. Interaction mechanisms and cross sections are developed.

**NERS 515. Nuclear Measurements Laboratory**

*Prerequisite: Permission of instructor. (4 credits)*

Principles of nuclear radiation detectors and their use in radiation instrumentation systems. Characteristics of important devices with applications in nuclear science. Gamma ray spectroscopy, fast and thermal neutron detection, charged particle measurements, pulse analysis, nuclear event timing and recent development in nuclear instrumentation.

**NERS 518. Advanced Radiation Measurements and Imaging**

*Prerequisite: NERS 315 or NERS 515. (2 credits)*

Detection and imaging of ionizing radiation that builds on a basic course in radiation measurements. Topics include statistical limits on energy and spatial resolution, analog and digital pulse processing, pulse shape analysis and discrimination, position sensing techniques, application of Ramo theorem for calculating induced charge and the use of statistical methods in data analysis. Specific devices used as examples of evolving technology include newly-developed scintillators and wave-shifters, optical sensors, gas-filled imag-

ing and spectroscopic detectors, semiconductor spectrometers from wide bandgap materials, gamma ray/neutron imaging systems and cryogenic spectrometers.

### **NERS 521. Radiation Materials Science I**

*Prerequisite: NERS 421 permission of instructor. (3 credits)*

Radiation damage processes; defect production, spike phenomena, displacement cascades, interatomic potential, channeling, focusing, slowing down. Physical effects of radiation damage, radiation induced segregation, dislocations, dislocation loop and void formation, phase stability, unique effects of ion irradiation, comparison between ion and neutron irradiation.

### **NERS 522. Radiation Materials Science II**

*Prerequisite: NERS 421, NERS 521 or permission of instructor. (3 credits)*

Mechanical and environmental effects of irradiation. Mechanical effects include hardening, embrittlement, fracture and creep. Thermodynamics and kinetics of corrosion, corrosion in high temperature aqueous environments, stress corrosion cracking and effects of irradiation on corrosion and stress corrosion cracking.

### **NERS 524. Nuclear Fuels**

*Prerequisite: Permission of instructor. (3 credits)*

Nuclear reactor fuels and the fuel cycle; mining, processing, isotope separation and fabrication. Fuel/clad behavior; radiation damage, thermal response, densification, swelling, fission gas release, burn-up, clad corrosion, design and modeling. Spent fuel; characterization, performance, reprocessing, disposal.

### **NERS 531 (EECS 529) (ENSCEN 529). Nuclear Waste Management**

*Prerequisite: Senior standing. (3 credits)*

Based on the nuclear fuel cycle, this course will review the origin, composition, form and volumes of waste generated by commercial reactors and defense programs. The scientific and engineering basis for near-field and far-field containment in a geologic repository will be reviewed in the context of performance assessment methodologies.

### **NERS 535. Detection Techniques of Nuclear Non-proliferation**

*Prerequisite: NERS 315 or equivalent. (4 credits)*

Laboratory course covering recent techniques for the detection, identification, and characterization of nuclear materials. It includes the study of Monte Carlo simulation and measurement techniques through hands-on experiments with isotopic gamma ray and neutron sources.

### **NERS 543. Nuclear Reactor Theory II**

*Prerequisite: NERS 441 or equivalent. (3 credits)*

A continuation of NERS 441 including neutron resonance absorption and thermalization, perturbation and variational methods, flux synthesis. Analytic and numerical solutions of the neutron transport equation including the  $S_n$  and B methods, collision probabilities and Monte Carlo methods.

### **NERS 544. Monte Carlo Methods**

*Prerequisite: Graduate standing in Engineering, Mathematics or Sciences. (2 credits)*

This course is an introduction to Monte Carlo methods, including basic probability and statistics, random number generation, sampling, scoring and tallies, error estimation, variance reduction and importance sampling. Examples are drawn from Monte Carlo particle transport.

### **NERS 546. Thermal Fluids for Nuclear Reactor Safety Analysis**

*Prerequisite: Concurrently with or prior to NERS 441, ME 320, or CEE 325 or equivalent, or graduate standing. (3 credits)*

This course gives a broad overview of thermal-hydraulics/fluids for nuclear reactor safety. First, the basic principles of mass energy and momentum are discussed for nuclear applications. Then group projects are performed using NRC computer codes for simulating light water and gas cooled reactors.

### **NERS 547. Computational Fluid Dynamics for Nuclear Applications**

*Prerequisite: NERS 344, MECHENG 320, CEE 325 or equivalent advanced math (Partial Differential Equations) (3 credits)*

Theoretical background on turbulence and modeling for single-phase and two-phase flow, and practical experience on using CFD codes. Topics includes: evaluate

simulations of 3-D flows, applicability/limitations of turbulence models, mesh generation and mesh convergence, numerical methods for solution of Navier-Stokes equation, theoretical exercises, computational project and presentation.

### **NERS 551. Nuclear Reactor Kinetics**

*Prerequisite: Preceded or accompanied by NERS 441. (3 credits)*

Derivation and solution of point reactor kinetic equations. Concept of reactivity, inhour equations and reactor transfer function. Linear stability analysis of reactors. Reactivity feedback and nonlinear kinetics. Space-dependent reactor kinetics and xenon oscillations. Introduction to reactor noise analysis.

### **NERS 554. Radiation Shielding Design**

*Prerequisite: NERS 441 or NERS 484. (4 credits)*

Neutron and photon transport using Monte Carlo and analytical methods. Student groups participate in a semester-long project to design radiation shields, collimators, sources and detectors for a variety of applications, including space, medical and security. Project results include a feasibility study, dosimetric assessments, detector response functions and materials selection.

### **NERS 555. Radiological Physics and Dosimetry**

*Prerequisite: NERS 311 and 312 and senior or graduate standing. (2 credits)*

Radiation physics, theoretical radiation dosimetry, fundamental radiometric quantities, fluence, exposure, kerma, collision kerma and dose for photons and electrons, equilibrium, Fano's theorem, Monte Carlo methods, convolution method, cavity theory, saturation theory, and other analytic methods in the discipline, the dosimetry chain. Lectures and examples.

### **NERS 561. Nuclear Core Design and Analysis I**

*Prerequisite: NERS 441. (3 credits)*

Analytical investigation of areas of special importance to the design of nuclear reactors. Includes development, evaluation and application of models for the neutronic, thermal-hydraulic and economic behavior of both thermal and fast reactors. Typical problems arising in both design and operation of nuclear reactors are considered. This course includes extensive use of digital computers.

### **NERS 562. Nuclear Core Design and Analysis II**

*Prerequisite: NERS 561. (3 credits)*

Continuation of subject matter covered under NERS 561 with emphasis on applications of analytical models to the solution of current problems in reactor technology.

### **NERS 571. Intermediate Plasma Physics I**

*Prerequisite: NERS 471 or Physics 405. (3 credits)*

Single particle motion, collision and transport; plasma stability from orbital considerations; Vlasov and Liouville equations; Landau damping; kinetic modes and their reconstruction from fluid description; electrostatic and electromagnetic waves, cutoff and resonance.

### **NERS 572 (APPPHYS 672). Intermediate Plasma Physics II**

*Prerequisite: NERS 571. (3 credits)*

Waves in non-uniform plasmas, magnetic shear; absorption, reflection and tunneling gradient-driven micro-instabilities; BGK mode and nonlinear Landau damping; macroscopic instabilities and their stabilization; non-ideal MHD effects.

### **NERS 573. Plasma Engineering**

*Prerequisite: NERS 471 or graduate standing. (3 credits)*

This course covers the theory and application of plasma concepts relevant to plasma engineering problems encountered in the workplace. Focus areas addressed include plasma propulsion, semiconductor processing, lighting, and environmental mitigation. Students will accumulate over the term a toolbox of concepts and techniques directly applicable to real world situations.

### **NERS 574. Introduction to Computational Plasma Physics**

*Prerequisite: NERS 320 or MATH 454, NERS 471, NERS 571 or an electricity and magnetism course. (3 credits)*

Develop understanding in the relationship between the hierarchy of kinetic models describing plasmas and numerical equivalents. Short projects will develop simple codes and demonstrate numerical modeling of plasma phenomena. Students will develop their own projects involving original numerical research with a final report in a style appropriate for an academic journal.

### **NERS 575 (EECS 519). Plasma Generation and Diagnostics Laboratory**

*Prerequisite: Preceded or accompanied by a course covering electromagnetism. (4 credits)*

Laboratory techniques for plasma ionization and diagnosis relevant to plasma processing, propulsion, vacuum electronics, and fusion. Plasma generation techniques includes: high voltage-DC, radio frequency, and e-beam discharges. Diagnostics include: Langmuir probes, microwave cavity perturbation, microwave interferometry, laser schlieren and optical emission spectroscopy. Plasma parameters measured are: electron/ion density and electron temperature.

### **NERS 576. Charged Particle Accelerators and Beams**

*Prerequisite: Physics 240 or EECS 331. (3 credits)*

Principles and technology of electrostatic and electrodynamic accelerators, magnetic and electrostatic focusing, transient analysis of pulsed accelerators. Generation of intense electron and ion beams. Dynamics, stability, and beam transport in vacuum, neutral and ionized gases. Intense beams as drivers for inertial confinement and for high power coherent radiation.

### **NERS 577. Plasma Spectroscopy**

*Prerequisite: Introductory courses in plasma and quantum mechanics. (3 credits)*

Basic theory of atomic and molecular spectroscopy and its application to plasma diagnostics. Atomic structure and resulting spectra, electronic (including vibrational and rotational) structure of molecules and the resulting spectra, the absorption and emission of radiation and the shape and width of spectral lines. Use of atomic and molecular spectra as a means of diagnosing temperatures, densities and the chemistry of plasmas.

### **NERS 578 (EECS 517). Physical Processes in Plasmas**

*Prerequisites: EECS 330. (3 credits)*

Plasma physics applied to electrical gas discharges used for material processing. Gas kinetics; atomic collisions; transport coefficients; drift and diffusion; sheaths; Boltzmann distribution function calculation; plasma simulation; plasma diagnostics by particle probes, spectroscopy, and electromagnetic waves; analysis of commonly used plasma tools for materials pro-

cessing.

### **NERS 579 (EHS 692). Physics of Diagnostic Radiology**

*Prerequisite: NERS 484 or graduate status. (3 credits)*

Physics, equipment and techniques basics to producing medical diagnostic images by x-rays, fluoroscopy, computerized tomography of x-ray images, mammography, ultrasound and magnetic resonance imaging systems.

### **NERS 580 (BIOMEDE 580). Computation Projects in Radiation Imaging**

*Prerequisite: Preceded or accompanied by NERS 481. (1 credit)*

Computational projects illustrate principles of radiation imaging from NERS 481 (BiomedE 481). Students will model the performance of radiation systems as a function of design variables. Results will be in the form of computer displayed images. Students will evaluate results using observer experiments. Series of weekly projects are integrated to describe the performance of imaging systems.

### **NERS 581. Radiation Therapy Physics**

*Prerequisite: NERS 555 or equivalent with minimum grade of C for enforced prerequisite and senior or graduate standing. (3 credits)*

Covers the physics concepts necessary for the understanding of modern radiation therapy techniques. External beam radiation therapy and brachytherapy fundamentals are covered, including treatment planning, evaluation, and delivery with an emphasis on current developments in the field.

### **NERS 582 (BIOMEDE 582). Medical Radiological Health Engineering**

*Prerequisite: NERS 484 (BIOMEDE 484) with minimum grade of C for enforced prerequisite and senior or graduate standing. (3 credits)*

This course covers the fundamental approaches to radiation protection in radiology nuclear medicine, radiotherapy, and research environments at medical facilities. Topics presented include health effects, radiation dosimetry and dose estimation, quality control of imaging equipment, regulations, licensing and health physics program.

**NERS 583. Radiological Dose Assessment and Response**

*Prerequisite: NERS 484 or graduate status. (3 credits)*

This course is structured around an event, such as a medical incident or nuclear accident, which encompasses open-ended problems common in radiological engineering practice. Student teams engage in standardized radiological dose assessment and apply radiation protection approaches culminating in comprehensive oral presentations and written reports.

**NERS 584. Radiation Biology**

*Prerequisite: Senior or graduate standing. (3 credits)*

Lecture course covering three main areas of radiation biology: molecular and cellular radiation biology, radiation and human health, principles of radiation therapy.

**NERS 585. Transportation of Radioactive Materials**

*Prerequisite: Junior status in engineering. Senior or graduate status in any field. (2 credits)*

Analysis of risks and consequences of routine transportation of radioactive materials and of transportation accidents involving these materials; history and review of regulations governing radioactive materials, overview of packaging design and vulnerabilities and current issues and concerns involving radioactive materials transportations. Essays and quantitative analysis both included.

**NERS 586. Applied Radiological Measurements**

*Prerequisite: NERS 484, NERS 515 or equivalent. (4 credits)*

Instrumentation and applied measurements of interest for radiation safety, environmental sciences, and medical physics. Dosimeters, radon gas, *in situ* gamma ray spectroscopy, skin dose, bioassay, internal dose evaluation, alpha detection, applied instrumentation and other selected medical physics and health measurements. Includes analytical modeling and computer simulation for comparison with several physical experiments.

**NERS 587. Internal Radiation Dose Assessment**

*Prerequisite: NERS 484 or graduate status. (3 credits)*

Determination of radiation doses due to internal deposition of radioactive materials in the human body. Intake and deposition models of radioactive materials via inhalation or oral ingestion with particular emphasis on

internationally accepted models for lungs, GI tract and bone. Concepts of Annual Limit of Intake to meet risk based standards. Derive Air Concentrations, submersion exposure, retention models and bioassay principles for determining intake and retention of radionuclides.

**NERS 588. Radiation Safety and Medical Physics Practicum**

*Prerequisite: Permission of instructor; mandatory satisfactory/unsatisfactory. (1-12 credits)*

Individuals intern at a medical or industrial facility. Students concentrate on a specific radiological health engineering problem and participate in broader facility activities. Assignments are arranged by agreement among the student, faculty member and facility personnel.

**NERS 590. Special Topics in Nuclear Engineering and Radiological Sciences II**

*Prerequisite: Permission of instructor. (1-4 credits)*

Selected advanced topics such as neutron and reactor physics, reactor core design and reactor engineering. The subject matter will change from term to term.

**NERS 599. Master's Project**

*Prerequisite: Permission of instructor. (1-3 credits)*

Individual or group investigations in a particular field or on a problem of special interest to the student. The course content will be arranged at the beginning of each term by mutual agreement between the student and a staff member. This course may be repeated for up to 6 credit hours.

**NERS 621 (EES 629) (MATSCIE 621) (ENSCEN 620). Nuclear Waste Forms**

*Prerequisites: NERS 531 (recommended). (3 credits)*

This interdisciplinary course will review the materials science of radioactive waste remediation and disposal strategies. The main focus will be on corrosion mechanisms, radiation effects and the long-term durability of glasses and crystalline ceramics proposed for the immobilization and disposal of nuclear waste.

**NERS 622 (MFG 622) (MATSCIE 622). Ion Beam Modification and Analysis of Materials**

*Prerequisite: NERS 421, NERS 521 or MATSCIE 351 or permission of instructor. (3 credits)*

Ion-solid interactions, ion beam mixing, compositional changes, phase changes, micro-structural changes; alteration of physical and mechanical properties such as corrosion, wear, fatigue, hardness; ion beam analysis techniques such as RBS, NRA, PIXE, ion channeling, ion microprobe; accelerator system design and operation as it relates to implantation and analysis.

#### **NERS 644. Transport Theory**

*Prerequisite: Math 555. (3 credits)*

Mathematical study of linear transport equations with particular application to neutron transport, plasma physics, photon transport, electron conduction in solids, and rarefied gas dynamics; one-speed transport theory; Wiener-Hopf and singular eigen function methods; time-dependent transport processes; numerical methods including spherical harmonics, discrete ordinates and Monte Carlo techniques; non-linear transport phenomena.

#### **NERS 671. Theory of Plasma Confinement in Fusion Systems**

*Prerequisite: NERS 572 advised. (3 credits)*

Study of the equilibrium, stability and transport of plasma in controlled fusion devices. Topics include MHD equilibrium for circular and non-circular cross section plasmas; magneto-hydrodynamic and micro-instabilities; classical and anomalous diffusion of particles and energy and scaling laws.

#### **NERS 673. Electrons and Coherent Radiation**

*Prerequisite: NERS 471 or Physics 405. (3 credits)*

Collective interactions between electrons and surrounding structure studied. Emphasis given to generation of high power coherent microwave and millimeter waves. Devices include: cyclotron resonance maser, free electron laser, peniotron, orbitron, relativistic klystron and crossed-field geometry. Interactions between electron beam and wakefields analyzed.

#### **NERS 674 (APPPHYS 674). High Intensity Laser-Plasma Interactions**

*Prerequisite: NERS 471, NERS 571 or permission of instructor. (3 credits)*

Coupling of intense electromagnetic radiation to electrons and collective modes in time-dependent and equilibrium plasmas, ranging from underdense to solid-

density. Theory, numerical models and experiments in laser fusion, x-ray lasers, novel electron accelerators and nonlinear optics.

#### **NERS 799. Special Projects**

*(1-6 credits)*

Individual or group investigations in a particular field or on a problem of special interest to the student. The project will be arranged at the beginning of the term by mutual agreement between the student and a staff member.

#### **NERS 990. Dissertation/Pre-Candidate**

*Prerequisite: (2-8 credits); (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

#### **NERS 995. Dissertation/Candidate**

*Prerequisite: Graduate School authorization for admission as a doctoral candidate. (8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Engineering Division

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### ENGR 100. Introduction to Engineering

*(4 credits)*

Focused team projects dealing with technical, economic, safety, environmental and social aspects of a real-world engineering problem. Written, oral and visual communication required within the engineering profession; reporting on the team engineering projects. The role of the engineer in society; engineering ethics. Organization and skills for effective teams.

### ENGR 101. Introduction to Computers and Programming

*Prerequisite: Prior or concurrent enrollment in MATH 115 or equivalent. (4 credits)*

Algorithms and programming in C++ and MATLAB, computing as a tool in engineering, introduction to the organization of digital computers.

### ENGR 110. Design Your Engineering Experience

*Prerequisite: None. (2 credits)*

This course provides first year engineering students with a broad overview of the engineering profession and of each of the academic units within the College of Engineering. The course covers topics of teamwork and innovation, design and creativity, multidisciplinary, cultural maturity and professional responsibility, as well as career paths including industry entrepreneurship/small business, research and the public sector.

### ENGR 151. Accelerated Introduction to Computers and Programming

*Prerequisite: Permission of instructor. (4 credits)*

Algorithms and programming in C++ and MATLAB. Procedural and object-oriented algorithm design, implementation and testing. Emphasis on engineering analysis and embedded computing application. This course is an advanced alternative to ENGR 101. Cannot take both ENGR 101 and 151.

### ENGR 190. Special Topics in Engineering

*Prerequisite: None. (1-6 credits)*

Special topics of current interest selected by faculty.

### ENGR 196. Outreach Internship

*Prerequisite: None. (1 credit)*

Practical work experience related to the student's field of study in consultation with an academic advisor.

### ENGR 255. Introductory Multidisciplinary Engineering Project

*Prerequisite: Permission of instructor. (1-3 credits)*

Intro course in which students acquire, develop, and refine skills for success in the modern engineering design process using mentored, multidisciplinary, team-based, project work. Students will integrate: (1) knowledge from previous courses; (2) knowledge of engineering design process; and (3) professional skills (e.g., teamwork, project planning, communications, etc.).

### ENGR 256. Peer Mentorship in Engineering Design

*Prerequisite: Permission of instructor. (1-2 credits)*

Peer mentorship of design-build-test engineering team projects at the first year level. Mentors assist teams on technology issues associated with design or production phases of the projects. Faculty oversight guides mentors in the development of leadership skills associated with design team project management.

### ENGR 260. Engineering Across Cultures

*Prerequisite: None. (1 credit)*

This course explores the role of local culture in identifying and solving engineering problems. Lectures, guest speakers and group discussions focus on intercultural knowledge and case studies of engineering projects in a global context. The final project is a culture-specific needs assessment of a technical project outside the United States.

### ENGR 280. Undergraduate Research

*Prerequisite: Permission of instructor. (1-4 credits)*

This course offers research experience to first- and second-year Engineering students in an area of mutual interest to the student and to a faculty member within the College of Engineering. For each hour of credit, it is expected that the student will work three hours per

week. The grade for the course will be based on a final project/report evaluated by the faculty sponsor and participation in other required UROP activities, including bimonthly research group meetings and submission of a journal chronicling the research experience.

### **ENGR 290. Special Topics in Engineering**

*Prerequisite: None. (1-6 credits)*

Special topics of current interest selected by faculty.

### **ENGR 301. Engineering Undergraduate Study Abroad**

*Prerequisite: Student must meet any other prerequisites designated by the host university. (1-16 credits)*

Students planning to study abroad for fall, winter, spring, summer or spring/summer on College of Engineering Study Abroad programs should register under Engineering Division (course #301). Separate course sections will be listed for each different study abroad destination.

### **ENGR 345. Introduction to Design Processes**

*Prerequisite: Permission of instructor. (2 credits)*

Processes of design, focusing on front-end strategies, including opportunity discovery, problem definition, developing robust mechanisms to gather information from users and other stakeholders, data synthesis methods for translating user data into design requirements, creating innovative solutions during concept generation, and decision-making systems for evaluating possible solutions.

### **ENGR 350. International Laboratory Experience for Engineers**

*Prerequisite: ENGR 100, permission of instructor (3 credits)*

This course provides practical laboratory experience at a partner institute abroad. Students work on small project teams with local students to design and conduct experiments, analyze results and present reports to faculty and industry representatives. Students gain international perspectives on the engineering field and develop intercultural communication and problem-solving skills.

### **ENGR 354. Engineering Design Practice**

*Prerequisite: Permission of instructor (1 credit)*

Lectures are structured around the modern design process common to all engineering disciplines. The importance of the development of clear and traceable requirements, analysis ranging from scaling and order-of-magnitude calculations to sophisticated simulations and tests. Project scoping exercise. Synthesis of solutions and trades are studied in detail. Students are encouraged to take ENGR 354 and 355 simultaneously.

### **ENGR 355. Intermediate Multidisciplinary Engineering Project**

*Prerequisite: Permission of instructor (1 to 4 credits)*

Intermediate course in which students acquire, develop, and refine skills for success in the modern engineering design process using mentored, multidisciplinary, team-based, project work. Students will integrate: (1) knowledge from previous courses; (2) knowledge of engineering design process; and (3) professional skills (e.g., teamwork, project planning, communications, etc.).

### **ENGR 371 (MATH 371). Numerical Methods for Engineers and Scientists**

*Prerequisite: ENGR 101 and MATH 216, 256, 286 or 316. (3 credits)*

This is a survey course of the basic numerical methods which are used to solve scientific problems. In addition, concepts such as accuracy, stability and efficiency are discussed. The course provides an introduction to MATLAB, an interactive program for numerical linear algebra as well as practice in computer programming.

### **ENGR 390. Special Topics in Engineering**

*Prerequisite: None. (1-6 credits)*

Special topics of current interest selected by faculty.

### **ENGR 391. Directed Overseas Study**

*Prerequisites: Foreign language skills as necessary; sophomore standing. (1-3 credits)*

Directed overseas study in an industrial placement that is overseen by a faculty member at host institution in conjunction with academic courses taken as part of a study abroad program.

### **ENGR 400. Engineering Cooperative Education**

*Prerequisite: Permission of program director. (no credit)*

Off-campus work under the auspice of the cooperative education program. Engineering work experience in government or industry.

### **ENGR 403. Scientific Visualization**

*Prerequisite: Upper division or graduate standing. (3 credits)*

Introduces engineering and science students to scientific visualization principles of data display. Use of color to encode quantitative information. Display of 2- and 3-D scalar and vector data. Interactive computer techniques emphasized. Extensive hands-on practice. Project or research paper required.

### **ENGR 405 (CHE 405). Problem Solving and Troubleshooting in the Workplace**

*Prerequisite: Senior standing. (3 credits)*

The course goals are to help students enhance their problem solving, critical thinking, creative thinking and troubleshooting skills and to ease the transition from college to the workplace. The course includes a few speakers from the industry. Students work in teams to complete the home problems and the term project.

### **ENGR 406 (EECS 406). High-Tech Entrepreneurship**

*Prerequisite: None. (4 credits)*

Four aspects of starting high-tech companies are discussed: opportunity and strategy, creating new ventures, functional development and growth and financing. Also, student groups work on reviewing business books, case studies, elevator and investor pitches. Different funding models are covered, including angel or VC funding and small business (SBIR) funding.

### **ENGR 410 (EECS 410). Patent Fundamentals for Engineers**

*Prerequisite: Junior or senior standing or graduate standing. (4 credits)*

This course covers the fundamentals of patents for engineers. The first part of the course focuses on the rules and codes that govern patent prosecution, and the second part focuses on claim drafting and amendment writing. Other topics include litigation, ethics and licensing.

### **ENGR 450. Multidisciplinary Design**

*Prerequisite: Must meet individual engineering departmental requirements for senior design. (4 credits)*

A senior capstone interdisciplinary engineering design experience. The student is exposed to the design process from concept through analysis to system integration, prototyping, testing and report. Interdisciplinary projects are proposed from the different areas within engineering. Two hours of lecture and two laboratories.

### **ENGR 455. Advanced Multidisciplinary Engineering Project**

*Prerequisite: Permission of instructor. (2-5 credits)*

Advanced course in which students acquire, develop, and refine skills for success in the modern engineering design process using mentored, multidisciplinary, team-based, project work. Students will integrate: (1) knowledge from previous courses; (2) knowledge of engineering design process; and (3) professional skills (e.g., teamwork, project planning, communications, etc.)

### **ENGR 456. Mentorship-Leadership in Multidisciplinary Design**

*Prerequisite: Permission of instructor. (1-2 credits)*

Students study models of leadership and mentorship while participating in reflective and integrative learning exercises based on previous design team experience. Simultaneously, students take on leadership/mentorship roles within a design team to offer technical, professional, and interpersonal guidance. Students must have significant previous multidisciplinary design project experience to enroll.

### **ENGR 480. Global Synthesis Project**

*Prerequisite: Admitted to Tauber Institute for Global Operations. (4 credits)*

Students will work on global operations or industry-relevant projects. Students will work on multidisciplinary teams with business students, under faculty supervision.

### **ENGR 490. Special Topics in Engineering**

*Prerequisite: None. (1-6 credits)*

Special topics of current interest selected by faculty.

### **ENGR 520. Entrepreneurial Business Fundamentals for Engineers & Scientists**

*Prerequisite: Senior or graduate standing. (3 credits)*

This course provides students with a perspective in looking to form or join startup companies and those that are looking to create corporate value via industrial research. The students are taught the entrepreneurial business development screening tools necessary to translate opportunities into businesses with focus on: strategy, finance and market positioning.

### **ENGR 521. Clean Tech Entrepreneurship**

*Prerequisite: Senior and graduate standing (3 credits)*

This course teaches the students how to screen venture opportunities in various cleantech domains. Venture assessments are approached through strategic, financial and market screens, and consider the impact of policy and regulatory constraints on the business opportunity. A midterm, final project and six homework assignments are required.

### **ENGR 523 (BA 518). Business of Biology**

Advances in life science research have enhanced our understanding of the human genome, human genetic variation, and the role that genes play in our everyday health, response to treatment and susceptibility to disease. This new frontier in genomic medicine ushers in both opportunity and peril for individuals, companies and societies. The objective in this interdisciplinary graduate course is to explore the intersections between science, technology, commerce and social policy as they come together to advance (and in some cases retard) progress toward more-personalized health care. The course is intended for graduate students in medicine, biomedical and health-related science, public health, law, engineering, and business interested in the future of health care. Due to variation in student backgrounds coming into the course, efforts are made to establish a shared vocabulary and knowledge base across the disciplines. Interdisciplinary student teams are assigned to a group research project which is presented at the end of the course.

### **ENGR 580 (CHE 580). Teaching Engineering**

*Prerequisite: Graduate standing. (3 credits)*

Aimed at doctoral students from all engineering disciplines interested in teaching. Topics include educational philosophies, educational objectives, learning styles, collaborative and active learning, creativity, testing and

grading, ABET requirements, gender and racial issues. Participants prepare materials for a course of their choice, including course objectives, syllabus, homework, exams and a mini-lecture.

### **ENGR 590. International Experience in Engineering**

*Prerequisite: Seniors and grad students of engineering only. (2-8 credits)*

This independent study course covers selected research areas in engineering. The topic and research plan must be approved by the instructor. A student is expected to participate in the planning of the course, visit a foreign research institution, participate in a research project (analytical and/or experimental) and write a report. The course may continue for more than one semester.

### **ENGR 591. Engineering Graduate Study Abroad**

*Prerequisite: Student must have 4-5 semesters of foreign language for immersion programs and fulfill any other prerequisites designated by the host university. (1-16 credits)*

Students planning to study abroad for fall, winter, spring, summer or spring/summer on College of Engineering Study Abroad programs should register under Engineering Division (course #591). Separate course sections will be listed for each different study abroad destination.

### **ENGR 599. Special Topics in Engineering**

*Prerequisite: Graduate standing or permission of instructor. (1-4 credits)*

Special topics in interdisciplinary engineering.

### **ENGR 600. Engineering Practicum Projects**

*Prerequisite: Graduate standing and permission of the department. (8 credits)*

This practice-oriented course is intended to provide students with industrial work experience in their academic discipline. Students may participate in individual or team projects in an industrial setting.

### **ENGR 996. Responsible Research Practices**

*(1-2 credits)*

The Research Responsibility Program introduces concepts and policies relating the responsible practice of research. It does not provide opportunities for students

to put what they are learning into practice in a scholarly context. The course is designed to provide the opportunity to apply what students are learning to the scholarly analysis of an issue that raises questions about responsible research practices. Attendance required.

# Applied Physics

## Program Administration

### Contacts

#### Program Director

Cagliyan Kurdak

Phone: (734) 647-4650

Applied Physics Program

University of Michigan

450 Church ST.

1425 Randall Laboratory

Ann Arbor, MI 48109-1040

Website: <http://www-applied.physics.lsa.umich.edu/>

### Overview

The quickening pace of development at the frontier between physics and engineering creates a need for interdisciplinary training and research which is not readily accommodated by traditional single-focus graduate programs. The University of Michigan Applied Physics Program is designed to fill this gap, providing students with the opportunity to gain a solid base in the fundamentals of modern physics while exploring applications in the context of various branches of engineering.

The program, which spans the Physical Science Division of the College of Literature Science and the Arts and the College of Engineering, as well as several other units of the University of Michigan, offers graduate studies leading to the Doctor of Philosophy (Ph.D.) degree in Applied Physics. Coursework and research are structured to meet individual goals so that the program is appropriate for students intending to pursue careers in industry, academia or government service.

From nonlinear optics to the latest developments in ultramicroscopy, Michigan has a distinguished record of innovation in applied physics. With a broad range of multidisciplinary research and access to the most ad-

vanced facilities, the program offers a dynamic environment for graduate training. Doctoral research may be performed in any appropriate department under the supervision of any of the 120+ faculty participating in the Applied Physics Program. The opportunities and challenges for bridging science and technology have never been more exciting, nor the potential impact on our society's needs greater. The University of Michigan Applied Physics Program is committed to a leading role in this endeavor.

## Graduate

### Admission Criteria for the Applied Physics Ph.D. Degree

The Applied Physics Program is designed for students intending to pursue coursework and research leading to the Ph.D. degree. Our students are usually eligible to receive a Masters degree in Applied Physics or Electrical Engineering at the time they become candidates for the Ph.D. degree.

A completed application and transcripts of all previous academic records must be on file.

The admission committee will take into account the applicant's background in the physical sciences, engineering physics and related disciplines. A good grounding in basic physics is expected with at least 15 hours of introductory and intermediate coursework in classical mechanics, statistical physics, electricity and magnetism and quantum physics. Graduate Record Examination general scores are required. Three letters of recommendation must be submitted. At least two of the letters must be from an academic institution. Students from non-English-speaking countries are required to demonstrate proficiency in English via the T.O.E.F.L. examination.

Applications will be processed for Fall Term admission. The deadline for applications for financial aid consideration is January 15.

## Requirements for the Applied Physics Ph.D. Degree

The curriculum leading to the Ph.D. degree in Applied Physics combines coursework in the fundamentals of physical theory, its applications to modern technology and practical "hands-on" training in the research laboratories.

Applied Physics is administered as an intercollegiate degree program with participating faculty in the College of Literature Science and the Arts and the College of Engineering and several other units of the University. General admission and degree requirements are administered by the Horace Rackham Graduate School.

The program is normally four to five years with an emphasis on coursework during the first two years. Students are encouraged to become involved in research at the earliest opportunity and are required to complete a supervised research project in their first year. When students complete the basic academic core, have satisfied the qualification procedure (see below), have formed a Dissertation Committee and have obtained approval for their Dissertation Prospectus, they are eligible for admission to Candidacy for the Ph.D. Candidacy is normally achieved after two or three semesters of graduate work.

### Candidacy

In order to achieve candidacy and form a dissertation committee, seven (7) prescribed 500-level courses must be passed with a grade "B" or better. In addition, four (4) elective courses (chosen in consultation with the program advisor according to the student's research needs) must be completed satisfactorily. Satisfactory completion of one (1) four-credit hour course on non-thesis research is also required, under the supervision of a faculty member. Prior approval by the program committee must be obtained before beginning this supervised research course. All first-, second- and third-year students are required to enroll in the weekly seminar course (AP 514).

## Qualifying Procedure

The decision to qualify a student for Ph.D. study is based on the student's academic record, performance in a four-credit hour supervised research project and the results of a qualifying examination. The qualifying examination is an oral examination, beginning with a brief presentation of the student's supervised research followed by questions on standard undergraduate-level physics. The student is expected to qualify within two years of entering the graduate program.

### Preliminary Examination

A preliminary examination of the plans for dissertation research will be made by the student's Dissertation Committee. The preliminary examination will take the form of a presentation to the committee of a Dissertation Prospectus stating the objectives and proposed methods of investigation. Over the signatures of the Dissertation Committee, the program committee will authorize the student to proceed with the thesis research.

Students normally will have formed their Dissertation Committee by the end of their fifth term in graduate school. Approval of the Dissertation Prospectus is a program requirement prior to Candidacy.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### APPPHYS 514. Applied Physics Seminar

*Prerequisite: Graduate studies. (1 or 2 credits)*

Graduate seminars are required each term to familiarize students with current research and problems. Given by a mix of faculty, external lecturers and the students themselves to acquaint students with the scope of research activity and opportunities, the goal of the seminar structure is to promote a strong interaction among the interdisciplinary work being done in applied physics.

### APPPHYS 530 (EECS 530). Electromagnetic Theo-

**ry I**

*Prerequisite: EECS 330 or Physics 438. (3 credits)*

Maxwell's equations, constitutive relations and boundary conditions. Potentials and the representation of electromagnetic fields. Uniqueness, duality, equivalence, reciprocity and Babinet's theorems. Plane, cylindrical and spherical waves. Waveguides and elementary antennas. The limiting case of electro- and magneto-statics.

**APPPHYS 537 (EECS 537). Classical Optics**

*Prerequisite: EECS 330 and EECS 334. (3 credits)*

Theory of electromagnetic, physical and geometrical optics. Classical theory of dispersion. Linear response, Kramers-Kronig relations and pulse propagation. Light scattering. Geometrical optics and propagation in inhomogeneous media. Dielectric waveguides. Interferometry and theory of coherence. Diffraction, Fresnel and Fraunhofer. Gaussian beams and ABCD law.

**APPPHYS 540 (EECS 540). Applied Quantum Mechanics I**

*Prerequisite: Permission of instructor. (3 credits)*

Introduction to nonrelativistic quantum mechanics. Summary of classical mechanics, postulates of quantum mechanics and operator formalism, stationary state problems (including quantum wells, harmonic oscillator, angular momentum theory and spin, atoms and molecules, band theory in solids), time evolution, approximation methods for time independent and time dependent interactions including electromagnetic interactions, scattering.

**APPPHYS 541 (EECS 541). Applied Quantum Mechanics II**

*Prerequisite: AP 540 or EECS 540. (3 credits)*

Continuation of nonrelativistic quantum mechanics. Advanced angular momentum theory, second quantization, non-relativistic quantum electrodynamics, advanced scattering theory, density matrix formalism, reservoir theory.

**APPPHYS 546 (EECS 546). Ultrafast Optics**

*Prerequisite: EECS 537. (3 credits)*

Propagation of ultrashort optical pulses in linear and nonlinear media and through dispersive optical elements. Laser mode-locking and ultrashort pulse genera-

tion. Chirped-pulse amplification. Experimental techniques for high time resolution. Ultrafast Optoelectronics. Survey of ultrafast high field interactions.

**APPPHYS 550 (EECS 538) (Physics 650). Optical Waves in Crystals**

*Prerequisite: EECS 434. (3 credits)*

Propagation of laser beam: Gaussian wave optics and the ABCD law. Crystal properties and the dielectric tensor; electro-optic effects and devices; acousto-optic diffraction and devices. Introduction to nonlinear optics: coupled mode theory and second harmonic generation; phase matching.

**APPPHYS 551 (EECS 539) (Physics 651). Lasers**

*Prerequisite: EECS 537 and EECS 538. (3 credits)*

Complete study of laser operation: the atom-field interaction; homogeneous and inhomogeneous broadening mechanisms; atomic rate equations; gain, amplification and saturation; laser oscillation; laser resonators, modes, and cavity equations; cavity modes; laser dynamics, Q-switching and modelocking. Special topics such as femto-second lasers and ultrahigh power lasers.

**APPPHYS 552 (EECS 552). Fiber Optical Communications**

*Prerequisite: EECS 434 or EECS 538 or permission of instructor. (3 credits)*

This course covers the basics of fibers and applications in fields as diverse as high power and broadband lasers, biomedical diagnostics and therapeutics, telecommunications, and internet communications. Propagation, optical amplification, and nonlinearities in fibers are discussed, and examples include transmission systems and lasers. Biomedical applications include dermatology, cardiology, and ophthalmology.

**APPPHYS 601 (Physics 540). Advanced Condensed Matter (3 credits)**

A unified description of equilibrium condensed matter theory (using Green's functions); critical phenomena, Anderson localization and correlated electron theory.

**APPPHYS 609 (EECS 638) (Physics 542). Quantum Theory of Light**

*Prerequisite: Quantum mechanics electrodynamics and atom physics. I even years. (3 credits)*

The atom-field interaction; density matrix; quantum theory of radiation including spontaneous emission; optical Bloch equations and theory of resonance fluorescence; coherent pulse propagation; dressed atoms and squeezed states; special topics in nonlinear optics.

**APPPHYS 611 (EECS 634) (Physics 611). Nonlinear Optics**

*Prerequisite: EECS 537 or EECS 538 or EECS 530. (3 credits)*

Formalism of wave propagation in nonlinear media; susceptibility tensor; second harmonic generation and three-wave mixing; phase matching; third order nonlinearities and four-wave mixing processes; stimulated Raman and Brillouin scattering. Special topics: nonlinear optics in fibers, including solitons and self-phase modulation.

**APPPHYS 619 (Physics 619). Advanced Solid State Physics**

*Prerequisite: Physics 520 (or 463), Physics 511, Physics 510 or permission of instructor. (3 credits)*

Photon, neutron and electron scattering in condensed matter: elastic and inelastic scattering in condensed matter. The theory of neutron, electron and photon (Rayleigh, Brillouin, Raman, and x-ray) scattering will be presented with an overview of the corresponding experimental techniques; linear response theory, fluctuation-dissipation theorem, elementary excitations in condensed matter, hydrodynamics and symmetry analysis using group theory. AP 633 (Physics 633). Fluid Dynamics

**APPPHYS 633 (Physics 633). Fluid Dynamics**

*(3 credits)*

The course begins with a derivation of the hydrodynamical equations as prototypical phenomenological equations, based on general conservation laws and the second law of thermodynamics; two dimensional ideal fluid flow, the Joukowski theory of the airfoil, gravity waves and the theory of tides, solitary waves, incompressible viscous flow and the Stokes formula, Sommerfeld's theory of lubrication, the turbulent wake, Prandtl's theory of the boundary layer, shock waves, relativistic hydrodynamics, fluctuations in hydrodynamics, etc.

**APPPHYS 644 (Physics 644). Advanced Atomic Physics**

*(3 credits)*

Laser atom interactions: Absorption, emission, and saturation, theory of line width, multiphoton absorption, stimulated and spontaneous Raman scattering; single photon, multiphoton and above-threshold ionization; Rydberg physics; AC stark shifts and ponderomotive effects; multichannel quantum defect theory; Floquet theory; Mechanical effects of light on atoms (atom traps, molasses), atom interferometry.

**APPPHYS 669 (Chem 669). Physics of Extended Surfaces**

*Prerequisite: Quantum mechanics or solid state physics, or permission of instructor. (3 credits)*

Chemical physics of extended surfaces: basic surface phenomena which control the physical and chemical properties of extended surfaces. A wide range of surface methods and issues regarding metal, semiconductor and insulator surfaces will be discussed. Fundamental principles regarding the geometric and electronic structure of surfaces, adsorption-desorption processes, surface reactions, and ion-surface interactions will be discussed.

**APPPHYS 672 (NERS 572). Intermediate Plasma Physics II**

*Prerequisite: NERS 571. (3 credits)*

Waves in non-uniform plasmas, magnetic shear; absorption, reflection and tunneling gradient-driven microinstabilities; BGK mode and nonlinear Landau damping; macroscopic instabilities and their stabilization; non-ideal MHD effects.

**APPPHYS 674 (NERS 674). High-Intensity Laser Plasma Interactions**

*Prerequisite: NERS 471, NERS 571 or permission of instructor. (3 credits)*

Coupling of intense electromagnetic radiation to electrons and collective modes in time-dependent and equilibrium plasmas, ranging from underdense to solid-density. Theory, numerical modes and experiments in laser fusion, x-ray lasers, novel electron accelerators and nonlinear optics.

# Environmental Sustainability

## Overview

### Concentrations in Environmental Sustainability (ConsEnSus)

Implementation of sustainable engineering practices in industry has created a demand for engineers skilled in both rigorous disciplinary background (i.e. Civil, Chemical, Electrical, Mechanical, etc. engineering) and working knowledge of environmental regulations, policies and practices. The Concentrations in Environmental Sustainability (ConsEnSus) Program is designed to prepare students to meet this demand by providing the opportunity to pursue an MSE degree in a traditional engineering discipline coupled with advanced study in issues relating to engineering practices that will ensure environmental sustainability. The concentration comprises a coherent sequence of courses designed to enhance general environmental literacy and prepare students to integrate environmental principles into professional practice.

### Who is eligible?

Students must be enrolled in one of the participating five (5)\* College of Engineering departments to receive credit for the ConsEnSus Program. Participating departments include:

- Climate and Space Sciences and Engineering (A.O.S.S. department name change effective 9/1/15)
- Civil and Environmental Engineering
- Chemical Engineering
- Mechanical Engineering
- Naval Architecture and Marine Engineering

\*Additional departments may offer ConsEnSus at a later date.

## Program Requirements

Successful completion of the ConsEnSus Program requires twelve credits of coursework in environmental sustainability. Two (2) specific courses comprising six (6) credit hours are required of all ConsEnSus participants: CEE 586/NRE 557 Industrial Ecology or ME 599 Eco-Design and Manufacturing and CEE 686/ChE 686 Case Studies in Environmental Sustainability (or equivalent). The remaining six (6) of the credit hours may be selected from a list of approved courses. Courses are divided into three categories:

- Environmental Law and Regulations
- Environmental Assessment and Policy
- Environmental Science and Technology

The six (6) elective credit hours required for completion of the ConsEnSus concentration must be selected from at least two of the three (3) course categories, with a maximum of three credits from Environmental Law and Regulations and up to six (6) from Environmental Assessment and Policy.

## Interim Contact

Susan Hamlin  
hamlins@umich.edu

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### Environmental Science and Technology

#### ENSCEN 211 (NERS 211). Introduction to Nuclear Engineering and Radiological Sciences

*Prerequisite: Preceded or accompanied by Math 216. (4 credits)*

This course will discuss different forms of energy, the history of nuclear energy, the fundamentals of fission and fusion nuclear power, radiological health applications, and electromagnetic radiation in the environment,

current topics in the media such as radon, radioactive waste, and nuclear proliferation will also be covered.

**ENSCEN 420 (NAVARCH 420) (AOSS 420). Environmental Ocean Dynamics\***

*Prerequisites: NAVARCH 320 or AOSS 305 or CEE 325. (4 credits)*

Physical conditions and physical processes of the oceans; integration of observations into comprehensive descriptions and explanations of oceanic phenomena. Emphasis on wave and current prediction, optical and acoustical properties of seawater, currents, tides, waves and pollutant transport.

**ENSCEN 451 (AOSS 451). Atmospheric Dynamics I**

*Prerequisite: AOSS 401 or Math 450. (4 credits)*

Quasi-geotropic energetics; fronts; the mean circulation; planetary and equatorial waves; overview of the dynamics of the middle atmosphere; wave-mean flow interaction; spectral methods; and tropical meteorology.

**ENSCEN 463 (AOSS 463). Air Pollution Meteorology\***

*Prerequisite: Math 215. (3 credits)*

Weather and motion systems of the atmosphere; topographic influences in winds; atmospheric stability and inversions; atmospheric diffusion; natural cleansing processes; meteorological factors in plant location, design and operation.

**ENSCEN 467 (AOSS 467) (Chem 467) (Geol Sci 465). Biogeochemical Cycles \***

*Prerequisite: Math 116, Chem 210, Physics 240. (3 credits)*

**ENSCEN 475 (AOSS 475). Earth System Interactions\***

*Prerequisite: Senior standing in science or engineering. (4 credits)*

Students will work on open-ended research problems with mathematical models from Earth System Science. The models may include, for example, surface characteristics, hydrology, solar-land-ocean-atmosphere exchanges, and space-based observations. Numerical experiments will promote further understanding and interpretation of earth system interactions, team building,

and scientific communication.

**ENSCEN 479 (AOSS 479). Atmospheric Chemistry\***

*Prerequisite: Chem 130, Math 216. (4 credits)*

Thermo-chemistry, photochemistry and chemical kinetics of the atmosphere; geo-chemical cycles, generation of atmospheric layers and the effects of pollutant are discussed.

**ENSCEN 484 (NERS 484) (BIOMEDE 484). Radiological Health Engineering Fundamentals\***

*Prerequisite: NERS 312 or equivalent or permission of instructor. (4 credits)*

Fundamental physics behind radiological health engineering and topics in quantitative radiation protection. Radiation quantities and measurement, regulations and enforcement, external and internal dose estimation, radiation biology radioactive waste issues, radon gas, emergencies, and wide variety of radiation sources from health physics perspective.

**ENSCEN 495 (AOSS 495). Upper Atmosphere and Ionosphere**

*Prerequisite: AOSS 464. (4 credits)*

Basic physical and chemical processes important in controlling the upper/middle atmosphere and ionosphere: photochemistry, convection, diffusion, wave activity, ionization, heating and cooling. The terrestrial, as well as planetary atmospheres and ionospheres are to be considered.

**ENSCEN 500 (CEE 500) (CHE 500). Environmental Systems and Processes I**

*Prerequisite: CEE 480 or equivalent. (3 credits)*

Concepts of environmental systems and principles of related transport and transformation phenomena and processes, focusing on aquatic systems; development of fundamental models for articulation of relevant process dynamics; system and process scaling factors and methods; extension of process models to ideal and non-ideal natural and engineered homogeneous environmental systems.

**ENSCEN 528 (CEE 528). Flow and Transport in Porous Media\***

*Prerequisite: CEE 428 or equivalent. (3 credits)*

**ENSCEN 533 (AEROSP 533). Combustion Processes***Prerequisite: AEROSP 225. (3 credits)*

This course covers the fundamentals of combustion systems, and fire and explosion phenomena. Topics covered include thermochemistry, chemical kinetics, laminar flame propagation, detonations and explosions, flammability and ignition, spray combustion, and the use of computer techniques in combustion problems.

**ENSCEN 563 (AOSS 563). Air Pollution Dispersion Modeling***Prerequisite: AOSS 463. (3 credits)*

Principles of modeling air pollution transport and dispersion. Discussion of models for line sources, area sources and point sources. Analysis of individual model data requirements, founding assumptions and inherent limitations. Practical experience using currently operational models.

**ENSCEN 564 (AOSS 564). The Stratosphere and Mesosphere***Prerequisite: AOSS 464. (3 credits)*

Physical, chemical, and dynamical properties of the atmosphere between the tropopause and the turbopause. Among the topics covered are the heat and radiation budgets, atmospheric ozone, stratospheric warming, the biennial stratospheric oscillation, and airglow.

**ENSCEN 575 (AOSS 575). Air Pollution Monitoring\****Prerequisite: AOSS 463, AOSS 578, NRE 538 (previously or concurrently). (3 credits)***ENSCEN 576 (AOSS 576). Air Quality Field Project***Prerequisite: AOSS 578, NRE 538, AOSS 575, or AOSS 563. (4 credits)*

Practical experience in all aspects of air quality field measurements from the design the planning stage through implementation and data analysis and interpretation. Emphasis on research design, sampling, data management systems, sample tracking, computerized data acquisition and processing, error analysis and reporting; team-oriented practicum for modelers and experimentalists.

**ENSCEN 686 (CEE 686) (CHE 686). Case Studies in Environmental Sustainability***Prerequisite: Senior or graduate standing. (2-3 credits)*

Case studies focusing on utilization of principles of environmental sustainability in professional practice. Development of environmental literacy through study of both current and historical environmental issues.

**Environmental Assessment, Management, and Policy****ENSCEN 105 (AOSS 105) (Chem 105). Our Changing Atmosphere***Prerequisite: None. (3 credits)*

The science of the greenhouse effect, stratospheric ozone depletion, polar ozone holes, and urban smog. These phenomena and their possible consequences are discussed, along with the properties and behavior of the atmosphere and its components of the environment.

**ENSCEN 171 (AOSS 171) (Biol 110) (Univ Course 110) (SNRE 110) (Geol Sci 171). Introduction to Global Change-Part I***Prerequisite: None. (4 credits)*

The Science Behind Sustainability --- Students learn about the evolution of the universe, Earth, our changing environment and our planets living organisms. Global Change I, which is part of the GC curriculum, assumes no prior science background. Homework and laboratories use computer-based systems modeling and analysis, and includes a group presentation.

**ENSCEN 531 (NERS 531). Nuclear Waste Management\****Prerequisite: Senior standing. (3 credits)*

Based on the nuclear fuel cycle, this course will review the origin, composition, form and volumes of waste generated by commercial reactors and defense programs. The scientific and engineering basis for near-field and far-field containment in a geologic repository will be reviewed in the context of performance assessment methodologies.

**ENSCEN 534 (CSIB 564). Strategy for Environmental Management***Prerequisite: CSIB 502. (1.5 credits)*

This course builds environmental awareness and literacy for strategic corporate managers. It focuses on how environmental problems and pressures currently impact competitive strategy, technology choices and production and marketing decisions. Environmental challenges, regulations, and values are explored in terms of business risk and opportunity. Companies at the leading edge of environmental management are profiled via cases and visiting speakers.

*\* Denotes courses approved for the **ConsEnSus Program***

**ENSCEN 535 (MBA 565). Strategy for Sustainable Development**

*Prerequisite: CSIB 564. (1.5 credits)*

This course examines the long-term strategic implication of the growing call for sustainable development, i.e., satisfying lives for all within the means of nature. It focuses on the natural and social state of the planet, the ethics and meanings of sustainability, and the business logics bearing upon the transition to sustainable enterprise. Emphasis is placed on transformational leadership in the face of the radical technological, social, economic and institutional changes.

**ENSCEN 585 (CEE 585). Solid Waste Management**  
*(3 credits)*

**ENSCEN 587 (NRE 558) (CEE 587). Water Resource Policy \***

*Prerequisite: Senior or graduate standing. (3 credits)*

**ENSCEN 588 (EHS 672). Life Cycle Assessment: Human Health and Environmental Impacts**  
*(3 credits)*

**ENSCEN 589 (NRE 595) (CEE 589). Risk and Benefit Analysis in Environmental Engineering\***

*Prerequisite: Senior or graduate standing. (3 credits)*

## **Environmental Laws and Regulations**

**ENSCEN 699 (EHS 699). Hazardous Wastes: Law Regulation, Remediation, and Worker Protection\***

*Prerequisite: Graduate standing and EHS 503 or EHS 508 or EHS 541 or EHS 650 or EHS 667 or permission of instructor. (3 credits)*

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# Engineering Sustainable Systems

## Dual Degree: Master of Science in Natural Resources and the Environment and Master of Science in Engineering

This dual-degree program between the College of Engineering and the School of Natural Resources and the Environment is a 54-credit program that provides graduate engineers with a comprehensive understanding of major sustainability challenges facing society in the 21st century including global climate changes, energy scarcity, ecological degradation, environmental threats to human health and resource scarcity. Students will achieve scientific literacy related to air, water and land pollution as well as ecological systems, energy systems and important regional/global cycles (e.g., material, nutrient, carbon, hydrologic). The program educates students in engineering design approaches for products, processes and services that facilitate the sustainable application of technology, and also provides students with the scientific knowledge and methods required to evaluate the sustainability of engineered systems. Currently three tracks exist in the fields of sustainable energy systems (M.E. and Ch.E.), sustainable design and manufacturing (M.E.) and sustainable water resources (C.E.E.).

### Administration Contact

Please go directly to the dual-degree website at S.N.R.E. to find out more about the program: [http://www.snre.umich.edu/degrees/masters/sustainable\\_systems/overview](http://www.snre.umich.edu/degrees/masters/sustainable_systems/overview)

# Entrepreneurship

## Center for Entrepreneurship Academic Programs

### Introduction

The Center for Entrepreneurship's academic and co-curricular programs support students' growth as entrepreneurs and innovative thinkers by offering exciting opportunities to create value, challenge the status quo, and develop new career possibilities. Students from across the University and the College of Engineering engage in our immersive curricular community and work together to turn their ideas into tangible, impactful projects.

The CFE's classes demand active participation in learning multiple skillsets and perspectives. We teach students how to identify challenges and facilitate hands-on practice in developing solutions that are scalable and impactful.

ENTR courses at The CFE cover a wide range of topics, all taught by *real* entrepreneurs who teach from experience.

### Co-Curricular Programs

The CFE offers a variety of opportunities for students to build entrepreneurial skills and experience inside and outside of the classroom. From startup treks to startup competitions, grant funding, advising, study abroad, mentoring, and more, there is something for everyone. Interested in learning more? Email us at [centerforentrepreneurship@umich.edu](mailto:centerforentrepreneurship@umich.edu).

For additional information on the CFE, visit the CFE website: <http://cfe.umich.edu>.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### ENTR 390. Special Topics in Entrepreneurship (1-15 credits)

Special topics of interest selected by entrepreneurial faculty.

### ENTR 407. Entrepreneurship Hour (1 credit)

This weekly seminar series invites disruptive, influential and respected entrepreneurs, venture capitalists and business leaders to speak to students about their personal experiences founding, financing and managing a startup venture. Following the lecture, students will be able to meet the guest speaker and network with members of the entrepreneurial community.

### ENTR 408. Patent Law (1 credit)

Inventors and entrepreneurs have four concerns related to patent law: protecting inventions during product development, determining invention patentability, avoiding infringement and leveraging a patent as a business asset. This course addresses these concerns through the application of case law and business cases to an invention of the student's choice.

### ENTR 409. Venture Business Development (1 credit)

This course prepares students to identify and evaluate commercial opportunities for emerging technologies. Emphasis is on design and evaluation of business models and methods necessary for rapid, rigorous analysis of these models. Students will develop preliminary business models and evaluate possible commercial opportunities.

### ENTR 411. Entrepreneurship Practicum

*Prerequisite: By application and permission of instructor (3 credits)*

The Practicum immerses students in the entrepreneurial process in a supportive classroom environment. Students critically evaluate and then pursue the develop-

ment of their own ideas for new ventures. Throughout the course, students work closely with entrepreneurship faculty and mentors.

**ENTR 417. Entrepreneurship Hour Discussion Session**

*Prerequisite: Concurrent enrollment in ENTR 407 Entrepreneurship Hour. (1 credit)*

In this faculty led discussion section for the Entrepreneurship Hour seminar series, students learn about, discuss and debate the key characteristics of entrepreneurship. Students also form small, multidisciplinary groups where they reflect on entrepreneurship and how it applies to their life goals.

**ENTR 490. Special Topics in Entrepreneurship**  
(1-15 credits)

Special topics of interest selected by entrepreneurial faculty.

**ENTR 500. An Introduction to Innovation: Tools for Career Success**

*Prerequisite: Senior or graduate standing (3 credits)*

Students will learn a wide range of concepts and skills to successfully navigate innovation-focused careers in small, medium, and large businesses and institutions. Students will study intellectual property, market and industry analysis, product-market fit, equity and stock options, program and project management, communication, securing investment and government funding, and more.

**ENTR 510. Compensation, Funding, and Ownership**

*Prerequisite: Senior or graduate standing (3 credits)*

Ownership in any size business is a continuum that ranges from 100% investor owned to 100% employee owned. Students will thoroughly deconstruct this continuum from all perspectives (as employees, founders, and investors) and learn by role playing how the myriad of models affects compensation and a company and society's culture.

**ENTR 520. Technology-Inspired Business Models**

*Prerequisite: Senior or graduate standing (3 credits)*

This course provides the framework that helps innovators understand the difference between innovative Val-

ue Creation and Innovative Value Capture. Built around a series of analytical tools, this course uses lectures, guest speakers, classroom discussions, group activities and personal research to explore the applications and interactions of these tools.

**ENTR 530. Innovation and Intellectual Property Strategy**

*Prerequisite: Senior or graduate standing (3 credits)*

The course examines intellectual property (IP) strategies for new ideas and startups, including barriers to entry for competitors and infringement risk reduction. Topics include IP procurement, technology transfer, due diligence, and preparing for and avoiding litigation. Students should have their own research to apply what's learned in the class.

**ENTR 540. Innovation and Intellectual Property Strategy**

*Prerequisite: Senior or graduate standing (1.5 credits)*

This course introduces non-business students to the essentials of "business math." Students will learn how existing departments or new companies raise funding, develop profit, deal with costs, mitigate risk and more - the basics of business performance and valuation through the numbers.

**ENTR 599. Special Topics for Entrepreneurship**  
(1-4 credits)

Special topics of interest selected by entrepreneurship faculty.

# Integrative Systems + Design Division (ISD)

## Overview

Engineering is critically important in today's technology-driven society. Globalization, changing demographics, and rapidly evolving technologies are dramatically affecting the nature of engineering practice, demanding broader skills than the mastery of scientific and technological disciplines. These complex challenges call for an integrative approach that goes beyond a deep expertise in a single discipline and that blends engineering with the behavioral, business, and social sciences. Integrative Systems + Design (ISD) addresses these challenges by providing versatile, interdisciplinary educational programs for lifelong learning, including graduate degrees, short courses, and certificates, with emphasis on systems and design thinking. ISD's programs horizontally integrate disciplinary knowledge across traditional fields of engineering with business and leadership skills. An important element of all ISD degree programs is a capstone project or practicum experience. Sponsoring organizations offer capstone project topics and work is conducted under faculty supervision and can be completed either on campus or at a sponsor's preferred location. Practicums are typically a 3- to 6-month-long work-study at the sponsor's location guided by a faculty member and a local mentor. ISD programs are offered on campus and several degrees are also available through online learning, creating a diverse learning community of students on campus and at locations around the world. ISD offers four Master's degree programs that can be completed entirely online. They are taught by the same U-M faculty using the same syllabi and offering the same content that is available to students on the Ann Arbor campus. ISD's graduates possess deep strengths in their engineering discipline, greater breadth in relevant engineering and science, and the ability to lead and innovate technical and design solutions for complex systems in a wide range of organizations and industries. Please visit the ISD website at [isd.engin.umich.edu](http://isd.engin.umich.edu).

## Department Administration

### Division Chair, Integrative Systems + Design

Professor Panos Papalambros  
2210 SI-North 1075 Beal Ave  
Ann Arbor, MI 48109-2112

### Director of Academic Programs and Outreach

Diane Landsiedel  
2401 Plymouth Rd, Suite A-B  
Ann Arbor, MI 48109

**Department Website:** <http://isd.engin.umich.edu/>

## Automotive Engineering

### Degree Programs

- Master of Engineering in Automotive Engineering

### Master of Engineering in Automotive Engineering

The Master of Engineering in Automotive Engineering blends engineering fundamentals and practice with an emphasis on systems thinking and the latest advances in technologies. The program provides students with a systems perspective and breadth of knowledge that cuts across departments, drawing upon many different engineering disciplines, such as mechanical engineering, chemical engineering, electrical engineering, computer science engineering, materials science, and industrial engineering. Students will deepen their knowledge of traditional mechanical engineering, but they can also take courses in electric machines, electronics, control systems, software development, and business. An important element of the program is a capstone project which offers students the opportunity to solve a real world problem with their new knowledge. The culminating project can be completed individually or on a team, virtually or locally, and in close interaction with faculty and industry leaders. Graduates of the Automotive Engineering program are prepared to move the automotive industry further into the 21st Century and beyond. The M.Eng. in Automotive Engineering degree is available for on campus or online study.

For more information, please visit the ISD Automotive Engineering website at [isd.engin.umich.edu/AutoEng](http://isd.engin.umich.edu/AutoEng).

## Online/Distance Learning Option

The Master of Engineering in Automotive Engineering can be earned entirely online by qualified students from around the world. ISD has built upon the University of Michigan's experience in offering distance learning courses over several decades. Courses in ISD programs are reengineered as Online-By-Design (OBD) where instructors and support staff deliver learning materials that purposefully take advantage of online tools to enrich the learning experience of students independently of their location on campus or remotely. To learn more about online learning with ISD, please visit the links below:

- Online Learning with ISD:  
[isd.engin.umich.edu/online-grad-programs](http://isd.engin.umich.edu/online-grad-programs)
- Online Learning FAQs:  
[isd.engin.umich.edu/online-faqs](http://isd.engin.umich.edu/online-faqs)

## Design Science

### Degree Programs

- Master of Science in Design Science
- Doctoral Program in Design Science

The new field of Design Science studies the creation of artifacts and their embedding in our physical, psychological, economic and social environment. Traditional science studies the world as we found it; design science studies the world as we make it. In an increasingly designed world, good design is the means to improving this world through innovative, sustainable products and services, creating value and reducing or eliminating the negative unintended consequences of technology deployment. The Design Science program is offered on campus in Ann Arbor.

### Master of Science in Design Science

The Master of Science in Design Science was launched in 2015 to address modern product development that integrates engineering with the behavioral, business

and social sciences. The program provides students flexibility in exploring across multiple disciplines to learn in-depth rigorous design methods and theory that drive the design process. Each student defines a custom program of study tailored to his or her background and design interests in consultation with a program advisor that includes at least two disciplines. This path integrates disciplines from top programs at the University of Michigan to balance rigorous coursework, trend-setting research and practical. In one year, graduates of the design science program are uniquely positioned to build bridges between key stakeholders, and possess the skills needed to meet the challenges of innovation in today's workplace.

### Doctoral Program in Design Science

The Design Science Ph.D. is interdisciplinary in nature. In consultation with faculty advisors and the program committee, the student defines a custom program of study that has the right mix of disciplinary depth and interdisciplinary breadth and is tailored to his or her background and interests. At least two disciplines permeate the program of study. Students are required to take a core set of classes that teaches them integrative design processes and research methods, and then deepen their knowledge in two or more disciplines by leveraging courses available across the university. Advised by two faculty in their respective fields, students integrate their disciplines through cutting-edge research to advance the field of design science in their dissertations. Students are expected to complete a one-semester equivalent of a practicum with an industrial or academic partner to further deepen their learning experience.

For more information about both degree programs, please visit the ISD Design Science website at: [isd.engin.umich.edu/design-science](http://isd.engin.umich.edu/design-science).

## Energy Systems Engineering

### Degree Programs

- Master of Engineering in Energy Systems Engineering
- Sequential Undergraduate/Graduate Study (SUGS)

B.S.E. Chemical Engineering  
Master of Engineering in Energy Systems Engineering

## Master of Engineering in Energy Systems Engineering

The Master of Engineering in Energy Systems Engineering (ESE) degree program is designed for students who are ready to accept the grand challenge of energy in all its diverse forms and applications. It provides critical engineering skills in interlocking energy disciplines. Energy Systems is a multidisciplinary specialization that includes science, engineering, and the development of policies that promote sustainable systems. Students select from a wide array of courses to create an individual plan of study with a concentration in one of three areas: Energy Generation, Distribution and Usage; Transportation Power; or Sustainable Chemical Conversion. The program also covers basic management issues and enables students to develop their ability to lead project teams. There is a significant and industrially relevant capstone project supervised by faculty and with industry or government participation. ESE graduates possess strengths in their engineering discipline, breadth in relevant engineering and science, and understanding of the critical role of the environment in energy systems, including economic factors. The degree is available for on-campus and online study. For more information, please visit the ISD Energy Systems Engineering website at: [isd.engin.umich.edu/ESE](http://isd.engin.umich.edu/ESE).

## Sequential Undergraduate/Graduate Study

*B.S.E. Chemical Engineering*  
*Master of Engineering in Energy Systems Engineering*

This Sequential Undergraduate/Graduate Study (SUGS) program leads to a Master of Engineering in Energy Systems Engineering sequentially with a Bachelor of Science in Engineering (B.S.E.) in Chemical Engineering. University of Michigan students who are pursuing a B.S.E. in Chemical Engineering and who meet all the SUGS requirements may apply to the Energy Systems Engineering program to pursue the five-year SUGS program.

For more information, please visit the ISD website at: [isd.engin.umich.edu/ESE/sugs](http://isd.engin.umich.edu/ESE/sugs).

## Online Learning

The Master of Engineering in Energy Systems Engineering can be earned entirely online by qualified students from around the world. ISD has built upon the University of Michigan's experience in offering distance learning courses over several decades. Courses in ISD programs are reengineered as Online-By-Design (OBD) where instructors and support staff deliver learning materials that purposefully take advantage of online tools to enrich the learning experience of students independently of their location on campus or remotely. To learn more about online learning with ISD, please visit the links below:

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## Global Automotive and Manufacturing Engineering

### Degree Program

- Master of Engineering in Global Automotive and Manufacturing Engineering

### Master of Engineering in Global Automotive and Manufacturing Engineering

The Master of Engineering in Global Automotive and Manufacturing Engineering program (GAME) is a one-of-a-kind engineering master's program that blends product development and manufacturing into a curriculum to address the integration challenges arising from the globalization of the automotive industry. The aim of the program is to develop technical leaders who have a holistic understanding of product creation and manufacturing, breadth across relevant engineering disciplines, depth in a key specialty area, and a global business sense with cross-cultural management and leadership skills. In collaboration with a faculty advisor, stu-

dents will develop a custom plan of study composed of courses in systems integration, engineering, and business. Students select from a wide selection of courses for their specialization in areas such as advanced powertrains, vehicle manufacturing, advanced materials, electrification, intelligent vehicle systems and design, and vehicle performance and controls. Students must successfully satisfy a global component requirement through a capstone project that is either completed through a virtual, global collaboration or, in an industry setting in a location outside the student's native country. Sponsoring companies offer project topics and work is conducted under faculty supervision. GAME graduates possess a comprehensive knowledge in the product development and manufacturing of vehicles; a technical proficiency in automotive systems, systems integration, or manufacturing; an ability to apply sound global business concepts to engineering applications; and competence in building and leading diverse teams in terms of culture, business environment, and disciplinary perspective. The GAME degree is available for on-campus and online study.

For more information, please visit the ISD GAME website at: [isd.engin.umich.edu/game](http://isd.engin.umich.edu/game)

## Online Learning

The Master of Engineering in Global Automotive and Manufacturing Engineering can be earned entirely online by qualified students from around the world. ISD has built upon the University of Michigan's experience in offering distance learning courses over several decades. Courses in ISD programs are reengineered as Online-By-Design (OBD) where instructors and support staff deliver learning materials that purposefully take advantage of online tools to enrich the learning experience of students independently of their location on campus or remotely. To learn more about online learning with ISD, please visit the links below:

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# Manufacturing

## Degree Programs

- Master of Engineering in Manufacturing
- Dual Degree: Master of Engineering in Manufacturing / MBA
- Doctor of Engineering in Manufacturing
- Sequential Undergraduate/Graduate Study

## Master of Engineering in Manufacturing

The Master of Engineering in Manufacturing is a graduate professional program designed for engineers who have already earned a B.S. in Engineering in any engineering discipline. The objective of the degree is to prepare these engineers for leadership roles in manufacturing. Students can choose from more than 80 courses offered through departments in the College of Engineering and the Ross School of Business. The degree can be earned in one calendar year, including a four-month team project in industry. It is available for on-campus and online study.

For more information, please visit the program website at: [isd.engin.umich.edu/mfgeng](http://isd.engin.umich.edu/mfgeng).

### *Team Project*

Students admitted to the program must conduct an industry-relevant project related to manufacturing. There are several options for part-time and full-time students to complete the project requirement. Project opportunities will be discussed and developed upon admission to the program. One option for applicants planning to pursue the program full-time and on campus is to apply to the Tauber Institute for Global Operations. The Tauber Institute assists students in finding projects in industry. To learn more about the Tauber Team Project option, please visit their website at: [tauber.umich.edu/prospective-students/elements-program/team-project](http://tauber.umich.edu/prospective-students/elements-program/team-project).

## Online Learning

The Master of Engineering in Manufacturing can be earned entirely online by qualified students from around the world. ISD has built upon the University of Michigan's experience in offering distance learning

courses over several decades. Courses in ISD programs are reengineered as Online-By-Design (OBD) where instructors and support staff deliver learning materials that purposefully take advantage of online tools to enrich the learning experience of students independently of their location on campus or remotely. To learn more about online learning with ISD, please visit the links below:

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## Dual Master of Engineering in Manufacturing/M.B.A.

In this dual degree program, qualified students can pursue concurrent work in manufacturing engineering and business administration that leads to both a Master of Engineering in Manufacturing from the College of Engineering and a Master of Business Administration (MBA) from the Ross School of Business. The program is arranged so that all requirements are satisfied simultaneously. The dual degree can be earned in two and one-half years by full-time students. It is also offered part-time through the Ross School of Business Evening Program.

Please visit the ISD website for more information at: [isd.engin.umich.edu/mem-mba](http://isd.engin.umich.edu/mem-mba).

## Doctor of Engineering in Manufacturing

The Doctor of Engineering in Manufacturing (D. Eng. in Mfg.) is a graduate professional degree in engineering for students who already have earned a B.S.E. degree, and either an M.S.E. degree in any field of engineering, or a Master of Business Administration (MBA). Students work with a faculty advisor to develop a custom plan of study that blends engineering disciplines with management and business. An important element of the program is an industrially relevant, engineering practice-oriented dissertation that is supervised by a dissertation committee. Graduates of this doctoral program possess a depth of knowledge in manufacturing systems and the skills to carry out high quality engineering research and development.

To learn more, please visit the ISD Doctoral Program in Manufacturing at: [isd.engin.umich.edu/degree-programs/manufacturing-engineering-doctorate/index.htm](http://isd.engin.umich.edu/degree-programs/manufacturing-engineering-doctorate/index.htm)

## Sequential Undergraduate/Graduate Study (SUGS)

Sequential Undergraduate/Graduate Study programs (SUGS) are offered through the Manufacturing Engineering Program. This program leads to the Master of Engineering in Manufacturing sequentially with a Bachelor of Science in Engineering (B.S.E.) through one of the following departments:

1. Aerospace Engineering (AERO)
2. Chemical Engineering (ChE)
3. Civil and Environmental Engineering (CEE)
4. Electrical Engineering and Computer Science (EECS)
5. Industrial and Operations Engineering (IOE)
6. Materials Science and Engineering (MSE)
7. Mechanical Engineering (ME)
8. Naval Architecture and Marine Engineering (NAME)

The eight engineering departments above participate in this program. Each department is represented on the Manufacturing Program Committee by a faculty member.

For more detailed information about the SUGS program, please visit the ISD website at:

[isd.engin.umich.edu/degree-programs/mfgeng/sugs](http://isd.engin.umich.edu/degree-programs/mfgeng/sugs).

## Systems Engineering + Design

### Master of Engineering in Systems Engineering + Design

Complex systems require specialized knowledge and training on how to design and deploy engineered systems. The Master of Engineering in Systems Engineering + Design degree (SE+D) closes the gap between design and systems engineering in complex product development. The program couples creative synthesis (design domain) and systems analysis (systems engi-

neering domain) in a multidisciplinary approach that prepares students to lead and discover innovative solutions for complex engineered systems. It blends design and engineering with human factors, organizational strategy, and social science thinking. All students in the SE+D program conduct a substantive, interdisciplinary and applied internship at a company location during their final semester. These internships, also called practicums, provide students the opportunity to apply their knowledge of the analysis, design, and operation of complex engineering systems and develop solutions for the integration issues involving cross-functional areas and multiple disciplines. Students will work on projects that are aligned with the company's business-critical needs and specifications involving areas such as products and processes.

University of Michigan faculty advisors guide and oversee the student's practicum and engage with the company project team before and during the internship. Usually, students work on an interdisciplinary project team directly under the supervision of the company sponsor. Taking on a pivotal role as the integrator and magnet for multidisciplinary resources, the student develops practical experience in teamwork, along with a greater understanding of how to deploy discipline-related knowledge in complex systems. The scope and duration of the practicum depends on the company's expectations for deliverables. The internship can range from three to nine months and six to nine semester credit hours and can be paid or unpaid. SE+D students typically do their practicum from May to December at the conclusion of their degree program.

Graduates of the Systems Engineering + Design program leverage and augment their core engineering discipline expertise; possess a broad systems engineering perspective; have knowledge and capabilities in the analysis, design, and operation of complex engineered systems; and are able to answer complex questions, deal with uncertainty, and integrate the social and human aspects in modern engineered systems.

For more information, please visit the ISD SE+D website at: [isd.engin.umich.edu/se+d](http://isd.engin.umich.edu/se+d).

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### Automotive Engineering Courses

#### **AUTO 499. Special Topics in Automotive Engineering**

*Prerequisite: Permission of instructor. (3 credits)*

Selected topics pertinent to Automotive Engineering.

#### **AUTO 501. Integrated Vehicle Systems Design**

*Prerequisite: Graduate student or permission of instructor. (3 credits)*

This course is intended to examine the process by which a first layout is developed for a new vehicle platform. The course will focus on the layout of the major space-defining vehicle subsystems required to arrive at a preliminary vehicle package drawing. The process followed will be based on systems engineering: requirements-to-design concepts-to-performance prediction-to-comparison to requirements-to-iteration.

#### **AUTO 503. Automotive Engineering Project**

*Prerequisite: Permission of the department. (3 credits)*

As an essential component of the Master of Engineering in Automotive Engineering program, students are required to participate in a sponsored project in automotive engineering. The intent of this project course is to provide students with a capstone project experience where they can apply the knowledge and skills acquired to relevant automotive engineering problems. Each project must have a clearly defined problem or need and a solution methodology. The project must provide value-add to the sponsor.

#### **AUTO 512. Lean Program Engineering**

*Prerequisite: Graduate student or permission of the instructor. (3 credits)*

This course provides an opportunity to acquire and demonstrate mastery of critical lean product design engineering disciplines within the context of an automotive vehicle program team. The course identifies and integrates engineering skills, tools, and processes required for successful automotive vehicle project plan-

ning and completion consistent with lean product development principles.

### **AUTO 533 (MECHENG 433). Advanced Energy Solutions**

*Prerequisite: MECHENG 235. (3 credits)*

Introduction to the challenges of power generation for a global society using the thermodynamics to understand basic principles and technology limitations. Covers current and future demands for energy; methods of power generation including fossil fuel, solar, wind and nuclear; associated detrimental by-products; and advanced strategies to improve power densities, efficiencies and emissions.

### **AUTO 563. Dynamics and Controls of Automatic Transmissions**

*Prerequisite: Graduate student or permission of instructor. (3 credits)*

Automatic transmission is a key element of automotive vehicles for improved driving comfort. This course will introduce the mechanisms, design and control of modern transmission systems. The emphasis will be on the dynamic analysis, and the application of modern control theories for the overall control design, analysis and synthesis problems.

### **AUTO 566 (MECHENG 566). Modeling, Analysis, and Control of Hybrid Electric Vehicles**

*Prerequisite: MECHENG 438 and MECHENG 461 or equivalent is recommended. (3 credits)*

Modeling, analysis and control of vehicles with electrified propulsion systems, including electric vehicles, hybrid vehicles, plug-in and fuel cell vehicles. Introduction of the concepts and technology, the state of the art development, energy conversion and storage options, modeling, analysis, system integration and basic principles of vehicle controls.

### **AUTO 590. Study of Research in Selected AUTO topics.**

*Prerequisite: None. (1-3 credits)*

Individualized study of specialized aspects/topics of Automotive Engineering.

### **AUTO 599. Special Topics in Automotive Engineering**

*Prerequisite: Graduate standing or permission of instructor. (3 credits)*

Selected topics pertinent to Automotive Engineering.

## **Energy Systems Engineering Courses**

### **ESENG 501. Seminars on Energy Systems, Technology and Policy**

*Prerequisite: Graduate student or permission by instructor (3 credits)*

This course is intended to provide students with an understanding the critical issues in energy technologies. Researchers, industry leaders, entrepreneurs, and policymakers discuss technology, policy and economic drivers for sustainable global energy systems. Students complete homework assignments and a term paper on an energy-themed subject.

### **ESENG 503. Energy Systems Engineering Project**

*Prerequisite: ESENG 501 (3 credits)*

This required project course is intended to provide students with a relevant experience in energy systems.

### **ESENG 505 (MECHENG 571). Energy Generation and Storage Using Modern Materials**

*Prerequisite: MECHENG 382 and MECHENG 335 or equivalents (3 credits)*

Energy and power densities previously unattainable in environmentally-friendly energy technologies have been achieved through use of novel materials. Insertion of new materials into power supplies has changed the landscape of options. Design strategies for power systems are described, in the context of growing global demand for power and energy.

### **ESENG 590. Study or Research in ESENG Topics**

*Prerequisite: none (1-3 credits)*

Individualized study of specialized aspects/topics of Energy Systems Engineering.

### **ESENG 599. Special Topics in Energy Systems Engineering**

*Prerequisite: Permission of instructor (3 credits)*

Selected topics pertinent to the Energy Systems Engineering program.

## Design Science Courses

### DESCI 501. Analytical Product Design

*Advised Prerequisite: Graduate standing. (3 credits)*

The design of artifacts is addressed from the multidisciplinary perspective that includes engineering, art, psychology, marketing, and economics. Using a decision-making framework, emphasis is placed on understanding basic quantitative methods employed by the different disciplines for making design decisions, building mathematical models, and accounting for interdisciplinary interactions throughout the design and development process. Students work in teams to apply the methods on design project from concept generation to prototyping and design verification.

### DESCI 502. Design Process Models

*Advised Prerequisite: DESCI 501 or permission of instructor. (3 credits)*

Interaction and coordination of decisions based on multi-discipline design analyses is studied in the context of a newly developed artifact. Innovation and creativity are addressed as elements of the design process. Enterprise design decisions made on functionality and business criteria are analyzed within organizational, cultural and social models. Students propose and test novel analysis methods and design process models.

### DESCI 590. Directed Design Research

*Prerequisite: Graduate standing. (3-6 credits)*

Students conduct independent practicum project integrating core design course material under direction of approved faculty or industrial mentor.

### DESCI 599. Special Problems

*Prerequisite: Graduate standing. (3 credits)*

Special topics course for DESCI students.

### DESCI 790. Design Science Colloquium

*Advised Prerequisite: Graduate standing. (1-4 credits)*

Topics on Design Science are presented by doctoral candidates and by invited speakers across campus and from outside the University. The aim of the colloquium is to aid in identifying appropriate dissertation topics.

### DESCI 791. Design Science Seminar

*Prerequisite: Graduate standing. (1-2 credits)*

Topics on Design Science are presented by doctoral candidates with an emphasis on interdisciplinary scholarship and students' own research projects. The aim of the seminar is to build community, discuss recent journal papers related to Design Science, and provide an opportunity for students to discuss their own research.

### DESCI 990. Dissertation/Pre-candidate

*Advised Prerequisite: Permission of advisor. (1-8 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

### DESCI 995. Dissertation/Pre-candidate

*Advised Prerequisite: Graduate School authorization for admission as a doctoral candidate. (4-8 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidate status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

## Integrative Systems + Design Courses

### ISD 503. Integrative Systems + Design Practicum

*Prerequisite: Enforced: ISD 520. (3-9 credits)*

The Practicum is a project course providing students with an integrative capstone experience where they apply knowledge and skills acquired from coursework to a complex engineering system design problem. Each project must have clearly defined goals and deliverables, and provide a solution methodology. A comprehensive project report is required at completion.

### ISD 520. Introduction to Systems Engineering

*Prerequisite: Enforced: Graduate student;. Advisory: background in multivariate calculus and statistics necessary. (3 credits)*

Introduction to the systems engineering process used to create multidisciplinary solutions to complex problems with multiple, often conflicting objectives; application to large developmental programs from such diverse areas as civil engineering and transportation, space and

missiles, ships and land vehicle systems.

### **ISD 590. Directed Study and Research**

*Prerequisite: None. (1-3 credits)*

Individualized study of specialized topics in Integrative Systems + Design.

### **ISD 599. Special Topics in ISD**

*Prerequisite: See individual department requirements; permission of instructor. (1-4 credits)*

Special topics in Integrative Systems and Design.

## **Manufacturing Courses**

### **MFG 402 (MECHENG 401). Statistical Quality Control and Design**

*Prerequisite: Senior or graduate standing. (3 credits)*

Evolution of quality method. Fundamentals of statistics. Process Behavior over time. Concept of statistical process control (SPC). Design and interpretation of control charts. Process capability study. Tolerance. Measurement system analysis. Correlation. Independent t-test and paired t-test. Design and analysis of two-level factorial experiments. Fractional factorial experiments. Response model building. Taguchi Methods. Case studies.

### **MFG 410 (NAVARCH 410). Marine Structures II**

*Prerequisite: NAVARCH 310. (4 credits)*

Structural modeling and analysis techniques applied to ship and marine structural components. Equilibrium and energy methods applied to elastic beam theory; static bi-axial bending, torsion and buckling. Shear flow in multicell cross sections. Stiffened and composite plates. Plastic analysis of beams and plates. Structural limit states and introduction to structural reliability.

### **MFG 426 (IOE 425). Manufacturing Strategies**

*Prerequisite: Senior standing. (2 credits)*

Review of philosophies, systems, and practices utilized by world-class manufacturing and services organizations focusing on "lean management," including material and information flow, in-process quality assurance, standardized work, continuous improvement, visual management, and lean leadership. Practical examples

and in-class exercises bring concepts to life.

### **MFG 440 (IOE 440). Operations Analysis and Management**

*Prerequisite: IOE 310 and 316 or graduate standing.*

*No credit granted for students who have credit for TO 605. (3 credits)*

Principles and models for analyzing, engineering, and managing manufacturing and service operations as well as supply chains. Emphasis on capacity management; queuing models of operational dynamics (including cycle time, work-in-progress, inventory, throughput, and variability); operational flexibility; the math and physics of lean enterprises.

### **MFG 441 (IOE 441). Production and Inventory Control**

*Prerequisite: IOE 310, IOE 316. (3 credits)*

Basic models and techniques for managing inventory systems and for planning production. Topics include deterministic and probabilistic inventory models; production planning and scheduling; and introduction to factory physics.

### **MFG 447 (IOE 447). Facility Planning**

*Prerequisite: IOE 310, IOE 316. (3 credits)*

Fundamentals in developing efficient layouts for single-story and multi-story production and service facilities. Manual procedures and microcomputer-based layout algorithms. Algorithms to determine the optimum location of facilities. Special considerations for multi-period, dynamic layout problems.

### **MFG 452 (MECHENG 452). Design for Manufacturability**

*Prerequisite: MECHENG 350. (3 credits)*

Study of systematic methods in product design which improve overall quality and cost. Methods include analysis of customer needs, function analysis, product architecture, material and process selection, design for assembly, robust design, and Taguchi methods. A course project to implement the methods by redesigning a product is required.

### **MFG 453 (MECHENG 451). Properties of Advanced Materials for Design Engineers**

*Prerequisite: MECHENG 382. (3 credits)*

Mechanical behavior and environmental degradation of polymeric-, metal-, and ceramic-matrix composites; manufacturability of advanced engineering materials; use of composite materials in novel engineering designs.

#### **MFG 455 (IOE 452). Corporate Finance**

*Prerequisite: IOE 201, IOE 310, IOE 366. (3 credits)*

The goal of this course is to introduce a basic understanding of financial management. The course develops fundamental models of valuation and investment from first principles and applies them to problems of corporate and individual decision-making. The topics of discussion will include the net present valuation, optimal portfolio selection, risk and investment analysis, issuing securities, capital structure with debt financing and real options.

#### **MFG 456 (IOE 453). Derivative Instruments**

*Prerequisite: IOE 201, IOE 310, IOE 366. Credit not granted for both IOE 453/MFG 456 and MATH 423. (3 credits)*

The main objectives of the course are first, to provide the students with a thorough understanding of the theory of pricing derivatives in the absence of arbitrage, and second, to develop the mathematical and numerical tools necessary to calculate derivative security prices. We begin by exploring the implications of the absence of static arbitrage. We study, for instance, forward and futures contracts. We proceed to develop the implications of no arbitrage in dynamic trading models: the binomial and Black-Scholes models. The theory is applied to hedging and risk management.

#### **MFG 458 (MATSCIE 485). Design Problems in Materials Science and Engineering**

*Prerequisite: MATSCIE 480. (1-4 credits) (to be arranged)*

The design of production and refining systems for engineering materials. Design of problems for the extraction and refining of metals, production and processing of ceramics, polymeric materials, and electronic materials. Written and oral presentation of solutions to processing design problems.

#### **MFG 461 (IOE 461). Quality Engineering Principles and Analysis**

*Prerequisite: IOE 366. (3 credits)*

This course provides students with the analytical and management tools necessary to solve manufacturing quality problems and implement effective quality systems. Topics include voice of the customer analysis, the Six Sigma problem solving methodology, process capability analysis, measurement system analysis, design of experiments, statistical process control, failure mode and effects analysis, quality function deployment, and reliability analysis.

#### **MFG 463 (IOE 463). Measurement and Design of Work**

*Prerequisite: IOE 333 or IOE 395 or BIOMEDE 231 and IOE 265 and STATS 412. (3 credits)*

Design of lean manufacturing systems requires knowledge and skills for describing manual work, identifying value and non-value added work elements, designing efficient work equipment and methods, preventing fatigue and related worker health problems and predicting work performance.

#### **MFG 466 (IOE 466) (STATS 466). Statistical Quality Control**

*Prerequisite: IOE 265 (STATS 265 and IOE 366 or STATS 401). (3 credits)*

Quality Improvement Philosophies; Modeling Process Quality, Statistical Process Control, Control Charts for Variables and Attributes, CUSUM and EWMA, Short Production Runs, Multivariate Quality Control, Auto Correlation, Engineering Process Control, Economic Design of Charts, Fill Control, Precontrol, Adaptive Schemes, Process Capability, Specifications and Tolerances, Gage Capability Studies, Acceptance Sampling by Attributes and Variables, International Quality Standards.

#### **MFG 470 (NAVARCH 470). Foundations of Ship Design**

*Prerequisite: NAVARCH 321, NAVARCH 332, NAVARCH 340, co-requisite: NAVARCH 310. (4 credits)*

Organization of ship design. Preliminary design methods for sizing and form; powering, maneuvering, and seakeeping estimation; arranging; propulsion; structural synthesis; and safety and environmental risk of ships. Extensive use of design computer environment. Given

owner's requirements, students individually create and report the conceptual/preliminary design for a displacement ship.

**MFG 480 (MATSCIE 480). Materials and Engineering Design**

*Prerequisite: Senior standing. (3 credits)*

Design concepts. Engineering economics. Problems of scaling. Materials substitution. Competitive processes. Case histories. Professional and ethical considerations. Written and oral presentations of solutions to design problems.

**MFG 488 (MECHENG 487). Welding**

*Prerequisite: MECHENG 382. (3 credits)*

Study of the mechanism of surface bonding, welding metallurgy, effect of rate of heat input on resulting microstructures, residual stresses and distortion, economics and capabilities of the various processes.

**MFG 492 (MECHENG 482). Machining Processes**

*Prerequisite: Senior standing. (3 credits)*

Introduction to machining operations. Cutting tools and tool wear mechanisms. Cutting forces and mechanics of machining. Machining process simulation. Surface generation. Temperatures of the tool and workplace. Machining dynamics. Non-traditional machining.

**MFG 499. Special Topics (to be specified by department)**

*(to be arranged)*

**MFG 501. Topics in Global Operations**

*Prerequisite: Restricted to Tauber Institute Students. (3 credits)*

This course is intended to provide students with an overview of various topics in operations, such as lean production systems, supply chain management, design for manufacturability, facilities planning, the environmental, legal and ethical issues in operations and product design. Students learn how all these aspects of operations interconnect.

**MFG 502. Manufacturing Systems Design**

*Prerequisite: Graduate standing or permission of instructor. (3 credits)*

Manufacturing system design methodologies and pro-

cedures. Topics: paradigms of manufacturing; building blocks of manufacturing systems; numerical control and robotics; task allocation and line balancing; system configurations; performance of manufacturing systems including quality, productivity, and responsiveness; economic models and optimization of manufacturing systems; launch and reconfiguration of manufacturing systems; Lean manufacturing.

**MFG 503. Manufacturing Project**

*Prerequisite: MFG 502. (3 credits)*

This project course is intended to provide students with an industrially-relevant team project experience in manufacturing.

**MFG 504. Tauber Institute Project**

*Prerequisite: Must be enrolled in Tauber Institute Program and MFG 501. (3 credits)*

Tauber Institute students will participate in the required Team Project, which is a multidisciplinary internship. In preparation, students will refine their communications, team building, and project management skills through specialized seminars. Upon completion, each student will perform an advanced analysis of the project results under the supervision of UM faculty.

**MFG 513 (MECHENG 513). Automotive Body Structures**

*Prerequisite: MECHENG 311. (3 credits)*

Emphasis is on body concept for design using first order modeling of thin walled structural elements. Practical application of solid/structural mechanics is considered to design automotive bodies for global bending, torsion, vibration, crashworthiness, topology, material selection, packaging, and manufacturing constraints.

**MFG 514 (MacroSE 514) (MATSCIE 514). Composite Materials**

*Prerequisite: MATSCIE 350. (3 credits)*

Behavior, processing and design of composite materials, especially fiber composites. Emphasis is on the basic chemical and physical processes currently employed and expected to guide the future development of the technology.

**MFG 517 (CHE 517). Biochemical Engineering**

*Prerequisite: CHE 344, and Biochem 415 or equiva-*

*lent; permission of instructor. (3 credits)*

Concepts necessary in the adaptation of biological and biochemical principles to industrial processing in biotechnology and pharmaceutical industries. Topics include rational screening, functional genomics, cell cultivation, oxygen transfer, etc. Lectures, problems and library study will be used.

**MFG 534 (BIOMEDE 534) (IOE 534). Occupational Biomechanics**

*Prerequisite: IOE 333, IOE 334 or IOE 433. (3 credits)*

Anatomical and physiological concepts are introduced to understand and predict human motor capabilities, with particular emphasis on the evaluation and design of manual activities in various occupations. Quantitative models are developed to explain (1) muscle strength performance, (2) cumulative and acute musculoskeletal injury, (3) physical fatigue, and (4) human motion control.

**MFG 535 (IOE 533). Human Motor Behavior and Engineering Systems**

*Prerequisite: IOE 333 and IOE 366. (3 credits)*

This course is designed to provide a basic perspective of the major processes of human motor behavior. Emphasis will be placed on understanding motor control and man-(Machine)-environment interaction. Information processing will be presented and linked to motor behavior. Applications of theories to the design of workplace, controls and tools will be underlined and illustrated by substantial examples.

**MFG 536 (CEE 536). Critical Path Methods**

*Prerequisite: Senior or graduate standing. (3 credits)*

Basic critical path planning and scheduling with arrow and precedence networks; project control; basic overlapping networks; introduction to resource leveling and least cost scheduling; fundamental PERT systems.

**MFG 539 (IOE 539). Safety Engineering Methods**

*Prerequisite: IOE 265 or Biostat 500. (3 credits)*

Recognition, evaluation and control of generic safety hazards (confined spaces, electricity, fire, mechanical energy, etc.) found in contemporary workplaces, using case studies from manufacturing, transportation and power generation. Students perform an interdisciplinary

team project using systems safety engineering methods to redesign a work station, manufacturing process or consumer product.

**MFG 541 (IOE 541). Inventory Analysis and Control**

*Prerequisite: IOE 310, IOE 316. (3 credits)*

Models and techniques for managing inventory systems and for planning production. Topics include single item and multi-item inventory models, production planning and control, and performance evaluation of manufacturing systems.

**MFG 543 (IOE 543). Scheduling**

*Prerequisite: IOE 316 and IOE 310. (3 credits)*

The problems that come with scheduling several tasks over time, including the topics of measures of performance, single-machine sequencing, flow shop scheduling, the job shop problem, and priority dispatching. Integer programming, dynamic programming, and heuristic approaches to various problems are presented.

**MFG 545 (IOE 545). Queue Networks**

*Prerequisite: IOE 515 or EECS 501. (3 credits)*

Introduction to queuing networks. Topics include product and non-product form networks, exact results and approximations, queuing networks with blocking, and polling systems. Applications from manufacturing and service industries are given as examples.

**MFG 549 (IOE 549). Plant Flow Systems**

*Prerequisite: IOE 310, IOE 416. (3 credits)*

Analytical models for the design and throughput performance evaluation of material handling systems used in discrete parts flow production facilities. Analysis of design and control issues for manual and automated handling systems including lift trucks, micro-load automatic storage/retrieval systems and automated guided vehicle systems.

**MFG 552 (MECHENG 552). Mechatronic Systems Design**

*Prerequisite: MECHENG 350, MECHENG 360, EECS 314 or equivalent. (3 credits)*

Mechatronics is the synergistic integration of mechanical disciplines, controls, electronics and computers in design of high-performance systems. Case studies,

hands-on lab exercises and hardware design projects cover the practical aspects of machine design, multi-domain systems modeling, sensors, actuators, drives, circuits, simulation tools, DAQ and controls implementation using microprocessors.

**MFG 553 (MECHENG 553). Microelectromechanical Systems**

*Prerequisite: Senior or graduate standing. (3 credits)*  
Basic integrated circuit (IC) manufacturing processes; electronics devices fundamentals; microelectromechanical systems fabrications including surface micromachining, bulk micromachining, LIGA and others. Introduction to microactuators and microsensors such as micromotors, grippers, accelerometers and pressure sensors. Mechanical and electrical issues in micromachining. IC CAD tools to design microelectromechanical structures using MCNC MUMPs service. Design projects.

**MFG 555 (MECHENG 555). Design Optimization**

*Prerequisite: Math 451 and Math 217 or equivalent. (3 credits)*

Mathematical modeling of engineering design problems for optimization. Boundedness and monotonicity analysis of models. Differential optimization theory and selected numerical algorithms for continuous nonlinear models. Emphasis on the interaction between proper modeling and computation. Students propose design term projects from various disciplines and apply course methodology to optimize designs.

**MFG 556 (MECHENG 576). Fatigue in Mechanical Design**

*Prerequisite: MECHENG 382 or equivalent. (3 credits)*

A broad treatment of stress, strain, and strength with reference to engineering design and analysis. Major emphasis is placed on the analytical and experimental determination of stresses in relationship to the fatigue strength properties of machine and structural components. Also considered are deflection, post-yield behavior, residual stresses, temperature and corrosion effects.

**MFG 557 (MECHENG 577). The Use of Materials and Their Selection in Design**

*Prerequisite: Senior or graduate standing. (3 credits)*

Material properties, including physical, mechanical, thermal, electrical, economic, corrosion and environmental properties interaction of function, shape, choice of materials, processing, economics and environmental impact in design. Methodology for materials selection and optimization, including performance indices, multiple constraints and multiple objectives. Introduction to analysis of environmental impact from materials selection.

**MFG 558 (MECHENG 558). Discrete Design Optimization**

*Prerequisite: Senior or graduate standing. (3 credits)*  
Fundamentals of discrete optimization for engineering design problems. Mathematical modeling of engineering design problems as discrete optimization problems, integer programming, dynamic programming, graph search algorithms, and introduction to NP completeness. A term project emphasizes applications to realistic engineering design problems.

**MFG 559 (MECHENG 559). Smart Materials and Structures**

*Prerequisite: EECS 314 or equivalent. (3 credits)*  
This course will cover theoretical aspects of smart materials, sensors and actuator technologies. It will also cover design, modeling and manufacturing issues involved in integrating smart materials and components with control capabilities to engineering smart structures.

**MFG 560 (MECHENG 551). Mechanisms Design**

*Prerequisite: MECHENG 350. (3 credits)*  
Basic concepts. Type synthesis - creative design of mechanisms; graph theory. Precision-point Burmester theory for dimensional synthesis of linkages. Applications. Cam and follower system synthesis. Joint force analysis and dynamic analysis formulations. Analytical synthesis of programmable and compliant mechanisms. Use of software for synthesis and analysis. Design projects.

**MFG 561 (IOE 565) (MECHENG 563). Time Series Modeling, Analysis, Forecasting**

*Prerequisite: IOE 366 or MECHENG 401. (3 credits)*  
Time series modeling, analysis, forecasting, and control, identifying parametric time series, autocovariance,

spectra, Green's function, trend and seasonality. Examples from manufacturing, quality control, ergonomics, inventory, and management.

### **MFG 562 (MECHENG 560). Modeling Dynamic Systems**

*Prerequisite: MECHENG 360. (3 credits)*

A unified approach to the modeling, analysis and simulation of energetic dynamic systems. Emphasis on analytical and graphical descriptions of state-determined systems using Bond Graph language. Analysis using interactive computer simulation programs. Applications to the control and design of dynamic systems such as robots, machine tools and artificial limbs.

### **MFG 563 (NAVARCH 562). Marine Systems Production Business Strategy and Operations Management**

*Prerequisite: NAVARCH 260 or P.I. or Graduate Standing. (4 credits)*

Business Strategy and Operations Management --- Examination of business strategy development, operations management principals and methods, and design-production integration methods applied to the production of complex marine systems such as ships, offshore structures, and yachts. Addresses shipyard and boat yard business and product strategy definition, operations planning and scheduling, performance measurement, process control and improvement.

### **MFG 567 (EECS 567) (MECHENG 567). Robot Kinematics and Dynamics**

*Prerequisite: Graduate standing or permission of instructor. (3 credits)*

Geometry, kinematics, differential kinematics, dynamics, and control of robot manipulators. The mathematical tools required to describe spatial motion of a rigid body will be presented in full. Motion planning including obstacle avoidance is also covered.

### **MFG 571 (NAVARCH 571). Ship Design Project**

*Prerequisite: Prior arrangement with instructor. (to be arranged)*

Individual (or team) project, experimental work, research or directed study of selected advanced topics in ship design. Primarily for graduate students.

### **MFG 572 (NAVARCH 570). Advanced Marine Design**

*Prerequisite: Graduate standing required. (4 credits)*

Organization of marine product development; concurrent marine design. Shipbuilding policy and build strategy development. Group behaviors; leadership and facilitation of design teams. General theories and approaches to design. Conceptual design of ships and offshore projects. Nonlinear programming, multicriteria optimization, and genetic algorithms applied to marine design.

### **MFG 575 (NAVARCH 575). Computer-Aided Marine Design Project**

*Prerequisite: None. (2-6 credits), (to be arranged)*

Development of computer-aided design tools. Projects consisting of formulation, design, programming, testing, and documentation of programs for marine design and constructional use.

### **MFG 577 (MATSCIE 577). Failure Analysis of Materials**

*Prerequisite: MATSCIE 350. (3 credits)*

Analysis of failed structures due to tensile overload, creep, fatigue, stress corrosion, wear and abrasion, with extensive use of scanning electron microscope. Identification and role of processing defects in failure.

### **MFG 578 (NAVARCH 580). Optimization and Management of Marine Systems**

*Prerequisite: None. (4 credits)*

Optimization methods (linear, integer, nonlinear, deterministic and stochastic sequential optimization) concepts and applications in the operations of marine systems. Elements of maritime management. Risk analysis and utility theory. Fleet deployment optimization for major ocean shipping segments. Forecasting concepts and applications to shipping and shipbuilding decisions.

### **MFG 579 (NAVARCH 582). Reliability and Safety of Marine Systems**

*Prerequisite: EECS 401 or Math 425 or Stat 412. (3 credits)*

Brief review of probability and statistics. Mathematical methods of reliability analysis for systems with or without repairs. Reliability, availability, maintenance, re-

placement, and repair decisions. Safety and risk analysis. Risk assessment methods and case studies. FMEA, fault tree and event tree analysis. Marine, Automotive, Manufacturing, Health Care and other applications.

**MFG 580 (MECHENG 572). Rheology and Fracture**

*Prerequisite: MECHENG 382. (3 credits)*

Mechanisms of deformation, cohesion, and fracture of matter. Unified approach to the atomic-scale origins of plastic, viscous, viscoelastic, elastic, and anelastic behavior. The influences of time and temperature on behavior. Stress field of edge and screw dislocations, dislocation interactions, and cross slip.

**MFG 584 (MECHENG 584). Advanced Mechatronics for Manufacturing**

*Prerequisite: ME 461 or equivalent. (3 credits)*

Theoretical principles and practical techniques for controlling mechatronic systems are taught in the context of advanced manufacturing applications. Specifically, the electro-mechanical design/modeling, basic/advanced control, and real-time motion generation techniques for computer-controlled manufacturing machines are studied. Hands-on labs and industrial case studies are used to re-enforce the course material.

**MFG 587 (MECHENG 587). Global Manufacturing**

*Prerequisite: One 500-level MFG, DES or BUS class. (3 credits)*

Globalization and manufacturing paradigms. Product-process-business integration. Product invention strategy. Customized, personalized and reconfigurable products. Mass production and lean production. Mathematical analysis of mass customization. Traditional manufacturing systems. Reconfigurable manufacturing systems. Reconfigurable machines. System configuration analysis. Responsive business models. Enterprise globalization strategies. The global integrated enterprise.

**MFG 588 (MECHENG 588) (IOE 588). Assembly Modeling for Design and Manufacturing**

*Prerequisite: MECHENG 381 and 401 or equivalent. (3 credits)*

Assembly as product and process. Assembly representation. Assembly sequence. Datum flow chain. Geometric Dimensioning and Tolerancing. Tolerance anal-

ysis. Tolerance synthesis. Robust design. Fixturing. Joint design and joining methods. Stream of variation. Auto body assembly case studies.

**MFG 590. Study or Research in Selected Manufacturing Topics**

*Prerequisite: Permission of instructor. (1-3 credits)*

Individual study of specialized aspects of Manufacturing engineering.

**MFG 591 (MECHENG 586). Laser Material Processing**

*Prerequisite: Senior or graduate standing. (3 credits)*

Application of lasers in materials processing and manufacturing. Laser principles and optics. Fundamental concepts of laser/material interaction. Laser welding, cutting, surface modification, forming, and rapid prototyping. Modeling of processes, microstructure and mechanical properties of processed materials. Transport phenomena. Process monitoring.

**MFG 599. Special Topics**

*Prerequisite: See individual department requirements. (3 credits)*

**MFG 605 (OMS 605). Manufacturing and Supply Operations**

*Prerequisite: None. (3 credits)*

This is a course on the basic concepts and techniques of operations and inventory management. The foundation of the course is a system of manufacturing laws collectively known as "Factory Physics". These laws relate to measures of plant performance, such as throughput, cycle time, work-in-process, customer service, variability, and quality, in a consistent manner and provide a framework for evaluating and improving operations. Concepts and methods are examined via exercises and case studies.

**MFG 622 (MATSCIE 622) (NERS 622). Ion Beam Modification and Analysis of Materials**

*Prerequisite: NERS 421, NERS 521 or MATSCIE 350 or permission of instructor. (3 credits)*

Ion-solid interactions, ion beam mixing, compositional changes, phase changes, micro-structural changes; alteration of physical and mechanical properties such as corrosion, wear, fatigue, hardness; ion beam analysis

techniques such as RBS, NRA, PIXE, ion channeling, ion micro-probe; accelerator system design and operation as it relates to implantation and analysis.

**MFG 990. Dissertation/Pre-Candidate**

*Prerequisite: Permission of thesis committee; mandatory satisfactory/unsatisfactory. (2-8 credits); (1-4 credits)*

Dissertation work by doctoral student not yet admitted to status as candidate. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**MFG 995. Dissertation/Candidate**

*Prerequisite: College of Engineering authorization for admission as a doctoral candidate; mandatory satisfactory/unsatisfactory. (8 credits); (4 credits)*

Election for dissertation work by a doctoral student who has been admitted to candidacy status. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Macromolecular Science and Engineering

## Overview

Macromolecular Science and Engineering (Macro) is an interdisciplinary program that provides the academic and research basis for studies in the science and technology of synthetic and natural macromolecules. Faculty and students bring their polymers expertise to over a dozen different fields at Michigan. Students are able to apply to both Ph.D. and Master's programs. The Macro program also offers a SUGS degree in collaboration with several departments, allowing current U-M students to receive an accelerated Master's.

Our faculty body draws mainly from Engineering (Aerospace, Biomedical, Chemical, Electrical, Materials Science, and Mechanical), the Dental School, and the Department of Chemistry. Their interests range from polymer synthesis, microfluidics, and tissue engineering to sensors, computational nanoscience, mechanical behaviors, and nanoelectronics.

Macro is a unique program in that it allows students to tailor their academic program to fit individual interests. Students can work with faculty on research within the College of Engineering, Medical School, Dental School, and College of Literature, Science, and the Arts. In the classroom students are able to pursue concentrations in the areas of Biomaterials Engineering, Biomedical Engineering, Chemistry, Chemical Engineering, Materials Science and Engineering, Organic Electronics or Physics. With faculty approval students may also design an individualized option.

Macro thrives on being an interdisciplinary program and we encourage students from a wide range of engineering and science backgrounds. Current students in our program have studied all manners of engineering in addition to chemistry, biology, and physics. The faculty believe that exposure to a diverse group of fields allows students to develop the skills needed to adapt to changes inherent in modern research and development.

# Program Administration

## Contact

### Program Director

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## Research

Ph.D. and Master's students are able to begin research during their first term. Ph.D. students may directly join a group or can conduct two semester-long research rotations during their first year.

## Representative Course Programs

There are different course requirements for Macro Master's and Ph.D. students. However it is recommended that all Macro students take Macro 412 (Polymeric Materials) or Macro 512 (Polymer Physics), particularly those students who do not have as strong of a polymers background. Students also should take Macro 538, Organic Chemistry of Macromolecules.

## Master's Students

Master's students are required to complete 30 credit hours to earn their degree.

They must take at least 3 courses (9 credit hours) of

Macro courses and 3 courses (9 credits hours) within their chosen option. In addition, students are required to take at least two additional courses (6 hours). These additional courses can be selected from anywhere in the College of Engineering, Chemistry, Physics, or Center for Entrepreneurship. With approval students may use other courses (Math, Business, etc.) for credit.

Master's students may use up to 6 credits of research courses towards their degree requirements. If doing so, students must present a work product (publication, thesis, other product subject to faculty approval) that has directly resulted from their Macro research.

SUGS students are able to use up to 15 credits of courses for their undergraduate degree towards the Master's. This includes double counting of courses and transferring unused courses towards their graduate degree. Prior approval from the undergraduate program and Macro Director are required.

## Ph.D. Students

Ph.D. students are required to complete 30 course credit hours to earn their degree. Students are required to take Macro 790 (1 credit) and Macro 800 (2 credits).

They must take at least 4 courses (12 credit hours) of Macro courses and 4 courses (12 credit hours) within their chosen option. In addition, students are required to take at least one additional course (3 hours). These additional courses can be selected from anywhere in the College of Engineering, Chemistry, Physics, or Center for Entrepreneurship. With approval students may use other courses (Math, Business, etc.) for credit.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **MacroSE 410 (BIOENG 410) (MATSCIE 410). Polymeric Materials**

*Prerequisites: MATSCIE 250 or permission. (3 credits)*

Interactions of materials implanted in the body. Histo-

logical and hematological considerations including general foreign body reactions, inflammation and reparations, carcinogenicity, thrombosis, hemolysis, protein and cellular issues, immunogenic and toxic properties. Basic discussion of implants vs. transplants and relevant biological components. Tours of relevant University facilities.

### **MacroSE 412 (CHE 412) (MATSCIE 412). Polymeric Materials**

*Prerequisites: MATSCIE 220 or 250. (3 credits)*

The synthesis, characterization, microstructure, rheology, and properties of polymer materials. Polymers in solution and in the liquid, liquid-crystalline, crystalline and glassy states. Engineering and design properties, including viscoelasticity, yielding and fracture. Forming and processing methods. Recycling and environmental issues.

### **MacroSE 511 (CHE 511) (MATSCIE 511). Rheology of Polymeric Materials**

*Prerequisite: A course in fluid mechanics or permission from instructor. (3 credits)*

An introduction to the relationships between the chemical structure of polymer chains and their rheological behavior. The course will make frequent reference to synthesis, processing, characterization and use of polymers for high technology applications.

### **MacroSE 512 (CHE 512) (MATSCIE 512). Polymer Physics**

*Prerequisite: Senior or graduate standing in engineering or physical science. (3 credits)*

Structure and properties of polymers as related to their composition, annealing and mechanical treatments. Topics include creep, stress relaxation, dynamic mechanical properties, viscoelasticity, transitions, fracture, impact response, dielectric properties, permeation and morphology.

### **MacroSE 514 (MFG 514) (MATSCIE 514). Composite Materials**

*Prerequisite: MATSCIE 350. (3 credits)*

Behavior, processing and design of composite materials, especially fiber composites. Emphasis is on the basic chemical and physical processes currently employed and expected to guide the future development of

the technology.

**MacroSE 515 (MATSCIE 515). Mechanical Behavior of Solid Polymeric Materials**

*Prerequisite: MECHENG 211, MATSCIE 412. (3 credits)*

The mechanical behavior of polymers from linear viscoelastic to yield and fracture are covered. Specific topics include dynamic-mechanical relaxations, creep, yielding, crazing, fatigue and fracture mechanics. The materials include toughened plastics, polymer alloys and blends and composite materials. Structured design with plastics is also considered.

**MacroSE 517 (MECHENG 517). Mechanics of Polymers I**

*Prerequisite: MECHENG 511 (AM 511) or permission of instructor. (3 credits)*

Constitutive equation for linear small strain viscoelastic response; constant rate and sinusoidal responses; time and frequency dependent material properties; energy dissipation; structural applications including axial loading, bending, torsion; three dimensional response, thermo-viscoelasticity, correspondence principle, Laplace transform and numerical solution methods.

**MacroSE 535 (Chem 535). Physical Chemistry of Macromolecules**

*Prerequisite: Chem 463 or Chem 468. (3 credits)*

The theory and application of useful methods for studying natural and synthetic polymers will be stressed. The methods discussed include osmotic pressure, sedimentation equilibrium, Brownian motion, diffusion, sedimentation transport, intrinsic viscosity, scattering of light and x-rays, optical and resonance spectra, flow and electric bi-refringence, depolarization of fluorescence, circular dichroism and magneto optical rotatory dispersion, electrophoresis, titration curves, kinetics of polymerization, suitable distribution functions for expressing heterogeneity, rigidity and viscosity of gels.

**MacroSE 536 (Chem 536). Laboratory in Macromolecular Chemistry**

*Prerequisite: Chem 535 or permission of instruction. (2 credits)*

Experimental methods for the study of macromolecular materials in solution and in bulk state.

**MacroSE 538 (Chem 538). Organic Chemistry of Macromolecules**

*Prerequisite: Chem 215, Chem 216, and Chem 230 or Chem 241/242, 260. (3 credits)*

The preparation, reactions and properties of high molecular weight polymeric materials of both natural and synthetic origin. Two lectures and reading.

**MacroSE 559 (MATSCIE 559). Foundations of Nano II**

*(3 credits)*

This course covers the synthesis, properties and processing of nanosized metal, metal oxide and semiconductor powders. It will also include some organic/inorganic and nanobio materials. The emphasis will be on particle properties and the use of these particles to make nanostructured shapes.

**MacroSE 751 (Chem 751) (MATSCIE 751) (Physics 751). Special Topics in Macromolecular Science**

*Prerequisite: Permission of instructor. (2 credits)*

**MacroSE 790. Faculty Activities Research Survey (1 credit)**

This course introduces students to the research activities of MacroSE faculty with the intent of helping a student to choose his research advisor in the first term.

**MacroSE 800. Macromolecular Seminar I, II**

*(2 credits)*

Student presentation of selected seminar topics in macromolecular science and engineering.

**MacroSE 890. Introduction to Research Techniques**

*Prerequisite: Permission of chairman. Every term (1-8 credits)*

This course is used for research carried out to earn the master's degree.

**MacroSE 990. Dissertation Research Precandidacy**

*Prerequisite: Permission. Every term (1-8 credits)*

This course number is used for doctoral research by students not yet admitted to candidacy. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

**MacroSE 995. Dissertation Research/Candidacy**

*Prerequisite: Permission. every term (8 credits); (4 credits) in half-term*

This course number is used for doctoral research by students who have been admitted to candidacy. The defense of the dissertation, that is, the final oral examination, must be held under a full-term candidacy enrollment.

# Military Officer Education Programs

## Overview

The University of Michigan, in cooperation with the armed services of the United States, provides an opportunity for eligible male and female students to earn a commission from the Army, Navy, Marine Corps and Air Force upon completion of the degree and commissioning requirements. This opportunity is available through enrollment in the Military Officer Education Program (M.O.E.P.), which is known nationally as the Reserve Officers Training Corps (R.O.T.C.).

All three officer education programs (Army, Navy, and Air Force) offer four- and two-year program options, financial benefits, and scholarship opportunities. Minor variations, however, do exist among the programs and students should consult the specific information under the applicable program.

## Financial Benefits

All students enrolled in advanced (junior and senior year) officer education courses, whether or not on scholarship, receive a monthly stipend for the academic year. Uniforms, required books and equipment are furnished to students. Additionally, pay and travel allowances are provided for attendance at summer field training courses.

## Scholarships

In addition to the financial benefits provided for all students contracted in the advanced courses, two-, three- and four-year merit-based scholarships are awarded on a competitive basis by each of the Officer Education Programs. These scholarships provide tuition, laboratory fees, payment for required books and a monthly stipend.

## Course Election by Non-Program Students

Officer education courses are also open to University students not enrolled in the program with the permission of the instructor.

## Army

### Army Officer Education Program

Upon graduation and completion of program requirements, students receive a commission as Second Lieutenant in the United States Army Reserve Forces or in the Active Army.

### Career Opportunities

Graduates may request active duty in the Army as commissioned officers or choose reserve duty service in the Army National Guard or Army Reserve in order to pursue a civilian career or graduate schooling.

Active duty officers are available for worldwide assignment. Service in one of the Army's 17 basic branches and the possibility for educational delay provides an opportunity for extensive leadership experience.

### Four-Year, Three-Year, and Two-Year Programs

Students may choose one of three program options as described in the general introduction to the Military Officer Education Programs. All programs include a four-week Cadet Leaders Course (C.L.C.) at Fort Knox, KY, which is taken as part of the advanced course sequence between the junior and senior years. The first two years of the four-year program can be taken without an obligation to the Army.

Students who intend to enroll in the two-year program should contact the Recruiting Officer by February of their sophomore year in order to discuss enrollment options before the following fall term. Two-year candidates must have a total of two years of school remaining at the undergraduate and/or graduate level. Students with prior military service (or prior R.O.T.C. training) may enroll in the program with advanced standing.

## Financial Benefits and Scholarships

Army R.O.T.C. scholarships are merit-based and provide full tuition plus books and fees. All scholarship students receive a monthly stipend to help cover additional expenses. The stipend is \$300/month for first-year students, \$350/month for second-year students, \$450/month for third-year students and \$500/month for fourth-year students. Engineering students may request an additional year of scholarship benefits if they are enrolled in a five-year program. Two, three & four year scholarships are available.

## Simultaneous Membership Program

Non-scholarship students can choose to join a Reserve or National Guard unit of their choice while enrolled at the University. The student trains as an officer trainee, gaining valuable leadership training as a member of the Reserve Forces and can collect over \$1,000 a month.

## Branch Assignments

In their senior year, cadets are assessed for branch assignments to one of the following 17 branches of the Army in accordance with their personal preference, aptitude, academic background, and the needs of the Army: Corps of Engineers, Cyber, Signal Corps, Aviation, Armor, Field Artillery, Air Defense Artillery, Adjutant General's Corps, Military Intelligence, Finance Corps, Infantry, Medical Service Corps, Military Police Corps, Ordnance Corps, Quartermaster Corps, Transportation Corps, Cyber and Chemical Corps.

## Course of Study

Students enroll in one Military Science (MS) class during each term of participation in the program for a total of 12 credit hours distributed as follows:

- Basic Course sequence (first and second years): Military Science 101, 102, 201, 202 (4 hours total).
- Advanced Course sequence (third and fourth years): Military Science 301, 302, 401, 402 (8 hours total).

The complete course of instruction includes professional ethics, professional writing and briefing, principles of military leadership, staff management principles, military justice, and tactics. In addition to the class-

room courses, students participate in Leadership Laboratories (one 120 minute period per week). Training includes orienteering, rappelling, marksmanship, land navigation and physical training. In addition, courses in effective writing and military history are required for completion of the program.

## Military Obligation

Students may request active duty or non-active duty assignments in the Army Reserve or National Guard. All Advanced Course students are obligated to four years of service which may be served in an active or reserve status depending on individual preference and Army needs and an additional four years of I.R.R. (on call) status. No obligation is incurred during the freshman and sophomore years, unless the student is on scholarship.

**Note:** A Leadership Laboratory (0 credit), meeting for two hours each week, accompanies each of the above listed MS courses.

## Army Officer Education Course Listings

(Subject = MILSCI)

Course descriptions are found on the College of Engineering web site at <http://courses.engin.umich.edu/>

### 101. Introduction to Officership

Prerequisite: none. (1 credit)

### 102. Introduction to Leadership

Prerequisite: none. (1 credit)

### 103. Leadership Laboratory

Prerequisite: none. (0 credit)

### 201. Innovative Tactical Leadership

Prerequisite: none. (1 credit)

### 202. Leadership in Changing Environments

Prerequisite: none. (1 credit)

### 301. Leading Small Organizations I

Prerequisite: permission of Chairman. (2 credits)

### 302. Leading Small Organizations II

Prerequisite: permission of Chairman. (2 credits)

### 401. Leadership and Management

Prerequisite: permission of Chairman. (2 credits)

### 402. Military Professionalism and Professional Ethics

Prerequisite: permission of Chairman. (2 credits)

## Military Obligation

Newly commissioned officers incur a minimum of four years of active duty service obligation.

**Chair:** Lieutenant Colonel Walter G. Cummings

Program Office

930 N. University Ave, Room 1090

Phones: (734) 764-4200

Recruiting Officer: (734) 936-2839

Website: [www.army.rotc.umich.edu](http://www.army.rotc.umich.edu)

## Air Force

### Air Force Officer Education Program

Students who enroll as cadets in the Air Force Officer Education Program, which is known nationally as the Air Force Reserve Officers Training Corps (A.F.R.O.T.C.), successfully complete the program and receive a University degree are commissioned as Second Lieutenants in the United States Air Force.

### Career Opportunities

Men and women can serve in a wide range of technical fields such as meteorology, research and development, communications and electronics, engineering, transportation, logistics and intelligence as well as in numerous managerial and training fields such as administrative services, accounting and finance, personnel, statistics, manpower management, education and training, investigation and information services. There are also opportunities in the pilot, combat systems officer, space operations and missile career fields. Advanced education or technical training for these career areas may be obtained on active duty at Air Force expense.

### Four-Year and Three-Year Programs

Students may choose one of two program options as described in the general introduction to Military Officer Education Programs. The four-year and three-year program options include a summer four-week field training course at Maxwell Air Force base between the sophomore and junior years. Students electing to take the three-year program will be required to take the basic course sequence in one year instead of two years.

No military obligation is incurred during the freshman year for scholarship recipients and none during the freshman or sophomore years for non-scholarship recipients.

### Financial Benefits and Scholarships

For a detailed description of the available financial benefits and scholarships, consult the appropriate sections in the general introduction to the Military Officer Education Programs.

### Course of Study

Students enroll in one course in Aerospace Studies (AS) during each term of participation in the program for a total of 16 credit hours.

- Basic course sequence (first and second year): Aerospace Studies 101, 102, 201, 202 (4 hours).
- Advanced course sequence (third and fourth years): Aerospace Studies 310, 311, 410, 411 (12 hours).

This sequence of courses attempts to develop an understanding of the global mission and organization of the United States Air Force, of the historical development of air power and its support of national objectives, of concepts of leadership, management responsibilities and skills, of national defense policy and of the role of the military officer in our society.

### Military Obligation

After being commissioned, graduates of the program will be called to active duty with the Air Force in a field usually related to their academic degree program. The period of service is four years for non-flying officers, six years for combat systems officers and air battle managers after completion of their training and ten years for pilots after completion of flight training.

### Air Force Officer Education Course Listings

(Subject = AERO)

Course descriptions are found on the College of Engineering web site at <http://courses.engin.umich.edu/>

#### 101. The Air Force Today

Prerequisite: none. I (1 credit)

### **102. The Air Force Today**

Prerequisite: AERO 101. II (1 credit)

### **201. Evolution of U.S. Air Power**

Prerequisite: AERO 102. I (1 credit)

### **202. Evolution of U.S. Air Power**

Prerequisite: AERO 201. II (1 credit)

### **310. Air Force Leadership and Management**

Prerequisite: AERO 202. I (3 credits)

### **311. Air Force Leadership and Management**

Prerequisite: AERO 310. II (3 credits)

### **410. National Security Forces in Contemporary American Society**

Prerequisite: AERO 311. I (3 credits)

### **411. National Security Forces in Contemporary American Society**

Prerequisite: AERO 410. II (3 credits)

**Note:** A Leadership Laboratory (0 credit), meeting for two-hours each week, accompanies each of the above-listed courses.

## **Navy**

### **Navy Officer Education Program**

Students enrolled as Midshipmen in the Navy Officers' Training Corps who receive a scholarship or advanced standing placement and successfully complete required courses and receive a degree from either the University of Michigan (Ann Arbor) or Eastern Michigan University will be commissioned as officers in the United States Navy or United States Marine Corps.

### **Career Opportunities**

Graduates of the program have a wide range of job and career opportunities. Navy officers will receive assignments in the surface, aviation, submarine, special warfare or nursing communities. Marine Corps officers will receive duty assignment to include those in aviation, infantry, armor or artillery specialties. After graduation, all commissioned officers receive additional training in their respective fields.

### **Scholarship Students**

Scholarship students make up the majority of the incoming freshman class and overall battalion. To earn a

national scholarship, please visit [www.nrotc.navy.mil](http://www.nrotc.navy.mil) for application instructions and eligibility. Scholarships cover tuition, books, uniforms, and provide a monthly stipend ranging from \$250 to \$400 depending on your class standing. For further information about earning a scholarship please email the NROTC Unit directly at [freshmanadvisor@umich.edu](mailto:freshmanadvisor@umich.edu).

### **College Program Students**

Earning a scholarship is not the only way to initially join the NROTC program. The College Program offers a unique opportunity to students who did not receive a national scholarship but who have a strong desire to become a naval officer. Students accepted into the College Program will be considered for a scholarship following their freshman and sophomore years in the program and must be nominated by their advisor, endorsed by the Professor of Naval Science, and granted a scholarship by Naval Science Training Command. The application process is extremely competitive and students will be competing with other College Program students from around the country. Scholarships are awarded based on academic performance, level of physical fitness, military aptitude, and funding availability from the Navy. If a College Program student is not awarded a scholarship after their sophomore year in the program they will be considered for advanced standing. If they are awarded advanced standing they will remain in the program and will commission upon completion of their degree. However, advanced standing midshipmen do not receive any financial benefits with the exception of the monthly stipend. All tuition, room and board, cost for books and other expenses will be paid for out of pocket. The application for the College Program can be found at [www.navy.rotc.umich.edu](http://www.navy.rotc.umich.edu). Specific questions related to joining the College Program can be emailed to [freshmanadvisor@umich.edu](mailto:freshmanadvisor@umich.edu).

### **Course of Study**

Students enroll in Naval Science (NavSci) courses during each term of participation in the program. Additionally, scholarship students are required to complete coursework in calculus, calculus-based physics, English, American History or National Security policy, and World Culture or Religious Studies courses. Scholarship students are also required to participate in a four-

to six-week training period each summer until graduation.

## Military Obligation

Newly commissioned officers incur a minimum of five years of active duty service. Aviation officers incur a minimum active duty service of up to 10 years.

## Navy Officer Education Course Listings

(Subject = NAVSCI)

Course descriptions are found on the College of Engineering web site at <http://courses.engin.umich.edu/> (Electrical Engineering), and at <http://www.lsa.umich.edu/cg/default.aspx> (NavSci)

### 101. Introduction to Naval Science

Prerequisite: none. (2 credits)

### 102. (UC 101). Seapower and Maritime Affairs

Prerequisite: none. (2 credits)

### 201. (NAVARCH 102). Introduction to Ship Systems

Prerequisite: none. (3 credits)

### 202. (EECS 250). Electronic Sensing Systems

Prerequisite: Prior or concurrent enrollment in Physics 240 (or 260) or EECS 230. (3 credits)

### 203. (UC 205). Leadership and Management

Prerequisite: NavSci 101 & 102 or Permission of Instructor. (3 credits)

### 301. (Astro 261). Navigation

Prerequisite: none. (3 credits)

### 302. Naval Operations

Prerequisite: NavSci 301. (3 credits)

### 310. (UC 310). Fundamentals of Maneuver Warfare

Prerequisite: Permission of Instructor (Offered Fall of odd years)

### 402. (UC 403). Leadership and Ethics

Prerequisite: NavSci 203 or Permission of Instructor II (2 credits)

### 410. (UC 410). Evolution of Warfare

Prerequisite: none. (3 credits)(Offered Fall of even years)

**Note:** The courses listed herein are offered primarily for the students participating in the program; however, they are open to, and may be taken by, any University-enrolled student. **Not all of them are accredited.**

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

## AERO (Air Force Officer Education Program)

### AERO 101. Air Force Today I

*Prerequisite: None. (1 credit)*

Examines the growth and development of the United States Air Force; covers Presidential, Secretary of Defense and JCS roles in the defense posture, and the national and U.S. military strategic concepts; studies the Air Force contribution to strategic offensive and defensive and General Purpose Forces and Air Force supporting forces. Compares the dynamics and interaction of all U.S. military forces in the General Purpose role and their cooperative efforts in the national security posture.

### AERO 102. Air Force Today II

*Prerequisite: AERO 101. (1 credit)*

This course is a continuation of the study of the growth and development of the United States Air Force begun in AERO 101. The course relates the mission and responsibilities of the various Air Force major commands to the U.S. defense posture and the U.S. military strategy. Emphasis is placed on the Air Force contribution to General Purpose forces and the dynamics, interactions, and cooperative efforts of all the Services in the General Purpose role for the national security posture.

### AERO 201 (UC 201). U.S. Aviation History & Its Development into Air Power

*Prerequisite: AERO 102. (1 credit)*

This course traces the development of aviation from the 18th century — a time of balloons and dirigibles — to the present, and examines how technology has affected the growth and development of air power. In addition, this course traces the use and development of air power through World War I and World War II, the Korean and Vietnamese conflicts, employment in relief missions and civic action programs in the late 1960s, and employment in military actions concluding with Desert

Shield/Desert Storm.

### **AERO 202 (UC 202). U.S. Aviation History & Its Development into Air Power**

*Prerequisite: AERO 201. (1 credit)*

Examines the development of aviation from the 18th century, from balloons and dirigibles, to the present, and how technology has affected growth and development of air power; traces use and development of air power through WW's I and II, the Korean and Vietnamese conflicts, employment in relief missions and civic action programs in the late 1960s, and employment in military actions concluding with Desert Shield/Desert Storm. Continuation of AERO 201.

### **AERO 310 (UC 309). Air Force Leadership and Management**

*Prerequisite: AERO 202. (3 credits)*

The concepts, principles, and techniques of leadership are presented within the framework of behavioral theories. Emphasis on the leader, group, situation, and their interaction as dynamic factors in an organizational environment. Historical overview of managerial development throughout recorded history with emphasis on the social and physical setting in which the manager operates. The curriculum includes effective communications, decision making, planning, and strategic management.

### **AERO 311. Management & Af Appl**

*Prerequisite: AERO 310. (3 credits)*

An integrated management course emphasizing the concepts and skills required by the successful manager and leader. Organizational and personal values (ethics), management of change, organizational power, politics, and managerial strategy and tactics are discussed within the context of the military organization. Actual Air Force case studies are used throughout the course to enhance the learning and communication process (lecture and seminar).

### **AERO 410. National Security Forces in Contemporary American Society**

*Prerequisite: AERO 311. (3 credits)*

Focuses on the Armed Forces as an integral element of society. Provides examination of a broad range of American civil-military relations, and the environmen-

tal context in which defense policy is formulated. Special themes include: societal attitudes toward the military; the role of the professional military leader-manager in a democratic society; the fundamental values and socialization processes associated with the Armed Services; the requisites for maintaining adequate national security forces; policy, economic, and social constraints on the national defense structure; the impact of technological and international developments on strategic preparedness; the manifold variables involved in the formulation and implementation of national security policy.

### **AERO 411. National Security Forces in Contemporary American Society**

*Prerequisite: AERO 410. (3 credits)*

This course is a continuation of AERO 410 which examines the role of the military in contemporary American society. The course covers current issues affecting the military in the aftermath of the end of the Cold War and the lessons learned from the recent war in the Persian Gulf. Finally, AERO 411 prepares officer cadets for future active duty services by explaining what is expected of them as professional military officers and how to prepare for the transition into the Air Force. Instruction is conducted via lecture and discussion.

## **MILSCI (Army Officer Education Program)**

### **MILSCI 101. Introduction to Officership**

*Prerequisite: None. (1 credit)*

Develops an understanding of the U.S. Army. Introduces the critical military leadership skills used by the Officer Corps of the Army. Topics include: customs and traditions of the service, organization of the Army, and the officer corps' role in the service of the country. Students have the opportunity to participate in various military skills training such as rappelling, land navigation, orienteering, briefing techniques, and physical fitness classes. There is no obligation to the military associated with this class.

### **MILSCI 102. Introduction to Leadership**

*Prerequisite: None. (1 credit)*

Learn/apply principles of effective leading. Reinforce

self-confidence through participation in physically and mentally challenging exercises with upper division ROTC students. Develop communication skills to improve individual performance and group interaction. Relate organizational ethical values to the effectiveness of a leader. Participation in a weekend exercise is optional, but highly encouraged.

### **MILSCI 201 (UC 203). Innovative Tactical Leadership**

*Prerequisite: None. (1 credit)*

The focus of this course is to develop the students' basic understanding of military leadership. The course focuses on current military leadership theory and its organizational application. It includes discussions of leadership styles, principles of leadership, human behavior, principles of motivation, ethics, counseling, communications and the military problem solving process. It also incorporates leadership assessment training and discussions of how leadership influences the achievement of organizational goals.

### **MILSCI 202 (UC 204). Leadership in Changing Environments**

*Prerequisite: None. (1 credit)*

Examines the challenges of leading in complex contemporary operational environments. Dimensions of the cross-cultural challenges of leadership in a constantly changing world are highlighted and applied to practical Army leadership tasks and situations.

### **MILSCI 301 (UC 301). Leading Small Organizations I**

*Prerequisite: Permission of Chairman. (2 credits)*

Series of practical opportunities to lead small groups, receive personal assessments and encouragement, and lead again in situations of increasing complexity. Uses small unit tactics and opportunities to plan and conduct training for lower division students both to develop such skills and as vehicles for practicing leading. Two hours and a required leadership lab, plus required participation in three one-hour sessions for physical fitness. Participation in one weekend exercise is also required.

### **MILSCI 302 (UC 302). Leading Small Organizations II**

*Prerequisite: MILSCI 301/UC 301; permission of Chairman. (2 credits)*

Continues methodology of MILSCI 301/UC 301. Analyze tasks; prepare written or oral guidance for team members to accomplish tasks. Delegate tasks and supervise. Plan for and adapt to the unexpected in organizations under stress. Examine and apply lessons from leadership case studies. Examine importance of ethical decision making in setting a positive climate that enhances team performance. Two hours and a required leadership lab, plus required participation in three one-hour sessions for physical fitness. Participation in one weekend exercise is required.

### **MILSCI 401 (UC 401). Leadership and Management**

*Prerequisite: MILSCI 302/UC 302; permission of Chairman. (2 credits)*

Plan, conduct, and evaluate activities of the ROTC cadet organization. Articulate goals and put plans into action to attain them. Assess organizational cohesion and develop strategies to improve it. Develop confidence in skills to lead people and manage resources. Learn/apply various Army policies and programs in this effort.

### **MILSCI 402 (UC 402). Military Professionalism and Professional Ethics**

*Prerequisite: MILSCI 401/UC 401. (2 credits)*

MILSCI 402 is an interdisciplinary course that integrates history, political science, ethics and morality, law, leadership and management. The course helps prepare students to ethically lead and manage complex organizations by focusing on the moral, ethical, legal and regulatory aspects of being a commissioned officer in the US Army.

### **MILSCI 499. Independent Study-Directed Readings**

*Prerequisite: Permission of instructor. (1-4 credits)*

Directed reading or research in consultation with a member of the Army Officer Education faculty.

## **NAVSCI (Navy Officer Education Program)**

### **NAVSCI 101. Introduction to Naval Science**

*Prerequisite: None. (2 credits)*

An introductory look at the organizational structure of the naval service. Attention is concentrated on leadership and management principles as they apply to the naval service and the shipboard organization. Additional subjects to be covered are military justice, and Navy policies and procedures.

### **NAVSCI 102 (UC 101). Seapower and Maritime Affairs**

*Prerequisite: None. (2 credits)*

This course focuses on the historical role of sea power, emphasizing the U.S. Navy. Topics include: development of naval power and applications as an instrument of foreign policy; historical relationship of navies with their respective domestic, political, and economic environment; and the rise of U.S. as a maritime power.

### **NAVSCI 201 (NAVARCH 102). Introduction to Ship Systems**

*Prerequisite: None. (3 credits)*

Types, structures and purposes of ships. Ship compartmentation, propulsion systems, auxiliary power systems, interior communications, and ship control. Elements of ship design to achieve safe operations, and ship stability characteristics. The course is taught in a lecture format with limited discussion. In addition to class sessions, there are several laboratory sessions which illustrate applications of the theories and concepts learned in the classroom.

### **NAVSCI 202 (EECS 250). Electronic Sensing Systems**

*Prerequisite: Prior or concurrent enrollment in Physics 240 (or 260) or EECS 230. (3 credits)*

Introduction to properties and behavior of electromagnetic energy as it pertains to naval applications of communication, radar, and electro-optics. Additional topics include sound navigation and ranging (SONAR) tracking and guidance systems, and computer controlled systems. Several laboratory demonstrations will illustrate applications of the theories and concepts learned in the classroom.

### **NAVSCI 203 (UC 205). Leadership and Management**

*Prerequisite: NAVSCI 101 & 102 or Permission of In-*

*structor. (3 credits)*

This course is specifically designed to teach introductory-level leadership and management concepts and applications to sophomore-level university students. The course starts with a basic overview of leadership and management, and then moves into basic skills including professional reading, writing, briefings, problem solving, team building, situational leadership, morality, ethics, and communications. After the basic skills are covered, the curriculum explores leader-subordinate and peer relationships, while taking an in-depth look at professional and unprofessional relationships. The course emphasizes ethics in leadership and management and explores subjects in power and influence, counseling, supervision, accountability, responsibility, and core values.

### **NAVSCI 301 (ASTRO 261). Navigation**

*Prerequisite: None. (3 credits)*

The purpose of this course is to educate students in all aspects of marine navigation, from getting a vessel underway from port through open ocean navigation using both celestial and electronic means. The content of the course is divided into three major areas. The first section focuses on piloting, emphasizing the safe navigation of vessels in coastal waters. This section provides an introduction to navigational instruments and aids to navigation. The second section concerns celestial navigation, the ability to determine position through observation of celestial bodies. Students learn how to determine position based on the use of the sextant and various almanacs and mathematical tables. The third section of the course considers electronic navigation.

### **NAVSCI 302. Naval Operations**

*Prerequisite: NAVSCI 301. (3 credits)*

A study of the international and inland rules of the nautical road, relative motion vector analysis, relative motion problems at sea, formation tactics, and ship employment. Also included is an introduction to naval operations and operations analysis, ship behavior and characteristics in maneuvering, applied aspects of shiphandling, seamanship, and afloat communications.

### **NAVSCI 310 (UC 310). Evolution of Warfare**

*Prerequisite: None. (3 credits)(Offered Fall of even years)*

Introduction to the history, development and innovations in warfare. The student acquires a general background and insight into the effect that society and technology has had on the evolution of warfare. There is a critical analysis of the changes in warfare, the changes in the views on war, and the thoughts and actions of military leaders and writers.

**NAVSCI 402 (UC 403). Leadership and Ethics**

*Prerequisite: NAVSCI 203 or Permission of Instructor.  
(2 credits)*

Exploration of Western moral traditions and ethical philosophy in topics to include military leadership, core values, and professional ethics. NAVSCI 410 (UC 410). Amphibious Warfare Prerequisite: none. I (3 credits)(Offered Fall of odd years) Exploration of the history, development, and techniques of amphibious operations to enable the student to acquire a general background in amphibious operations.

# Robotics

## Overview

<http://robotics.umich.edu/academic-program/>

The Robotics program welcomed its first class of students in Fall 2014! Robotics is part of an interdisciplinary effort to bring together the many disciplines that contribute to research on robotics. Robotics is the design, creation, analysis, and use of embodied computational systems that interact with the physical and human environment. The study of robotics and its place in the world draws on many fields of engineering, including computer science, mechanical engineering, artificial intelligence, computer vision, electrical engineering, control systems, human-robot/computer interaction, and biomedical engineering. Robotics will integrate knowledge from these fields for applications to Robotics.

U-M Robotics currently offers Masters and Ph.D. degrees. Both programs share a common set of course requirements. Ph.D. students must additionally complete a set of qualifying exams to become Ph.D. candidates, and then complete a thesis.

This program will have three main core technical areas. These three areas are integrated in order to implement a functioning robot: (1) Sensing of the environment, external agents, and internal body information to determine state information, (2) Reasoning with that information to make decisions for guidance, control, and localization, and (3) Acting upon the body and environment to produce motion or other outputs that enable the robot to locomote or interact with the environment. Each of these areas may be considered a subplan for coursework and research study. The goal of the proposed Robotics Program is to train students to be independent researchers and engineers, and future leaders in robotics research, in academia, industry and government.

## Contact

General Email: [robotics@umich.edu](mailto:robotics@umich.edu)

Faculty: <http://robotics.umich.edu/faculty/>

## Course Requirements (Masters and Ph.D.)

The Robotics Masters (M.S.) degree program requires completion of 30 credits of letter-graded coursework including directed study for three (3) to six (6) credits. Ph.D. programs have very similar course requirements. Ph.D. students earn a Masters degree as part of their Ph.D. program. To complete the Ph.D., students will typically complete a minimum of six (6) additional credits to satisfy specific course requirements. The Rackham Residency requirement states that at least 18 of the 36 course credits required for a Ph.D. be earned at the University of Michigan, for those entering with M.S. degrees from other institutions.

The robotics program classifies most of its courses as belonging to one of three core subdisciplines:

- Sensing – Includes computer vision, mapping, signal processing
- Reasoning – Includes planning, multi-agent coordination, machine learning, artificial intelligence
- Acting – Includes control, kinematics, dynamics, mechanical, bio-mechanical systems design, manipulation, real-time systems

Note: For a list of approved courses go to:

<http://robotics.umich.edu/academic-program/>

The following table summarizes robotics program course requirements. The “Other Electives” course set is quite general and should be discussed with a student’s advisor and documented on the student’s course plan. Some suggested math and robotics courses hosted in traditional departments are listed at: <http://robotics.umich.edu/academic-program/requirements-obtain-ph-d-m-s-robotics/robotics-possible-elective-courses/>

Course / Category	Description	Requirement
ROB 501	Math for Robotics	3 credits
ROB 550	Robotic Systems Laboratory	4 credits
Breadth	One course from each core area: sensing, reasoning, acting	3 courses (9+ credits)
Cognate	One technical course from <i>outside</i> the core areas	4 credits
Directed Study	Research supervised by a robotics faculty member	3+ credits
Other Electives (PhD only)	400 level or higher (approved by a faculty advisor)	3+ credits

## 1st Year Students

All first-year M.S. and Ph.D. robotics students are advised to take three (3) courses in the first (fall) semester: Math for Robotics (ROB 501), Robotic Systems Laboratory (ROB 550), plus a third course related to their primary area of interest. In the second term, students are advised to take two (2) courses, e.g., from other breadth areas, plus a directed study course.

Each student is strongly encouraged to meet with his/her research advisor or the graduate chair soon after arrival on campus to discuss course options. The goal

of this meeting is to develop a course plan that satisfies course requirements and student interests. It is expected that each student will identify and meet with a (directed study) research advisor by the beginning of their second term.

## Qualification Process (Ph.D.)

A major milestone for Ph.D. students is to pass the qualifying exams, which advances the student to Ph.D. candidate status. The qualification process is comprised of a review of academic performance, technical qualifying exam, and a research preliminary exam. A Ph.D. student is considered to have adequate performance in coursework if his/her grade-point average is 3.5 or above. Both components of the exam are typically completed after three semesters in the program.

### *Technical Qualifying Exam*

This is an oral exam in which the student is examined by two faculty members. The faculty will examine the student’s understanding of technical fundamentals gained from coursework.

### *Research Preliminary Exam*

The student delivers an oral presentation describing a research problem. Following the presentation (which may focus, for example, on a literature review, a replication study, or original research), two faculty members will question the student on their understanding of their subject.

## Thesis Proposal and Defense (Ph.D.)

Ph.D. students must propose, write, and defend a thesis on an original research topic. At least a year prior to the final thesis defense, the student must defend a proposal to the Ph.D. committee.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **ROB 501. Mathematics for Robotics**

*Prerequisite: Graduate standing or permission of instructor. Advisory: Differential equations and matrix algebra recommended. (3 credits)*

Applied mathematics for robotics engineers. Topics include vector spaces, orthogonal bases, projection theorem, least squares, matrix factorizations, Kalman filter and extensions, particle filters, underlying probabilistic concepts, norms, convergent sequences, contraction mappings, Newton Raphson algorithm, nonlinear constrained optimization, local vs global convergence, convexity, linear and quadratic programs, and randomized search strategies.

### **ROB 550. Robotic Systems Laboratory**

*Prerequisite: Graduate standing or permission of instructor. (4 credits)*

Multidisciplinary laboratory course with exposures to sensing, reasoning, and acting for physically-embodied systems. Intro to kinematics, localization and mapping, planning, control, user interfaces. Design, build, integration, and test of mechanical, electrical, and software systems. Projects based on a series of robotic platforms: manipulators, mobile robots, aerial or underwater vehicles.

### **ROB 590. Directed Study**

*Prerequisite: Permission of instructor. (1-6 credits)*

Individual study of specialized aspects of robotics. Graduate students only.

# Technical Communications

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **TCHNCLCM 215. Technical Communication for Electrical and Computer Engineering**

*Prerequisite: Engineering 100, Corequisite: EECS 215. (1 credit)*

Professional communication to the general public, managers and other professionals about electrical and computer engineering ideas. Functional, physical and visual/diagrammatic description. Report writing about circuits, signals and systems, including description and analysis. Job letters and resumes.

### **TCHNCLCM 281. Technical Communication for Computer Science and Engineering**

*Prerequisite: Engineering 100, Corequisite: EECS 281. (1 credit)*

Introduction to professional communication for computer scientists and engineers. Communication to managers and programmers about data structures, algorithms and programs. Coding conventions and documentation. Functional and visual/diagrammatic descriptions. Letters of transmittal and reports on software systems. Job letters and resumes.

### **TCHNCLCM 300. Technical Communication for Electrical and Computer Science**

*Prerequisite: Engineering 100. (1 credit)*

Professional communication to the general public, managers and other professionals about electrical and computer engineering ideas as presented in written reports and oral presentations. Functional, physical and visual/diagrammatic description; job letters and resumes.

### **TCHNCLCM 380. Technical Communication in IOE**

*Prerequisite: Preceded or accompanied by IOE 366 and 373. (2 credits)*

Successful professional and technical communication

commands a wide range of skills, including critical inquiry, analysis and collaboration. Through regular practice, feedback, reflection and revision, this course examines technical communication principles and how to apply them in IOE environments. Specifically, the course emphasizes strategies for effective argumentation and persuasion as well as effective language use and style in written reports and oral presentations intended for IOE audiences.

### **TCHNCLCM 401. Special Topics Strategic Planning & Proposal Writing**

*Prerequisite: Junior or senior standing. (4 credits)*

Student teams provide expert consulting services to community service organizations. Team assignments include preparing an environmental scan, a strategic plan and a grant proposal. Special emphasis is given to oral communication, writing to effect organizational change, design and management of large documentation projects, major designs reviews and creative thinking.

### **TCHNCLCM 450. Web Page and Site Design**

*Prerequisite: Junior or senior standing. (4 credits)*

Practical skills and theoretical principles necessary to design effective WWW pages and sites, including HTML, tools for creating Web pages, graphics, scripting, animation, multimedia (practical skills) and information design, visual design and theoretical principles (theory). Design and analysis of Web sites.

### **TCHNCLCM 496. Advanced Technical Communication for Electrical Engineering and Computer Engineering**

*Prerequisites: TCHNCLCM 300 Co-Requisites: Senior Design Course. (2 credits)*

Development of advanced communication skills required of electrical and computer engineers and managers in industry, government and business. Design and writing of reports, proposals and memoranda on complex technical material for diverse organizational audiences. Preparation and delivery of organizational oral presentations and briefings.

### **TCHNCLCM 497. Advanced Technical Communication for Computer Science**

*Prerequisite: TCHNCLCM 300 Co-Requisites: Major*

*Design Experience Course in Computer Science. (2 credits)*

Advanced technical communication for computer science. Design and writing of user and task analysis, requirements documents, specifications, proposals, reports and documentation, all aimed at diverse organizational audiences. Preparation and delivery of final oral presentations and written project reports.

**TCHNCLCM 498. Technical and Professional Writing for Industry, Government, and Business**

*Prerequisite: Senior or graduate standing. (3 credits)*

Development of the communication skills required of engineers and managers in industry, government and business. Focus on (1) the design and writing of reports and memoranda that address the needs of diverse organizational audiences and (2) the preparation and delivery of organizational oral presentations and briefings. Writing and speaking about design and research problems in terms that will satisfy both specialists and non-specialists. A series of short explanatory papers and speeches leading up to a final formal report and public lecture.

**TCHNCLCM 499. Scientific and Technical Communication**

*Prerequisite: Permission of Technical Communication faculty. (elective credit only)*

Conferences and tutorial sessions that provide opportunities for students with special interests to work on a tutorial basis with a member of the Technical Communication faculty. Not intended as substitutes for regularly scheduled courses. Conference and signed contract required with an instructor about the proposed study before enrollment possible. (Directed Study contract forms and additional information are available from the Technical Communication office.)

**TCHNCLCM 575. Directed Study**

*Prerequisite: Permission of instructor. (to be arranged)*

Conferences and tutorial sessions for students with special interests. May be taken for 1-4 credit hours as arranged by the instructor.

**TCHNCLCM 610. Dissertation, Dissertation Proposal, and Thesis Writing**

*Prerequisite: Graduate standing. (3 credits)*

Intended for American and foreign students writing their dissertations, dissertation proposals or theses. Writing guidelines and their scientific base for problem definition and literature review; argument structures for the discussion of problems criteria, methodology, results, and conclusions; selection and ordering of information; editing visual aids; and special grammatical problems.

**TCHNCLCM 675. Directed Study**

*Prerequisite: Graduate standing, permission of instructor. (to be arranged)*

Conferences and tutorial sessions for students with special interests. May be taken for 1-4 credit hours as arranged by the instructor.

# UARTS

*ArtsEngine's mission is to maximize the creative production of U-M students, faculty, and staff by integrating the arts, architecture, and engineering, benefiting the individuals who exercise their creativity, informed by the cultures that are transformed by their work.*

A collaboration among U-M's Taubman College of Architecture + Urban Planning, School of Art & Design, School of Music, Theatre & Dance, and College of Engineering, ArtsEngine stimulates and supports integrative, project-based creative work and sustained research among faculty and students from its founding schools and other U-M units.

Working together, artists, engineers, architects, performers and designers discover fresh angles of vision and synergize knowledge to spur creative new solutions. Smart surfaces that are also visually compelling, operatic productions that are both beautiful and "green," digital technologies that reflect the insights and meet the needs of artists, nano-engineered materials inspired by earthbound creative work, and many other innovations demonstrate the power of such collaborations. Strategically combining faculty and students in the arts, architecture, engineering, and other disciplines across campus yields imaginative, transformative results.

U-M has unique assets in arts and engineering: top-rated professional schools, co-located on U-M's North Campus, led by collaborative, visionary deans. ArtsEngine is the expression and driver of the innovative use of these unparalleled assets.

## Courses

*Note: Courses are accurate as of the time of publication. Please refer to the online Course Bulletin for the most up-to-date course listings.*

### **UARTS 101. Creativity and Collaborations I**

*Prerequisite: None. (1 credit)*

This is a required class for members of Living Arts.

This hands-on, yearlong workshop will provide students with an opportunity to explore their own creative processes and collaborative styles as they work on projects and performances that engage North Campus, the University of Michigan, and the surrounding community. Creativity and Collaboration will feature workshops led by faculty and visiting artists and entrepreneurs, and interdisciplinary student teams will be given the opportunity to brainstorm, draft, edit, revise, present (or perform), and critique original projects.

### **UARTS 102. Creativity and Collaborations II**

*Prerequisite: None. (1 credit)*

This is a required class for members of Living Arts. This hands-on, yearlong workshop will provide students with an opportunity to explore their own creative processes and collaborative styles as they work on projects and performances that engage North Campus, the University of Michigan, and the surrounding community. Creativity and Collaboration will feature workshops led by faculty and visiting artists and entrepreneurs, and interdisciplinary student teams will be given the opportunity to brainstorm, draft, edit, revise, present (or perform), and critique original projects.

### **UARTS 150. Introduction to the Creative Process**

*Prerequisite: None. (3 credits)*

This course is available to Living Arts Students. It provides a conceptual and experiential foundation for the cultivation of creativity within and across academic disciplines. It is designed to prepare Living Arts students to recognize, understand, articulate, and utilize their creative abilities in their chosen field.

### **UARTS 200. Living Arts Peer Mentorship**

*Prerequisite: None. (1 credit)*

Students in this experiential class learn strategies for effective peer mentoring and engage their mentees in discussions regarding transition issues commonly experienced by the first-year students. Class time is dedicated to learning campus resources and discussing case studies. Peer mentors development in electronic portfolio that requires reflection on their identities as students, leaders, and creators.

### **UARTS 250. Creative Process**

*Prerequisite: None. (4 credits)*

This course provides a conceptual and experiential foundation for the cultivation of creativity within and across academic disciplines. It is designed to prepare UM students to recognize, understand, articulate, and utilize their creative abilities in their chosen field.

**UARTS 290. Special Topics in University Arts**

*Prerequisite: None. (1-4 credits)*

Special topics of current interest selected by faculty.

**UARTS 390. Special Topics in University Arts**

*Prerequisite: None. (1-4 credits)*

Special topics of current interest selected by faculty.

**UARTS 490. Special Topics in University Arts**

*Prerequisite: None. (1-4 credits)*

Special topics of current interest selected by faculty.

**UARTS 550. Creative Process**

*Prerequisite: None. (4 credits)*

This course provides a conceptual and experiential foundation for the cultivation of creativity within and across academic disciplines. It is designed to prepare UM students to recognize, understand, articulate, and utilize their creative abilities in their chosen field.

# Michigan Engineering Offices

<b>Michigan Engineering Offices (area code 734)</b>	
General Information: <a href="http://www.engin.umich.edu">www.engin.umich.edu</a>	647-7000
Academic Records and Services (Withdrawal/Disenrollment), 145 A Chrysler Center	647-7111
CAEN, Main Office, 1315 Duderstadt Center	764-CAEN
CAPS Embedded Counselor, Engineering	764-8312
Center for Engineering Diversity and Outreach (CEDO), 1108 LEC	647-7120
Center for Entrepreneurship (CFE), 3350 Duderstadt Center	763-1021
Engineering Career Resource Center (students and alumni), 230 Chrysler Center	647-7160
Engineering Learning Center (ELC), 273 Chrysler Center	615-8438
Engineering Advising Center (EAC), 230 Chrysler Center	647-7106
Engineering Scholarship Office, 143 Chrysler Center	647-7113
Engineering Student Organizations, 143 Chrysler Center	647-7155
Integrative Systems + Design, 2214 SI-North	647-7024
Office of Graduate Education, 1240 LEC	647-7077
International Programs in Engineering Office (IPE), 245 Chrysler Center	647-7129
Multidisciplinary Design Program (MDP), 203 Gorguze Family Laboratory	763-7421
Office of Student Affairs (OSA), 143 Chrysler Center	647-7118
Office of Student Support and Accountability (OSSA)	615-1405
Recruitment and Transfer Admissions, 153 Chrysler Center	647-7101
Scholastic Standing Committee, 129 Chrysler Center	647-7106
Undergraduate Education, 1261 LEC	647-7150
Wilson Student Team Project Center	615-6400
Women in Science & Engineering Program (WISE), 3236 Undergraduate Science Building	615-4455

# University of Michigan

## University of Michigan Offices (area code 734)

Admissions, Undergraduate, 1220 Student Activities Bldg. (SAB)	764-7433
Campus Information Center	764-INFO
Career Center, 3200 Student Activities Building (SAB)	764-7460
Cashier's Office, 2226 Student Activities Building (SAB)	764-7447
Counseling and Psychological Services, 3100 Michigan Union	764-8312
English Language Institute, 555 S. Forrest Ave.	764-2413
Employment: Student, 2500 Student Activities Building (SAB) Hospital, 2901 Hubbard, Suite 1100 Recruitment and Employment, G250 Wolverine Tower Temporary Staffing Services, 3003 S. State St. #250	763-4128 647-5538 615-2000 763-5740
Financial Aid, 2500 SAB	763-6600
Graduate School, Rackham Bldg., 915 E. Washington Admissions	764-8129
Housing Information Services, 1011 Student Activities Building (SAB):	763-3164
International Center, Central Campus, 603 E. Madison	764-9310
International Institute, 1080 South University Ave., Suite 2660	
Ombuds, 6015 Fleming Bldg.	763-3545
Office of New Student Programs, 1100 LSA Orientation University Mentorship Program Arts at Michigan Welcome to Michigan	764-6413
Office of the President, 2074 Fleming Bldg.	764-6270
Office of the Provost, 3074 Fleming Bldg.	764-9290
Office of Student Conflict Resolution, 100 SAB	936-6308
Office of the Vice President and Secretary of the University, 2013 Fleming Bldg.	763-5553
Services for Students with Disabilities (SSD), G-664 Haven Hall	763-3000
Student Financial Operations (Room, Board, and Tuition), 2226 SAB	764-7447
Student Activities and Leadership, 2205 Michigan Union	763-5900
Student Legal Services, 715 N. University, Suite 202	763-9920
University Health Service, 207 Fletcher	764-8325
Appointments Information	764-8320
Veterans and Military Services Program (VMSP), 1100 LSA	764-6413
Veterans Benefits, Office of the Registrar, 1207 LSA	763-9066

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**ENGINEERING**