<table>
<thead>
<tr>
<th>Department</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case School of Engineering</td>
<td>2</td>
</tr>
<tr>
<td>Biomedical Engineering</td>
<td>15</td>
</tr>
<tr>
<td>Chemical and Biomolecular Engineering</td>
<td>38</td>
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<tr>
<td>Civil Engineering</td>
<td>48</td>
</tr>
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<td>Data Science</td>
<td>57</td>
</tr>
<tr>
<td>Electrical Engineering and Computer Science</td>
<td>64</td>
</tr>
<tr>
<td>Engineering Physics</td>
<td>113</td>
</tr>
<tr>
<td>Macromolecular Science &amp; Engineering</td>
<td>115</td>
</tr>
<tr>
<td>Materials Science &amp; Engineering</td>
<td>134</td>
</tr>
<tr>
<td>Mechanical &amp; Aerospace Engineering</td>
<td>153</td>
</tr>
<tr>
<td>Division of Engineering Leadership and Professional Practice</td>
<td>173</td>
</tr>
<tr>
<td>Index</td>
<td>175</td>
</tr>
</tbody>
</table>
CASE SCHOOL OF ENGINEERING

Engineering seeks to create new processes, products, methods, materials, or systems that impact and are beneficial to our society. To enable its graduates to lead the advancement of technology, the Case School of Engineering (http://engineering.case.edu) offers fourteen degree programs at the undergraduate level (twelve engineering degrees, plus the BS in computer science and the BS in data science and analytics). At the post-graduate level, the School of Engineering offers Master of Science programs and the Doctor of Philosophy for advanced, research-based study in engineering. The Case School of Engineering offers two specialized degrees at the master’s level: a Master of Engineering specifically for practicing engineers, and an integrated Master of Engineering and Management jointly administered with the Weatherhead School of Management. The Case School of Engineering offers Graduate Certificates which provide an introductory graduate level understanding in the fields of Wireless Health and Wearable Computing. The Case School of Engineering also offers two dual-degrees at the graduate level jointly administered with the School of Medicine: a Doctor of Medicine/Master of Science and a Doctor of Medicine/Doctor of Philosophy. The faculty and students participate in a variety of research activities offered through the departments and the interdisciplinary research centers of the university.

At the core of its vision, the Case School of Engineering seeks to set the standards for excellence, innovation, and distinction in engineering education and research prominence.

Statement of Educational Philosophy

The Case School of Engineering prepares and challenges its students to take positions of leadership in the professions of engineering and computer science. Recognizing the increasing role of technology in virtually every facet of our society, it is vital that engineering students have access to progressive and cutting-edge programs stressing five areas of excellence:

- Mastery of fundamentals
- Creativity
- Societal awareness
- Leadership skills
- Professionalism

Emphasizing these core values helps ensure that tomorrow’s graduates are valued and contributing members of our global society and that they will carry out the tradition of engineering leadership established by our alumni.

The undergraduate program aims to create life-long learners by emphasizing engineering fundamentals based on mathematics, physical, and natural sciences. Curricular programs are infused with engineering innovation, professionalism (including engineering ethics and the role of engineering in society), professional communications, and multidisciplinary experiences to encourage and develop leadership skills. To encourage societal awareness, students are exposed to and have the opportunity for in-depth study in the humanities, social sciences, and business aspects of engineering. Undergraduate students are encouraged to develop as professionals. Opportunities include the Cooperative Education Program, on-campus research activities, and participation in the student chapters of professional societies. Graduates are prepared to enter the workforce and be strong contributors as practicing engineers or continue for advanced study in engineering.

At the graduate level, the Case School of Engineering combines advanced classroom study with a rigorous independent research experience leading to significant results appropriate for publication in archival journals and/or presentation at leading technical conferences. Scientific integrity, engineering ethics, and communication skills are emphasized throughout the program.

Brief History

The Case School of Engineering was established on July 1, 1992, by an action of the Board of Trustees of Case Western Reserve University as a professional school dedicated to serving society and meeting the needs of industry, government and academia through programs of teaching and research.

The Case School of Engineering continues the tradition of rigorous programs based on fundamental principles of mathematics, science and engineering that have been the hallmark of its two predecessors, the Case School of Applied Science (1880) and the Case Institute of Technology (1947). The formation of the Case School of Engineering is a re-commitment to the obligations of the gift of Leonard Case, Jr., to serve the citizens of Northern Ohio. The Case School of Engineering has been a leader in many educational programs, being the first engineering school to offer undergraduate programs in computer engineering, biomedical engineering, polymer engineering, and systems and control engineering.

Statistics

Enrollment Statistics by Degree Program (Fall 2013 through Fall 2017). Data reflects sophomore, junior and senior declared Majors.

<table>
<thead>
<tr>
<th>CSE Degree Fall 2013</th>
<th>Fall 2014</th>
<th>Fall 2015</th>
<th>Fall 2016</th>
<th>Fall 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerospace Engineering</td>
<td>106</td>
<td>96</td>
<td>97</td>
<td>113</td>
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<tr>
<td>Biomedical Engineering</td>
<td>369</td>
<td>407</td>
<td>435</td>
<td>394</td>
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<td>Chemical Engineering</td>
<td>123</td>
<td>145</td>
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<td>Civil Engineering</td>
<td>48</td>
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<td>58</td>
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<tr>
<td>Computer Engineering</td>
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<td>54</td>
<td>56</td>
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<tr>
<td>Computer Science (BA and BS)</td>
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<td>194</td>
<td>229</td>
<td>281</td>
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<tr>
<td>Electrical Engineering</td>
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<td>84</td>
<td>118</td>
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<tr>
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<tr>
<td>Engineering 15 Physics</td>
<td>23</td>
<td>24</td>
<td>28</td>
<td>26</td>
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<tr>
<td>Materials Science and Engr</td>
<td>38</td>
<td>48</td>
<td>53</td>
<td>52</td>
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<tr>
<td>Mechanical Engineering 244</td>
<td>274</td>
<td>291</td>
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Graduation Statistics by Degree Program (AY 2013-14 through AY 2017-18)

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<tr>
<th>CSE Degree Program</th>
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<th>2014-15</th>
<th>2015-16</th>
<th>2016-17</th>
<th>2017-2018</th>
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<td>68</td>
<td>106</td>
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<td>BA in Computer Science</td>
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<td>54</td>
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<tr>
<td>Engineering 0 (Undesignated)</td>
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<td>0</td>
<td>1</td>
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<td>Engineering 5 Physics</td>
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<td>9</td>
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<tr>
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<td>Mechanical Engineering</td>
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<td>0</td>
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<td>Polymer Science and Engr</td>
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<td>22</td>
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<tr>
<td>Systems and Control Engr</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

Degrees Granted

Bachelor of Science in Computer Science (p. 68)

Bachelor of Arts in Computer Science (p. 68) (granted by the College of Arts and Sciences and administered by the Department of Electrical Engineering and Computer Science)

Bachelor of Science in Data Science and Analytics

Bachelor of Science in Engineering with the following major field designations:
- Aerospace Engineering (p. 157)
- Biomedical Engineering (p. 22)
- Chemical Engineering (p. 39)
- Civil Engineering (p. 50)
- Computer Engineering (p. 68)
- Electrical Engineering (p. 68)
- Engineering Physics (p. 113)
- Materials Science and Engineering (p. 137)
- Mechanical Engineering (p. 157)
- Polymer Science and Engineering (p. 119)
- Systems and Control Engineering (p. 68)

Bachelor of Science in Engineering with a major in General Engineering (http://bulletin.case.edu/schoolofengineering/generalengineering)(for programs that emphasize interdisciplinary areas or for programs that include some emphasis on non-technical fields)

Bachelor of Science in Engineering/Master of Engineering

Bachelor of Science in Engineering/Master of Science

 Administration

Venkataramanan Balakrishnan, PhD
(Stanford University)
Dean of the Case School of Engineering

Marc Buchner, PhD
(Michigan State University)
Associate Dean of Academics

Lisa Camp, MS
(Case Western Reserve University)
Associate Dean of Strategic Initiatives

Daniel Ducoff, MS
(University of California, Berkeley)
Vice Dean for External Relations of the Case School of Engineering

Cena Hilliard, MS
(University of Wisconsin-Madison)
Associate Dean of Finance, Administration, and Business Operations

Deborah J. Fatica, MA
(Bowling Green State University)
Assistant Dean of the Division of Engineering Leadership and Professional Practice

K. Peter D. Lagerlof, PhD
(Case Western Reserve University)
Faculty Director of Program Evaluation and Assessment

Chris Zorman, PhD
(Case Western Reserve University)
Interim Associate Dean of Research
Case School of Engineering

- Materials Science and Engineering
- Mechanical Engineering
- Polymer Science and Engineering/Macromolecular Science and Engineering
- Systems and Control Engineering

Master of Engineering (practice-oriented program)

Master of Engineering and Management

Master of Science with the following major field designations:

- Aerospace Engineering (p. 162)
- Biomedical Engineering (p. 28)
- Chemical Engineering (p. 44)
- Civil Engineering (p. 53)
- Computer Engineering (p. 85)
- Computing and Information Science (p. 85)
- Electrical Engineering (p. 85)
- Macromolecular Science and Engineering (p. 123)
- Materials Science and Engineering (p. 142)
- Mechanical Engineering (p. 162)
- Systems and Control Engineering (p. 85)

Master of Science with the following major field designations and optional track:

- Biomedical Engineering:
  - Translational Health Technology
  - Wireless Health
- Electrical Engineering:
  - Wearable Computing
  - Wireless Health
- Macromolecular Science and Engineering:
  - Fire Science and Engineering
- Mechanical Engineering:
  - Fire Science and Engineering

Master of Science in Engineering, (Undesignated) (http://bulletin.case.edu/schoolofengineering/msundesignated)

Doctor of Medicine/Master of Science

- Biomedical Engineering

Doctor of Philosophy with the following major field designations:

- Biomedical Engineering
- Mechanical Engineering

Engineering Minors

Students enrolled in other majors may elect to pursue a minor. The minor program advisor’s approval is required. The successful completion of a minor will be indicated on a student’s transcript. For a full list of engineering and university minors, go to the Office of Undergraduate Studies (https://case.edu/ugstudies/programs-requirements/majors-minors) website.

List of Minors

Engineering Minors

- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Computer Science
- Electrical Engineering
- Materials Science and Engineering
- Polymer Science and Engineering
- Systems and Control Engineering

University Minors

- Artificial Intelligence (p. 68)
- Applied Data Science (p. 59)
- Computer Gaming (p. 68)
- Mechanical Design and Manufacturing (p. 157)

Bachelor of Science in Engineering

In addition to the major department requirements, each engineering undergraduate degree program includes the Engineering Core (Engineering General Education Requirements), which provides a foundation in mathematics and sciences as well as aspects of engineering fundamentals for programs in engineering. The Engineering Core is also designed to develop communication skills and to provide a body of work in areas of study outside of engineering, science, and mathematics. Requirements of the Engineering Core can be found in the Undergraduate Studies (http://bulletin.case.edu/undergraduatestudies/csedegree) section of this bulletin.

Details of the specific curricular requirements for the undergraduate majors are described in the respective departmental descriptions. Details of the requirements of the undesignated engineering undergraduate degree are described under the Engineering Undesignated description.

Bachelor of Science in Engineering/Master of Science

The integrated BS/MS program is intended for highly motivated and qualified undergraduate students who wish to pursue an advanced degree. Students admitted to the program may, in the senior year, take up
to nine credits of graduate courses that will count toward both BS and MS requirements.

Bachelor of Science in Engineering/ Master of Engineering

Students who have received a BS degree in engineering or computer science from the Case School of Engineering, and who are accepted for admission into the Master of Engineering (ME) degree program within a period of 24 months after graduation, are entitled to transfer up to six credit hours of course work from their BS degree to their ME degree program.

The courses to be considered for transfer should be specified at the time of application to the ME program, and require approval by the director of the Master of Engineering Program and the Dean of Engineering. Once approved, a request for an internal transfer of credit will be sent to the Registrar, and these courses will be included in the student’s planned program of study for the ME degree.

Master of Engineering

The Master of Engineering Program is a graduate degree program that targets engineers currently employed in industry. The objective of this program is to provide engineers in industry with technical as well as business, management, and teamwork skills. The program differs from a traditional Master of Science degree in engineering by combining core courses that focus on the engineering-business environment and technical elective courses that concentrate on contemporary industrial practice rather than on research.

The Master of Engineering Program prepares students to enhance their role as corporate leaders and provides an environment in which practicing engineering professionals can address the increasingly wide range of technical, management, financial and interpersonal skills demanded by an ever-expanding and diverse global industry base.

The Master of Engineering Program requires 30 credit hours of coursework that include 18 credit hours of online core courses and 12 credit hours of technical electives that are chosen from focus areas (see below). It is possible to complete the Master of Engineering degree program within a two-year (six semester), part-time, program of study, although most students choose to complete the program over a seven-nine semester period.

The program is composed of online and traditional on-campus classes, with core courses aimed at equipping participants with knowledge on how engineering is practiced in contemporary industry, and technical electives that provide depth in a chosen specialty area. All core courses are provided in an exclusively online format. The technical elective sequences for Biomedical Engineering (EBME), Engineering Innovation, Management and Leadership (EIIML), Mechanical Engineering (EMAE) and Systems & Control Engineering (SCS) are also in an online format. Other technical elective courses are held on campus in the late afternoon or evening hours, and in an online distance-learning format to minimize disruption at the workplace and home. Because the program makes extensive use of computers, participants need to have access to computer facilities.

For more details about the exclusively online Master of Engineering degree program, visit online-engineering.case.edu/masters/.

For local students wanting to take on-campus technical electives, please contact the Program Director, Sree N. Sreenath (nx6@case.edu).

Curriculum

The program consists of a set of six core courses and a four-course technical elective sequence (a total of 30 credit hours are required). The core courses provide a common base of study and experience with problems, issues, and challenges in the engineering business environment. The technical course sequence provides an opportunity to update disciplinary engineering skills and to broaden interdisciplinary skills. Up to six transfer credits may be approved for graduate-level courses taken at Case Western Reserve or another accredited university.

Core Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPOM 400</td>
<td>Leadership and Interpersonal Skills</td>
<td>3</td>
</tr>
<tr>
<td>EPOM 401</td>
<td>Introduction to Business for Engineers</td>
<td>3</td>
</tr>
<tr>
<td>EPOM 403</td>
<td>Product and Process Design and Implementation</td>
<td>3</td>
</tr>
<tr>
<td>EPOM 405</td>
<td>Applied Engineering Statistics</td>
<td>3</td>
</tr>
<tr>
<td>EPOM 407</td>
<td>Engineering Economics and Financial Analysis</td>
<td>3</td>
</tr>
<tr>
<td>EPOM 409</td>
<td>Master of Engineering Capstone Project</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Total Units</td>
<td>18</td>
</tr>
</tbody>
</table>

Technical Electives

Four courses are chosen from technical concentration areas. For detailed course offerings in these areas, visit online-engineering.case.edu/masters/.

Master of Engineering and Management

The Master of Engineering and Management (MEM) program provides the business context and leadership skills needed to uniquely position graduates for rapid advancement in technology-orientated organizations. MEM is the result of years of research and interviews with over 110 professionals and twenty-eight corporations across the country. This interdisciplinary, joint degree program combines the problem-solving rigor of the Case School of Engineering and the organizational insights of the Weatherhead School of Management. MEM is a 1 year, lock-step program that starts every year in June. This program is designed for engineering majors only and is focused on developing the high-impact talent companies are actively seeking. Students can enter this program after their junior year or upon graduation.

Curriculum

The program includes 42 credit hours of graded coursework. The 10-course core sequence makes up 30 of the required credit hours. For the remaining 12 credit hours, students can choose from any 400 level Case School of Engineering course for which prerequisites are met or select Weatherhead School of Management courses. Below is the list of required core courses and a representative sample of elective courses.

Required Core Courses (30 credit hours)

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIME 400</td>
<td>Leadership Assessment and Development (LEAD)</td>
<td>3</td>
</tr>
<tr>
<td>IIME 405</td>
<td>Project Management</td>
<td>3</td>
</tr>
<tr>
<td>IIME 410</td>
<td>Accounting, Finance, and Engineering Economics</td>
<td>3</td>
</tr>
</tbody>
</table>
when any change in the original plan occurs. It will be routed for appropriate approvals. Students must submit a Planned Program of Study via the Student Information System where advisor, the department chair, and the dean of graduate studies.

All Master of Science degree programs require the submission of a Specialized online degrees are available in the following disciplines:

- Business Administration and Management
- Engineering Management
- Information Systems
- Information Technology
- Supply Chain Management

For these students, a minimum of 30 hours of coursework and the final evidence of this experience in the form of a publication or internal report. Special Problems course may be waived for students who have had industrial design or research experience and who submit sufficient evidence of this experience equivalent to a thesis may petition the Graduate Committee of the Case School of Engineering for substitution of nine hours of coursework for the thesis requirement. In this case, the thesis examination above is replaced by a similar examination covering the submitted research work and publications. Additional requirements may be specified by individual degree programs.

**Master’s Comprehensive Plan (Plan B)**

Students may pursue either a project or non-project track under this option. Minimum requirements for the degree of Master of Science in a major field under this plan are one of the following:

**Project track**

Completion of 30 hours of graduate coursework at the 400 level or higher, including three to six hours of Special Problems. Special Problems coursework must consist of an engineering project approved by the chair of the department offering the degree and may be carried out at the student’s place of employment with nominal supervision by a faculty advisor or in the school’s laboratories under direct supervision. The project must culminate in a written report and examination by at least three professors, plus approval by the chair of the department offering the degree. The Special Problems course may be waived for students who have had industrial design or research experience and who submit sufficient evidence of this experience in the form of a publication or internal report.

For these students, a minimum of 30 hours of coursework and the final oral examination covering the submitted publications or reports as well as related course material will be required for the master’s degree.

**Non-project track**

Completion of 30 hours of graduate coursework at the 400 level or higher, not including Special Problems coursework, must, also, pass satisfactorily a comprehensive examination to be administered by the department or curricular program committee. The examination may be written or oral, or both. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master’s Comprehensive Exam before taking the examination.

**Distance Education**

The Case School of Engineering offers four graduate degree programs exclusively online, giving working engineers the opportunity to advance their careers from anywhere.

Specialized online degrees are available in the following disciplines:
The programs are designed for working professionals and can be completed in fewer than two years. All courses are taught by the same world-renowned faculty who teach graduate students on campus. With the same in-depth, rigorous content delivered in a convenient online format, students who participate in the online programs receive the same robust education and training as traditional on-campus master’s students.

Learn more and apply. (https://online-engineering.case.edu)

Additional Distance Learning Opportunities
In addition to the online-exclusive programs, the Case School of Engineering offers select classes in its campus-based graduate degree programs in a convenient online format designed for students who need additional flexibility.

Learn more about available online courses. (http://engineering.case.edu/current-students/distance-learning/registration)

Doctor of Medicine/Master of Science
(http://casemed.case.edu/admissions/education/dual_programs.cfm?program_id=11)

Medicine is undergoing a transformation based on the rapid advances in science and technology that are combining to produce more accurate diagnoses, more effective treatments with fewer side effects, and improved ability to prevent disease. The goal of the MD/MS in Engineering is to prepare medical graduates to be leaders in the development and clinical deployment of this technology and to partner with others in technology-based translational research teams. For further information, see the MD/MS Program in the Biomedical Engineering graduate section of this bulletin (p. 28). Interested students should apply through the biomedical engineering department.

Doctor of Philosophy

The student's PhD program should be designed to prepare him or her for a lifetime of creative activity in research and in professional engineering practice. This may be coupled with a teaching career. The mastery of a significant field of knowledge required to accomplish this purpose is demonstrated by an original contribution to knowledge embodied in a thesis and by satisfactory completion of a comprehensive course program which is intensive in a specific area of study and includes work in other areas related to, but not identical with, the major field. The necessity for breadth as well as depth in the student's education cannot be overemphasized. To this end, any engineering department may add additional requirements or constraints to ensure depth and breadth appropriate to its field.

No student may be admitted to candidacy for the PhD degree before approval of his or her Planned Program of Study via the Student Information System. After this approval has been obtained, it is the responsibility of the student’s department to notify the dean of graduate studies of his or her admission to candidacy after the student has fulfilled any additional department requirements. Minimal requirements in addition to the university requirements are:

1. The minimum course requirement beyond the BS level is 36 credit hours of courses taken for credit, at least 18 hours of which must be taken at Case Western Reserve University. The following courses taken for credit will be acceptable for a PhD program of study:
   i. All 400-, 500-, and 600-level courses
   ii. Approved graduate-level courses taken at other institutions
2. A minimum depth in basic science equivalent to six semester hours (for credit) is required. This requirement is to be satisfied by courses that have been previously approved by the faculty of the department in which the student is enrolled.
3. The requirement for breadth is normally satisfied by a minimum of 12 semester hours of courses (for credit) outside the student’s major area of concentration as defined by the student’s department and does not include courses taken to fulfill the basic science requirement.
4. A minimum of three teaching experiences as defined by the student’s department. All programs of study must include departmental 400T, 500T, and 600T courses to reflect this requirement. All students fulfilling teaching duties must complete UNIV 400A or UNIV 400B.
5. The minimum requirement for research is satisfied by at least 18 hours of thesis (701) credits.
6. A cumulative quality-point average of 3.0 or above in all courses taken for credit as a graduate student at Case Western Reserve University (excluding grades in thesis research and grades of R) is required for the award of the doctoral degree.

Qualifying Examination
The student must pass a qualifying examination relevant to his or her area of study as designated by the curricular department with which he or she is affiliated. For students who obtain the MS degree from Case Western Reserve University, the qualifying examination should be taken preferably before the end of the student’s fourth semester of graduate study but no later than the end of the fifth semester at the university. For students entering with the master’s degree, the examination should be taken no later than the end of the third semester at the university.

Planned Program of Study

Each student is required to submit a Planned Program of Study, detailing his or her coursework, thesis schedule, and qualifying examination schedule and indicating that all the minimum requirements of the university and the faculty of the Case School of Engineering are satisfied. This Planned Program of Study must be submitted via the Student Information System for approval before registering for the last 18 credits hours of the program.

If the student is pursuing the PhD degree without acquiring the MS degree, a petition to waive the requirement of the MS degree should be approved by the departmental advisor and the chair and submitted to the dean of graduate studies. All required courses taken at the university beyond the BS degree should be shown on the Planned Program of Study
with the grade if completed. If the requirements are to be fulfilled in ways other than the standard described above, a memorandum requesting approval should be submitted to the dean of graduate studies.

The Planned Program of Study must be submitted within one semester after passing the qualifying examination.

**Doctor of Medicine/Doctor of Philosophy (http://mstp.case.edu)**

Students with outstanding qualifications may apply to the MD/PhD program. Students interested in obtaining a combined MD/PhD, with an emphasis on basic research in biomedical engineering are strongly encouraged to explore the Medical Scientist Training Program (https://case.edu/medicine/admissions-programs/md-phd-program) (MSTP), administered by the School of Medicine. For further information, please see the Medical Scientist Training Program (MSTP) section of this bulletin (http://bulletin.case.edu/schoolofmedicine/dualdegreeprograms/#medicalsciencetrainingprogramtext). Interested students should apply through the MSTP office (mstp@case.edu) in the School of Medicine.

**Graduate Certificates**

Graduate Certificates are discipline independent and intended to enable knowledgeable entry into the field of study. They are prescribed 3-course, 9-credit subsets of our MS degree offerings

- **Wearable Computing**
- **Wireless Health**

For more details, please refer to the Graduate Certificate (http://engineering.case.edu/sandiego/gc) information on the Case School of Engineering - San Diego website.

**Interdisciplinary Research Centers**

Interdisciplinary research centers act as intensive incubators for students and faculty doing research and studying applications in specialized areas. Research centers and research programs at the Case School of Engineering have been organized to pursue cutting-edge research in collaboration with industrial and government partners. The transfer of technology to industry is emphasized in all the centers.

The educational programs of these centers encompass the training of graduate students in advanced methods and strategies, thus preparing them to become important contributors to industry after graduation; the involvement of undergraduates in research; the presentation of seminars that are open to interested members of the community; and outreach to public schools to keep teachers abreast of scientific advances and to kindle the interest of students in seeking careers in engineering.

**Advanced Manufacturing and Mechanical Reliability Center (AMMRC)**

White Building (7205)
Phone: 216.368.4234
John J. Lewandowski, Director
john.lewandowski@case.edu

Website: http://ammrc.case.edu

The Advanced Manufacturing and Mechanical Reliability Center (AMMRC) was established to provide advanced manufacturing (e.g. deformation processing, extrusion, forming, etc.) and mechanical characterization (e.g. mechanical testing, reliability testing, fatigue, etc.) expertise to the CWRU campus, medical, industrial, legal, outside university, and government laboratory communities. The center, housed in the Charles M. White Metallurgy building, currently maintains equipment valued in excess of $4.5M and has been accessed by the local, national, and international communities. The CWRU campus community can access the facility via the use of a valid CWRU university account number that will be charged at an internal rate for machine time, including set up and any technician time involved. Long-term testing can be provided at pro-rated charges in consultation with the center directors. Arrangements can be made to train users on the equipment and reserve time for equipment use by contacting the center co-director. Outside (i.e. non-CWRU) users can access the facility via a number of different mechanisms by contacting the center director.

In general, the center is capable of mechanically evaluating and deformation processing materials that range in size scale from the micrometer range up through bulk quantities. This unique facility enables mechanical characterization at loading rates as low as one micrometer/ hour (i.e. rate of fingernail growth!) up through impact (e.g. 3-4 meters/sec) at temperatures ranging from -196°C (i.e. liquid nitrogen) up to 1400°C. Hot microhardness testing up to 1000°C is available. Monotonic as well as cyclic fatigue testing is possible in addition to evaluations of mechanical behavior and processing with superimposed pressures up to 2 GPA. Novel high-rate and multiple-deformation sequence forging simulations are possible with the use of a multi-actuator forging simulator, in addition to sheet metal forming experimentation with independent control of forming rate and blank hold down force. Hot extrusion is also possible at temperatures up to 900°C on 0.5” diameter billets. Materials systems that have been investigated span the range of organic and inorganic materials, including metals, ceramics, polymers, composites, electronic materials, and biomedical materials systems. Descriptions of specific equipment and capabilities are provided with the website link.

**Advanced Platform Technology (APT) Center**

Louis Stokes Cleveland Veterans Affairs Medical Center
10701 East Boulevard, Mail Stop 151 W/APT
Cleveland, Ohio 44106
Phone: 216.707.6421 Fax: 216.707.6420
Ronald J. Triolo, Executive Director
ronald.triolo@case.edu

The Advanced Platform Technology (APT) Center at the Louis Stokes Cleveland Veterans Affairs Medical Center (LSCVAMC) is one of 13 designated Centers in the Rehabilitation Research and Development Service. The APT Center focuses on serving veterans with sensorimotor dysfunction, cognitive impairment, or limb-loss using cutting-edge technologies and rehabilitation techniques, translating them from proof of concept to viable clinical options. Advances in material science, microfabrication and microsystem design, neural engineering, mechanics and communications are captured and integrated for applications in prosthetics/orthotics, neural interfacing, wireless health monitoring and maintenance and all forms of enabling and emerging technologies. The APT Center is able to provide or facilitate access to the following resources:
1. Neural modeling and analysis of interface designs
2. Polymer and bioactive material development
3. Microelectromechanical (MEMS) systems design and fabrication
4. 3-D and laser printing/prototyping, mechanical testing and dynamic simulation
5. Pre-clinical in vitro and in vivo verification of device performance
6. Circuit, sensor and software design and fabrication
7. System validation and design control documentation
8. Professional engineering support and project management
9. Administrative support for intellectual property protection, regulatory affairs, and quality systems

The APT Center was established in 2005 as a collaboration between the LSCVAMC and Case Western Reserve University (CWRU). Over 50 Engineers and Clinician Scientists at the LSCVAMC, CWRU, Cleveland Clinic, University Hospitals, Cleveland State University, Kent State University, University of Michigan, and Cornell University are affiliated with the APT Center and contribute to its mission.

**Center for Advanced Polymer Processing (CAPP)**

Kent Hale Smith Building, 3rd floor  
Phone: 216.368.6372 Fax 216.543.4202  
Joao Maia, Director  
joao.maia@case.edu

CAPP is a state-of-the-art center for advanced polymer blending and compounding and reactive extrusion at CWRU able to perform basic research and applied research and development in support of the Ohio and US plastics industry. The main tools of CAPP are:

- State-of-the-art sensors that allow multiple rheological, physical, chemical and morphological quantities to be measured along the screw axis of twin-screw extruders;
- Advanced multi-scale computational simulation capabilities to build physical-chemical-structural models of polymer systems under flow in realistic polymer transformation processes;
- Integration of on-line sensors and multi-scale softwares to develop new advanced and functional multiphase complex materials or optimize the performance of existing ones.

**Center for Biomaterials**

202 Wickenden Building (7207)  
William Marx, Interim Director  
william.marx@case.edu

Anirban Sen Gupta, Associate Director  
Phone: 216.368.4564  
anirban.sengupta@case.edu

The Center for Biomaterials carries out research and development projects to investigate new biomaterials, tissue engineered materials, and targeted drug delivery systems for use in cardiovascular applications and implants. The Center for Biomaterials also provides researchers access to shared use facilities, which includes high-resolution microscopy such as AFM, molecular spectroscopies, surface analysis, and polymer and peptide synthesis capabilities. The chemical and mechanical interface between the biomaterial and the host tissue are the focus of major study, with the goals being to improve biologic function and biocompatibility in the response of the human body to implants. Current projects include investigation of thrombosis (blood clotting) and infection mechanisms due to cardiovascular prosthesis, biomimetic design of novel biomaterials for cardiovascular and neural implants; and cardiovascular and neural tissue engineering based on biomimetic designs. Studies at the cell and molecular level assist our understanding of the underlying mechanisms so that novel biomedical materials may be designed, prepared, and characterized.

**Center for Computational Imaging and Personalized Diagnostics (CCIPD)**

Wickenden Building Room 523  
Phone: 216.368.8519  
Anant Madabhushi, Director  
anant.madabhushi@case.edu

The Center of Computational Imaging and Personalized Diagnostics at Case Western Reserve University is involved in various different aspects of developing, evaluating and applying novel quantitative image analysis, computer vision, signal processing, segmentation, multi-modal co-
Center for Dielectrics and Energy Storage (CDES)

312 Kent Hale Smith Building  
Phone: 216.368.5861  
Lei Zhu, Director  
lxz121@case.edu

CDES mission is to discover, develop, and translate novel dielectric technologies for energy storage and capacitor applications. Researching high energy density, high temperature, and low loss dielectric film capacitors, we integrate these innovations with storage devices, hybrid electric vehicles, multi-megawatt power conditioning, pulsed power, and high energy physics applications. Originating from the Center for Layered Polymeric Systems (CLiPS), a National Science Foundation Science and Technology Center focuses on research, innovation, and education through a unique multilayer film technology, CDES extends this technology into new energy frontiers.

CDES has access to state-of-the-art equipment, which includes process equipment for fabricating, stretching, and testing dielectric films, including:

- Novocontrol Concept 80 Broadband Dielectrics Spectrometer
- Radiant Premier II Ferroelectric Tester
- Bruckner Kato IV Biaxial Stretcher

In addition to research, CDES plays a significant role in educating undergraduate students, graduate students, and post-doctoral associates to work in advanced energy material fields.

Center for Layered Polymeric Systems (CLiPS)

NSF Science and Technology Center  
420 Kent Hale Smith Building (7202)  
Phone: 216.368.4203 Fax 216.368.6329  
Eric Baer, Director  
eric.baer@case.edu

CLiPS researchers and educators work together to accomplish the Center’s mission of advancing the nation’s science and technology agenda through development of new materials systems and for educating a diverse American workforce through interdisciplinary education programs.

CLiPS research focuses on exploration of multilayered polymeric systems at the micro- and nano-layer levels and has revealed unique properties and capabilities that are different, and often not predicted, from systems involving the same materials on a larger scale. Technology refined within CLiPS allows the production of films and membranes composed of hundreds or thousands of layers. These extremely thin layers promote interactions approaching the molecular level between the materials used in the process.

The research activities are organized into five platforms to exploit the microlayer and nanolayer structures: (1) Rheology and New Processing focuses on integrating rheology into the multilayering process, and will explore combinations of rheologically dissimilar materials to create new polymer-based structures; (2) advanced Membranes and Transport Phenomena that exploit the layered hierarchy to achieve unique transport properties; (3) novel Optic and Electronic Systems based on the advanced layered materials; (4) Science and Technology Initiatives that probe a fundamental understanding and explore new opportunities for the layered structures; and (5) Templated Interfaces and Reactions looking at polymer materials that are amenable to patterning and ordering, and exhibit a specific field response. Of particular interest are polymer systems and nanomaterials that are appropriate for biological applications.

CLiPS was established in 2006 with funding by the National Science Foundation as a Science and Technology Center. It is the first NSF STC ever to be established at Case Western Reserve University. CLiPS is a national center involving close partnership with the University of Texas, Fisk University, the University of Southern Mississippi, and the Naval Research Laboratory, and an important educational partnership with the Cleveland Metropolitan School District.

Cleveland Functional Electrical Stimulation Center (FES)

10701 East Boulevard, Cleveland, Ohio 44106  
Phone: 216.231.3257 Fax: 216.231.3258  
Robert J. Kirsch, Executive Director  
info@FEScenter.org

Functional Electrical Stimulation (FES) is the application of electrical currents to either generate or suppress activity in the nervous system. FES can produce and control the movement of otherwise paralyzed limbs, for standing and hand grasp, activate visceral bodily functions such as micturition, create perceptions such as skin sensibility, arrest undesired activity, such as pain or spasm, facilitate natural recovery, and accelerate motor relearning. FES is particularly powerful and clinically relevant since many people with neurological disabilities retain the capacity for
neural conduction and are thus amenable to this intervention. The center focuses its activities in four major areas:

- Fundamental studies to discover new knowledge
- Enabling technologies for clinical application or the discovery of knowledge
- Clinical research that applies this knowledge and technology to individuals with neurological dysfunction
- Transfer of knowledge and technology to the clinical community and to industry

The FES Center was established as a VA RR&D Center of Excellence in 1991 and is based at the Louis Stokes Cleveland VAMC (VAMC). The center is a consortium with four institutional partners: VAMC, Case Western Reserve University (CWRU), the MetroHealth Medical Center (MHMC), and University Hospitals of Cleveland (UHC). The center accomplishes its mission by integrating and facilitating the efforts of scientists, engineers, and clinicians through common goals and directions in the major clinical areas, and by providing mechanisms to accomplish these goals across the institutional partners.

**Control and Energy Systems Center (CESC)**

Olin Building, 6th Floor  
Phone: 216.368.5122  
Mario Garcia-Sanz, Director  
mario@case.edu  
Website: http://cesc.case.edu

With an interdisciplinary and concurrent engineering approach, the Control and Energy Systems Center (CESC) focuses on bridging the gap between fundamental research and applied industrial projects in Advanced Control and Systems Engineering, with special emphasis in energy innovation, wind energy, power systems, water treatment plants, sustainability, spacecraft, environmental and industrial applications. Fundamental research is conducted to gain knowledge and understanding on multi-input-multi-output systems, distributed parameter systems and nonlinear plants with uncertainty, and to develop new methodologies to design quantitative robust controllers to improve the efficiency and reliability of such systems.

The CESC’s expertise has been applied to real-world problems with industrial partners and space agencies in the following main areas:

- Multi-Megawatt Onshore and Offshore Wind Turbines  
- Airborne Wind Energy Systems  
- Renewable Energy Plants, Advanced Energy Systems  
- Power System Dynamics and Control, Grid Integration, Energy Storage  
- Large Radio Telescope Control, Optical Telescope Control  
- Formation Flying Spacecraft, Satellites with Flexible Appendages  
- Wastewater Treatment Plants, Desalination Systems  
- Heating Systems, Fluid Dynamics  
- Robotics, Parallel Kinematics

The CESC’s capabilities and equipment include:

- Fully instrumented wind tunnel to test prototypes at wind speeds up to 20 m/s
- Lab-scale wind turbine blade manufacturing units
- State-of-the-art computer programs for commercial wind turbine design
- Aerodynamics, Solid Modeling, and Electrical Design CAD/CAE software
- Advanced software to design robust QFT control systems
- Software for analysis and simulation of dynamic systems
- Multiple laboratory scale wind turbines with a variety of collinear and orthogonal rotors, electrical generators, gearboxes, sensors, actuators and hierarchical real-time torque/pitch/yaw control systems
- Lab-scale wind farms with flexible configurations
- Fully-controlled 6-DOF Stewart platform for lab-scale Floating Wind Turbine experimentation
- Laboratory helicopter to test advanced control systems

**Electronics Design Center (EDC)**

112 Bingham (7200)  
Phone: 216.368.2935 Fax: 216.368.8738  
Chung-Chiu Liu, Director  
chung-chiu.liu@case.edu

The Electronics Design Center (EDC) is a multi-disciplinary educational and research center focusing on the applications of microfabrication processing to the advancement of chemical and biological microsystems specializing in application-oriented electrochemical-based biosensors. The center has complete thick film and thin film processing facilities, including screen printing, ink jet printing, and sputtering equipment. Other facilities supporting the microfabrication processing are also readily available. The EDC is a resource for industrial and academic researchers, offering access to equipment, laboratories, and trained staff.

**Great Lakes Energy Institute (GLEI)**

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Phone: 216.368.0748  
Alexis Abramson, Director  
alexis.abramson@case.edu

The Great Lakes Energy Institute empowers faculty, students, and partners to catalyze breakthroughs in energy sustainability that address the most pressing problems facing our world. Since 2008, GLEI has helped catalyze a five-fold increase in energy research, won awards from NSF, DOE, (ARPA-E, EERE, OE), Ohio Third Frontier and other organizations, attracted over $80 million in awards, worked with over 100 different industry partners, and encouraged multidisciplinary proposals throughout the university. At the heart of these efforts are over 90 engaged faculty, hailing from engineering, arts & sciences, management, and law. And while GLEI’s work supports all types of energy, the focus lies in five priority areas:

**Future Power** - CWRU’s energy program is underpinned by research in power systems. Strengths in controls, sensors, and electronics provide a core foundation for smart grid connectivity of energy and storage.

**Energy Storage** - Storage research builds on historical strengths in electrochemistry, materials and lifetime and degradation science. Recent research awards include ARPA-E and DOE.
Solar - Research in next-generation photovoltaics (PV) focuses on organics and lifetime and degradation science, stemming from a strong reputation in materials, research, and development.

Wind Energy - Wind energy emphasizes offshore deployment and is founded on wind and ice measurement, controls, power management, and grid interface expertise. Much of this work is supported by DOE awards and the State of Ohio.

Oil and Gas - Research focuses on technologies that enhance safe extraction, transport, and processing of shale gas and oil in Ohio. Strengths are present in macromolecules, sensors, corrosion-resistant casings, cementitious materials, and modeling and simulation of hydro-fracking process.

The role of CWRU in energy also touches economic development and education. Through research and investment, university spin-outs are poised to contribute to a new energy economy while working toward a clean and sustainable future. Students undertake key roles in the research and commercialization of the energy technologies contributing to worldwide impact.

Materials for Opto/Electronics Research and Education (MORE) Center
616 White Building (7204)
Phone: 216.368.4007
Ina Martin, Operations Director
ina.martin@case.edu

Kenneth Singer, Faculty Director
kenneth.singer@case.edu (kenneth.singer@case.edu)

The Materials for Opto/Electronics Research and Education (MORE) Center advances science and innovation with facilities and expertise enabling the fabrication and characterization of materials and devices for emerging electronic and optoelectronic technologies, including solar cells and lighting. Located in the Charles M. White Metallurgy Building, the MORE Center is a hub for undergraduate and graduate research, education, and collaboration. The center has 21 tools available for both direct use and service work; in addition to a suite of thin film deposition options, the MORE Center has large-area profilometry, ellipsometry, mechanical testing, and microscopy characterization tools, a cleanroom facility, electron and photolithography capabilities, and inert gloveboxes for work with air-sensitive materials.

Established in 2011, the MORE Center has amassed over 300 users from 40 research groups across the College of Arts and Sciences, the Case School of Engineering, and the CWRU School of Medicine. The MORE Center is open to internal and external academic and industrial users.

Microfabrication Laboratory (MFL)
342 Bingham Building (7200)
Phone: 216.368.6117 Fax: 216.368.6888
Christian Zorman, Director
christian.zorman@case.edu

MFL houses a state-of-the-art facility that provides the latest in microfabrication and micromachining processes. The laboratory focuses on the applications of microfabrication and micromachining technology to a wide range of sensors, actuators, and other microelectromechanical (MEMS) systems. In addition to silicon-based technology, the laboratory has a unique strength in silicon carbide micromachining that is particularly valuable for applications in harsh environments. To support the development of flexible microsystems, polymer micromachining is also available. Undergraduate students, graduate students, and post-doctoral assistants use the laboratory’s facilities to carry out their research or special projects.

Researchers not affiliated with CWRU can also use the laboratory through a facilities use agreement.

National Center for Space Exploration Research (NCSER)
21000 Brookpark Rd., MS 110-3
Phone: 216.433.5031
Mohammad Kassemi, Director
mohammad.kassemi@case.edu

The National Center for Space Exploration Research (NCSER) is a collaborative effort between the Universities Space Research Association (USRA), Case Western Reserve University (CWRU), and NASA Glenn Research Center (GRC) that under the NASA Advanced Research and Technology Service (ARTS) contract provides GRC with specialized research and technology development capabilities essential to sustaining its leadership role in NASA missions. Expertise resident at NCSER includes reduced gravity fluid mechanics, reduced gravity combustion processes; heat transfer, two-phase flow, micro-fluidics, and phase change processes; computational multiphase fluid dynamics, heat and mass transfer, computational simulation of physico-chemical fluid processes and human physiological systems. This expertise has been applied to:

- Cryogenic fluid management
- On-orbit repair of electronics
- Spacecraft fire safety
- Exploration life support
- Energy storage
- Dust management
- Thermal management and control
- Environmental monitoring/control
- ISS experiment development Integrated system health monitoring
- Astronaut health
- Planetary Surface Mobility
- In situ resource utilization
- Materials synthesis
- Bio-fluid mechanics
- Biosystems modeling
- Fluid-Structural-Interaction and tissue mechanics in physiological systems

Neural Engineering Center (NEC)
112 Wickenden (7207)
Phone: 216.368.3974 Fax: 216.368.4872
Dominique Durand, Director
dominique.durand@case.edu

The research mission of the center is to bring to bear combined tools in physics, mathematics, chemistry, engineering, and neuroscience to analyze the mechanisms underlying neuronal function and to solve the clinical problems associated with neuronal dysfunction. Research areas include: Neuromodulation, Neuroprostheses, Quantitative
Neurophysiology, Neural Dynamics, Neuro-Mechanical Systems, Neural Regeneration, Neural Interfacing, Neural Imaging and Molecular Sensing, Neuro-Magnetism, and Systems Neuroscience. The education mission of the center is to provide engineers and scientists with an integrated knowledge of engineering and neuroscience capable of solving problems in neuroscience ranging from the molecules to the clinic. The center is also an outlet for technology transfer of new ideas to be commercialized by industrial partners. The center’s goals are accomplished by fostering interdisciplinary research between clinicians, scientists, students and local industry, educational experiences including didactic material, laboratory experience, and clinical exposure, and close ties to industrial partners.

**Nitinol Commercialization Accelerator (NCA)**

White Building (7205)
Phone: 216.368.4234
John J. Lewandowski, Director
john.lewandowski@case.edu
Matthew A. Willard, Co-Director
matthew.willard@case.edu
Website: http://amnrc.case.edu/node/51

The Ohio Third Frontier Wright Projects Program has funded the Nitinol Commercialization Accelerator (NCA), a collaborative effort between the Cleveland Clinic, CWRU, University of Toledo, NASA Glenn Research Center, and Norman Noble, Inc. in order to develop a better understanding of the metallurgical processing and mechanical characterization of nitinol for use in biomedical and aerospace applications. Biomedical applications range from orthodontia to implantable devices while higher temperature shape memory alloys are of interest for aerospace. The collaboration is designed to create synergy amongst collaborators in the research and development of nitinol products.

The laboratory housed at CWRU’s Material Science and Engineering Department contains processing and characterization (thermal and mechanical) equipment that allows for the manufacture and analysis of nitinol products. Processing equipment includes a vacuum arc casting unit, vacuum heat treatment system, and hot extrusion capabilities. Thermal characterization equipment includes a high-temperature Differential Scanning Calorimeter (DSC) while mechanical characterization equipment for testing wire/foil includes a number of flex bending fatigue machines, rotary bending fatigue machines, and tabletop tension testing machines.

The Cleveland Clinic and NASA Glenn Research Center also house equipment associated with the NCA program including Raydiance-Rofin Femtosecond Laser, Techne FB-08 Precision Calibration Bath, MTS Cryochamber and Grips, and an Aramis/Optotrac Certus 3D Strain Mapping system.

**SDLE Research Center**

Labs: White Building, 5th Floor / Sun Farm: CWRU West Campus
Phone: 216.368.3655/216.368.0374
Roger H. French, Director
roger.french@case.edu

Christopher Littman, Commercialization & Operations Director
christopher.littman@case.edu

The SDLE Research Center was established in 2011 with funding from Ohio Third Frontier and is dedicated to advancing the field of lifetime and degradation science. The research center activities focus on durability and degradation of environmentally exposed, long-lived materials and technologies such as photovoltaics (PV), energy efficient lighting, and building envelope applications. The Center develops real-time and accelerated protocols for exposure to solar radiation and related environmental stressors to enable the evaluation of the environmental durability and lifetime of materials, components, and products. Data scientists identify statistically significant relationships using a data analytics platform (Energy-CRADLE) developed in the center. Researchers perform post-exposure optical and thermo-mechanical measurements to develop quantitative mechanistic models of degradation processes. The SDLE Research Center’s capabilities and equipment include:

- Outdoor solar exposures: SunFarm with 14 dual-axis solar trackers with multi-sun concentrators, and power degradation monitoring
- Solar simulators for 1-1000X solar exposures
- Multi-factor environmental test chambers with temperature, humidity, freeze/thaw, and cycling
- A full suite of optical, interfacial, thermo-mechanical and electrical evaluation tools for materials, components, and systems

**Swagelok Center for Surface Analysis of Materials (SCSAM)**

110 Glennan Building
Phone: 216.368.3868
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Amir Avishai, Director
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The Swagelok Center for Surface Analysis of Materials is one of Case Western Reserve University's largest core facilities, providing a variety of instrumentation for microstructural and compositional characterization of materials as well as surface and near-surface chemical analysis. A staff of professionals are available to assist and train academic researchers and commercial users of the Center’s equipment. Fully trained users are permitted independent access to the instruments, while users with particularly difficult samples or those who are unsure how to obtain the best possible data can utilize the services of staff experts. Some of the routine services offered include guidance with sample preparation, technical assistance to obtain data, and data analysis. Additionally, the expert staff are available to meet with research groups to assist with acquiring data needed for proposal submission as well as consulting and developing methods tailored to fit specific research needs.

The Center is administered by the Case School of Engineering and used by undergraduate students, graduate students, post-doctoral researchers. SCSAM instruments are utilized by more than 40% of the Engineering School’s faculty as well as researchers from the College of Arts and Sciences, the School of Medicine and the Dental School. Further, the Center serves as a micro-characterization hub for over 100 external commercial and non-profit entities, including the NASA Glenn Research Center, the Cleveland Clinic, numerous Ohio universities, and over 70 industrial R&D laboratories. Combined internal and external usage of the Center exceeds 250 users each year. Instruments are housed in a
The instruments in the WERC Center include: Automation, Inc., Swiger Coil Systems LLC., and Wm. Sopko & Sons Co. Corporation, Parker Hannifin Corporation, Azure Energy LLC., Rockwell inaugural industrial partners: Cleveland Electric Laboratories, The Lubrizol Department of Energy. Additional support was provided by the following Department of Development Third Frontier Wright Project and the The WERC Center was established in 2010 with funding from the Ohio characterization and research platforms in operating wind turbines.

David H. Matthiesen, Director
Phone: 216.368.1366, Fax: 216.368.3209
Great Lakes Energy Institute
307 Olin Building
Commercialization (WERC) Center
Wind Energy Research and Commercialization (WERC) Center
307 Olin Building
Great Lakes Energy Institute
Phone: 216.368.1366, Fax: 216.368.3209
David H. Matthiesen, Director
david.matthiesen@case.edu

The WERC Center is a multidisciplinary center for use by students, faculty, and industry providing instrumentation for wind resource characterization and research platforms in operating wind turbines. The WERC Center was established in 2010 with funding from the Ohio Department of Development Third Frontier Wright Project and the Department of Energy. Additional support was provided by the following inaugural industrial partners: Cleveland Electric Laboratories, The Lubrizol Corporation, Parker Hannifin Corporation, Azure Energy LLC., Rockwell Automation, Inc., Swiger Coil Systems LLC., and Wm. Sopko & Sons Co.

The instruments in the WERC Center include:

- A continuous scan ZephIR LiDAR, manufactured by Natural Power. This instrument measures horizontal and vertical wind velocity along with wind direction at 15-second intervals at five user set heights up to 200 m.
- A Nordex N-54 wind turbine originally manufactured by Nordex in Germany. This 1.0MW utility-scale wind turbine has a gearbox drive generator, stall control blades with a 54 m rotor diameter, and a 70 m hub height. In addition, it has a 50kW generator for low wind generation. This wind turbine is located at an industrial site in Euclid, OH about 15 minutes from campus and began operation in March 2012.
- A Vestas V-27 wind turbine originally manufactured by Vestas in Denmark. This 225kW medium scale wind turbine has a gearbox drive generator, pitch controlled blades with a 27 m rotor diameter, and a 30 m hub height. In addition, it has a 200kW generator for low wind generation. This wind turbine is located at a test site in Euclid, OH about 15 minutes from campus and began operation in October 2012.
- Five meteorological measurement systems: 3 on campus; 1 with the off-campus wind turbines; and one at the City of Cleveland’s water intake crib located 3.5 miles offshore in Lake Erie.
- An ice thickness sensor that is deployed at the bottom of Lake Erie each fall and retrieved in the spring.

**Educational Facilities**

**CSE Portal** ([https://cseportal.cwru.edu](https://cseportal.cwru.edu))
The CSE Portal is a virtual computer lab available to students, faculty, and staff in the Case School of Engineering. The virtual lab utilizes Citrix technology to deliver Windows desktops and software applications to users at any time, in any location, and on any device. Users can run available applications, such as SolidWorks or Matlab, on Windows and Mac computers, as well as Android, iOS, and Windows tablets and smartphones. All application processing takes place on the secure CSE server infrastructure, so users experience consistent performance regardless of the device being used.

To use the CSE Portal from a desktop or laptop, simply go to the following website from your browser: [https://cseportal.cwru.edu](https://cseportal.cwru.edu)

For instructions on how to setup your tablet or smartphone to access the CSE Portal, please visit: [http://engineering.case.edu/it/citrix](http://engineering.case.edu/it/citrix)

For a complete list of applications currently available on the CSE Portal, please visit: [http://engineering.case.edu/it/available-applications-through-citrix-xenapp](http://engineering.case.edu/it/available-applications-through-citrix-xenapp)

**Nord Computer Laboratory**
The Nord Computer Laboratory is a general purpose computer facility, provided by the Case School of Engineering, open 24 hours a day, available to all CWRU students. The lab contains 56 Thin Clients running Windows 7 Enterprise. Software includes MS Office, MATLAB, SolidWorks, Aspen, MultiPhysics, ChemBioDraw, CES EduPack, and many others. Facilities for color printing, faxing, copying and scanning are provided.
Larry Sears and Sally Zlotnick Sears think[box] (http://thinkbox.case.edu)

Housed in the recently renovated Richey Mixon Building, the Larry Sears and Sally Zlotnick Sears think[box] houses all the resources budding innovators need to bring their ideas to life. At 50,000 square feet, this innovation-focused makerspace is one of the largest such facilities at any university in the world. Four floors are now open to the public, each dedicated to a specific stage of the innovation process, including open areas and meeting spaces for interaction, prototyping tools and equipment, a fabrication machine shop and project space. In the 2018 calendar year, two additional floors will open, dedicated to supporting entrepreneurship and student startup companies.

Vision

The vision of think[box] is to change the economic and social culture of the university and region by emphasizing cross-discipline and cross-institution collaborative endeavors that push creativity and innovation to their limits. Think[box] will provide a project-based learning environment where students from all courses of study have an opportunity to understand how innovation and creativity can lead to economic and social advancement. This exposure will encourage entrepreneurial thinking among our students, who will then be poised to become the leaders and innovators of the future. Simultaneously, think[box] will create an entrepreneurial environment where these ideas can be nurtured, developed, funded, and commercialized.

Mission

The mission of think[box] is to establish, on campus, a physical and cultural focal point that will:

- Provide an educational environment that fosters collaboration, creativity, and invention.
- Provide comprehensive resources for innovation and value creation.
- Create an engine for entrepreneurial growth within our community by identifying and nurturing the talents and expertise of CWRU students, faculty, and staff, as well as those of the surrounding community.

Department of Biomedical Engineering

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Robert F. Kirsch, Chair
bmedept@case.edu

The Department of Biomedical Engineering was established in 1968 at Case Western Reserve University, founded on the premise that engineering principles provide an important basis for innovative and unique solutions to a wide range of biomedical and clinical challenges. As one of the pioneering programs in the world, the department has established rigorous yet flexible educational programs that are emulated by many other institutions and is a national leader in cutting-edge research in several important areas. The cornerstone of the program is quantitative engineering and analytic methods for biomedical applications, a feature that distinguishes Biomedical Engineering from other biomedical science programs. The department's educational programs provide training in cellular and subcellular mechanisms for understanding fundamental physiological processes, in dealing with biomedical problems at the tissue and organ system level, and in integrating this knowledge in systems approaches to solving clinical problems.

Current degree programs include the BSE, MS, ME, combined BS/MS, PhD, MD/MS, and MD/PhD in Biomedical Engineering. In all of the BME programs at Case, the goal is to educate engineers who can apply engineering methods to problems involving living systems. The Case School of Engineering and the School of Medicine are in close proximity on the same campus, and Biomedical Engineering faculty members carry joint appointments in both of these two schools, participating in the teaching, research, and decision-making committees of both. The department is also tightly linked with several major medical centers (University Hospitals, Cleveland Clinic, VA Medical Center, and MetroHealth Medical Center) that are nearby. As a result, there is an unusually free flow of academic exchange and collaboration in research and education among the two schools and the four medical institutions. All of Case Western Reserve's BME programs take full advantage of these close relationships, which adds significant strength to the programs.

Mission

To educate leaders who will integrate principles of both engineering and medicine to create knowledge and discoveries that advance human health and well-being. Our faculty and students play leading roles ranging from basic science discovery to the creation, clinical evolution, and commercialization of new technologies, devices, and therapies. In short, we are “Engineering Better Health.”

Background

Graduates in biomedical engineering are employed in industry, hospitals, research centers, government, and universities. Biomedical engineers also use their undergraduate training as a basis for careers in business, medicine, law, consulting, and other professions.

Research

Several research thrusts are available to accommodate various student backgrounds and interests. Strong research collaborations with clinical and basic science departments of the university and collaborating medical centers bring a broad range of opportunities, expertise, and perspective to student research projects.

Biomaterials/Tissue Engineering/Drug and Gene Delivery

Fabrication and analysis of materials for implantation, including neural, orthopaedic, and cardiovascular tissue engineering, biomimetic materials, liposomal and other structures for controlled, targeted drug delivery, and biocompatible polymer surface modifications. Analysis of synthetic and biologic polymers by AFM, nanoscale structure-function relationships of biomaterials. Applications in the nervous system, the cardiovascular system, the musculoskeletal system, and cancer.

Biomedical Imaging

MRI, PET, SPECT, CT, ultrasound, acoustic elastography, optical coherence tomography, cardiac electrical potential mapping, human visual perception, image-guided intervention, contrast agents. In vivo microscopic and molecular imaging, and small animal imaging.

Biomedical Sensing

Optical sensing, electrochemical and chemical fiber-optic sensors, chemical measurements in cells and tissues, endoscopy.
Big Data Analytics and Health Informatics
Radiomics, Radiogenomics, computer-assisted diagnosis, digital pathology, co-registration, cancer detection, decision making, precision medicine, bioinformatics, image informatics, machine learning, pattern recognition, artificial intelligence, deep learning.

Neural Engineering and Neural Prostheses
Neuronal mechanisms; neural interfacing for electric and magnetic stimulation and recording; neural dynamics, ion channels, second messengers; neural prostheses for control of limb movement, bladder, bowel, and respiratory function; neuromodulation systems for movement disorders, epilepsy, pain mitigation, visceral functions; computational modeling and simulation of neural structures.

Transport and Metabolic Systems Engineering
Modeling and analysis of tissue responses to heating (e.g., tumor ablation) and of cellular metabolism related to organ and whole-body function in health (exercise) and disease (cardiac).

Biomechanical Systems
Computational musculoskeletal modeling, bone biomechanics, soft tissue mechanics, control of neuroprostheses for motor function, neuromuscular control systems, human locomotion, cardiac mechanics.

Cardiovascular Systems
Normal cardiac physiology, pathogenesis of cardiac diseases, cardiac development, therapeutic technologies, including cardiac regeneration; electrophysiological techniques, imaging technologies, mathematical modeling, gene regulation, molecular biology techniques; cardiac bioelectricity and cardiac biomechanics.

Primary Appointments

Robert F. Kirsch, PhD
(Northwestern University)
Professor and Chair, Executive Director, Functional Electrical Stimulation Center
Restoration of movement using neuroprostheses; neuroprosthesis control system design; natural control of human movements; brain-computer interfacing; biomechanics of movement; computer-based modeling; and system identification

A. Bolu Ajiboye, PhD
(Northwestern University)
Assistant Professor
Development and control of brain-computer-interface (BCI) technologies for restoring function to individuals with nervous system injuries

Eben Alsberg, PhD
(University of Michigan)
Professor of Biomedical Engineering and Orthopaedic Surgery
Biomimetic tissue engineering; innovative biomaterials and drug delivery vehicles for functional tissue regeneration and cancer therapy; control of stem cell fate decision; precise temporal and spatial presentation of signals to regulate cell behavior; mechanotransduction and the influence of mechanics on cell behavior and tissue formation; and cell interactions

James M. Anderson, MD (Case Western Reserve University), PhD (Oregon State University)
Professor of Pathology, Macromolecular Science and Biomedical Engineering; Distinguished University Professor
Blood and tissue/material interactions as they relate to implantable devices and biomaterials

James P. Basilion, PhD
(The University of Texas)
Professor of Biomedical Engineering and Radiology
High resolution imaging of endogenous gene expression; definition of "molecular signatures" for imaging and treatment of cancer and other diseases; generating and utilizing genomic data to define informative targets; strategies for applying non-invasive imaging to drug development; and novel molecular imaging probes and paradigms

Jeffrey Capadona, PhD
(Georgia Institute of Technology)
Associate Professor
Advanced materials for neural interfacing; biomimetic and bio-inspired materials; host-implant integration; anti-inflammatory materials; and novel biomaterials for surface modification of cortical neuroprostheses

Patrick E. Crago, PhD
(Case Western Reserve University)
Professor Emeritus
Control of neuroprostheses for restoration of motor function; neuromechanics; and modeling of neuromusculoskeletal systems

Dominique M. Durand, PhD
(University of Toronto, Canada)
Elmer Lincoln Lindseth Professor in Biomedical Engineering; Director, Neural Engineering Center
Neural engineering; neural interfacing; neural prostheses; computational neuroscience; neural dynamics; neuromodulation; neurophysiology and control of epilepsy

Steven J. Eppell, PhD
(Case Western Reserve University)
Associate Professor
Biomaterials; instrumentation; nanoscale structure-function analysis of orthopaedic biomaterials; and scanning probe microscopy and spectroscopy of skeletal tissues

Miklos Gratzl, PhD
(Technical University of Budapest, Hungary)
Associate Professor
Biomedical sensing and diagnostics in vitro and in vivo; electrochemical and optical techniques; BioMEMS for cellular transport; cancer multidrug resistance at the single cell level; and silver sensor for multi-analyte patient monitoring
Kenneth Gustafson, PhD  
(Arizona State University)  
Associate Professor  
Neural engineering; neural prostheses; neurophysiology and neural control of genitourinary function; devices to restore genitourinary function; and functional neuromuscular stimulation  

Efstathios (Stathis) Karathanasis, PhD  
(University of Houston)  
Associate Professor  
Fabricating multifunctional agents that facilitate diagnosing; treating and monitoring of therapies in a patient-specific manner  

Zheng-Rong Lu, PhD  
(Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences)  
M. Frank and Margaret Domiter Rudy Professor of Biomedical Engineering  
Drug delivery and molecular imaging; novel targeted imaging agents for molecular imaging; novel MRI contrast agents; image-guided therapy and drug delivery; polymeric drug delivery systems; multi-functional delivery systems for nucleic acids  

Anant Madabhushi, PhD  
(Rutgers University)  
F. Alex Nason Professor II  
Quantitative image analysis; Multi-modal, multi-scale correlation of massive data sets for disease diagnostics, prognostics, theragnostics; cancer applications  

Cameron McIntyre, PhD  
(Case Western Reserve University)  
Professor of Biomedical Engineering and Molecular Medicine  
Theoretical modeling of the interaction between electric fields and the nervous system; deep brain stimulation  

J. Thomas Mortimer, PhD  
(Case Western Reserve University)  
Professor Emeritus  
Neural control and prostheses; electrical activation of neural tissue; and membrane properties and electrodes  

P. Hunter Peckham, PhD  
(Case Western Reserve University)  
Donnell Institute Professor; Distinguished University Professor  
Rehabilitation engineering in spinal cord injury; neural prostheses; and functional electrical stimulation and technology transfer  

Andrew M. Rollins, PhD  
(Case Western Reserve University)  
Professor  
Biomedical optics; real-time in-vivo microstructural, functional, and molecular imaging using optical coherence tomography; diagnosis and guided therapy for cancer, cardiovascular, and ophthalmic disease  

Gerald M. Saidel, PhD  
(The Johns Hopkins University)  
Professor; Director, Center for Modeling Integrated Metabolic Systems  
Mass and heat transport and metabolism in cells, tissues, and organ systems; mathematical modeling and simulation of dynamic and spatially distributed systems; optimal nonlinear parameter estimation and design of experiments  

Nicole Seiberlich, PhD  
(University of Wurzburg)  
Elmer Lincoln Lindseth Associate Professor in Biomedical Engineering  
Advanced signal processing and data acquisition techniques for rapid Magnetic Resonance Imaging (MRI)  

Anirban Sen Gupta, PhD  
(The University of Akron)  
Associate Professor  
Targeted drug delivery; targeted molecular imaging; image-guided therapy; platelet substitutes; novel polymeric biomaterials for tissue engineering scaffolds  

Sam Senyo, PhD  
(University of Illinois)  
Assistant Professor  
Cardiovascular regeneration; microenvironment; stable isotopes; biomaterials, microfabrication; and drug delivery  

Pallavi Tiwari, PhD  
(Rutgers University)  
Assistant Professor  
Developing Image Analysis and Machine Learning Tools for Neuroimaging applications  

Ronald J. Triolo, PhD  
(Drexel University)  
Professor, Orthopaedics, University Hospitals-Case Medical Center, VA Medical Center, MetroHealth Medical Center  
Neural prostheses, rehabilitation engineering and restoration of lower extremity function, biomechanics of human movement quantitative analysis and control of gait, standing balance and seated posture  

Dustin J. Tyler, PhD  
(Case Western Reserve University)  
Kent Hale Smith Professor for the Case School of Engineering II  
Neuromimetic neuroprostheses; laryngeal neuroprostheses; clinical implementation of nerve electrodes; cortical neuroprostheses; minimally invasive implantation techniques; and modeling of neural stimulation and neuroprostheses  

Horst A. von Recum, PhD  
(University of Utah)  
Professor  
Affinity-based delivery of small molecule drugs and biomolecules for applications in device infection, HIV, orthopedics, cardiovascular, ophthalmology and cancer; directed differentiation of stem cells for tissue engineering applications, such as endothelial cells, cardiomyocytes, motor neurons and T-cells  

Satish Viswanath, PhD  
(Rutgers University)  
Assistant Professor  
Medical image analysis, image radiomics, and machine learning schemes, focused on the use of post-processing, co-registration, and biological quantitation; with applications in image-guided interventions, directed guidance, and quantitative evaluation of response to treatment in gastrointestinal cancers and inflammatory diseases
David L. Wilson, PhD
(Rice University)

Robert J. Herbold Professor
Biomedical image processing; digital processing and quantitative image quality of X-ray fluoroscopy images; interventional MRI

Xin Yu, ScD
(Harvard-MIT)
Professor
Magnetic resonance imaging and spectroscopy; applications of MRI and MRS to cardiovascular research

Secondary Appointments

Rigoberto Advincula, PhD
(University of Florida)
Professor, Macromolecular Science & Engineering
Design, synthesis, and characterization of polymers and nanostructured materials capable of controlled-assembly, tethering, and self-organization in ultrathin films

Ozan Akkus, PhD
(Case Western Reserve)
Professor, Mechanical Aerospace Engineering
Development of novel biomaterials that will substitute bone and soft tissues, bioinspired from the synthesis of bone such that ductile biocompatible polymer matrices are subjected to mineralization. Tendon replacement strategy involves alignment of collagen monomers by a novel electrochemical method to obtain strong bundles

Jay Alberts, PhD
(Arizona State University)
Assistant Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)
Neural basis of upper extremity motor function and deep brain stimulation in Parkinson's disease

Harihara Baskaran, PhD
(Pennsylvania State University)
Associate Professor, Chemical and Biomolecular Engineering
Design and build microvascular flow analogs that can be used to overcome nutrient limitations in tissue-engineered products

Jonathan Baskin, MD
(New York University)
Associate Professor, Chief, Otolaryngology-Head & Neck Surgery, University Hospitals-Case Medical Center, VA Medical Center
Bioengineering of bone substitutes using nanotechnology

Arnold Caplan, PhD
(Johns Hopkins University)
Professor, Biology
Development and refinement of the technology necessary to isolate a rare stem cell, the mesenchymal stem cell (MSC)

M. Cenk Cavusoglu, PhD
(University of California, Berkeley)
Professor, Electrical Engineering & Computer Science
Robotics, systems and control theory, human-machine interfaces emphasizing medical robotics, haptics, virtual environments, surgical simulation, and bio-system modeling and simulation

John Chae, MD
(New Jersey Medical School)
Professor, Physical Medicine and Rehabilitation, MetroHealth Medical Center
Stroke rehabilitation, neuromuscular electrical stimulation to restore upper and lower extremity function after stroke

Hillel J. Chiel, PhD
(Massachusetts Institute of Technology)
Professor, Biology
Biomechanical and neural basis of feeding behavior in the marine mollusk Aplysia californica, neuromechanical system modeling, analysis of neural network dynamics

Margot Damaser, PhD
(University of California)
Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)
Biomechanics and neural control of the female pelvic floor and lower urinary tract in normal and dysfunctional cases

Kathleen Derwin, PhD
(University of Michigan)
Assistant Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)
Tendon mechanobiology and tissue engineering

Isabelle Deschenes, PhD
(Laval University)
Professor, Cardiology, MetroHealth Medical Center
Molecular mechanisms of cardiac arrhythmias, ion channels structure-function

Agata Exner, PhD
(Case Western Reserve University)
Professor, Radiology, University Hospitals-Case Medical Center
Development and imaging characterization of drug delivery for cancer chemotherapy, interventional radiology

Christopher Flask, PhD
(Case Western Reserve University)
Associate Professor, Radiology, University Hospitals-Case Medical Center
Development of Quantitative and Molecular MRI Imaging Methods, MRI Physics

Roger French, PhD
(Massachusetts Institute of Technology)
Professor, Materials Science and Engineering, Macromolecular Science and Engineering, Physics
Lifetime and degradation science, photovoltaics, OLED and LED lighting and displays, polymer degradation

Kiyotaka Fukamachi, MD, PhD
(Kyushu University)
Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)
Research activities entail promoting human health through the development of various surgical treatments for heart failure, encompassing a broad range of options
Linda M. Graham, MD  
(University of Michigan)  
Professor, Surgery, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)  
Cell movement and vascular healing, vascular tissue engineering

Mark Griswold, PhD  
(University of Wuerzburg, Germany)  
Professor, Radiology, University Hospitals-Case Medical Center  
Rapid magnetic resonance imaging, image reconstruction and processing and MRI hardware/instrumentation

Vikas Gulani, MD, PhD  
(University of Illinois)  
Associate Professor, Radiology, University Hospitals-Case Medical Center  
Diffusion tensor imaging and diffusion anisotropy, MRI microscopy, body MRI, and functional MRI

Umut A Gurkan, PhD  
(Purdue University)  
Assistant Professor, Mechanical and Aerospace Engineering, Orthopaedics  
Micro/nano engineered systems and biomedical technologies

Alex Y. Huang, MD, PhD  
(Johns Hopkins University)  
Associate Professor, Pediatrics, Pathology, University Hospitals-Case Medical Center/Rainbow Babies and Children's Hospital  
Study various aspects of anti-tumor immune responses, immune – host – pathogen interaction, T cell-mediated memory immunity, and chemokine - receptor biology

Michael Jenkins, PhD  
(Case Western Reserve University)  
Assistant Professor, Pediatrics, Biomedical Engineering  
Biomedical imaging and instrumentation to determine congenital heart defects

Michael W. Keith, MD  
(Ohio State University)  
Professor, Orthopaedic Surgery, MetroHealth Medical Center  
Restoration of motor function in hands

Kandice Kottke-Marchant, MD, PhD  
(Case Western Reserve University)  
Professor and Chair, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)  
Thrombosis, hemostasis and vascular disease, hypercoagulable states, bleeding disorders, endothelial cell function, atherosclerosis

Vinod Labhasetwar, PhD  
(Nagpur University, India)  
Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)  
Cancer treatment and detection, delivery of anti-oxidant enzymes in stroke and development of a non-stent approach to inhibition of restenosis

Kenneth Laurita, PhD  
(Case Western Reserve University)  
Associate Professor, Cardiology, MetroHealth Medical Center  
Cellular mechanisms of cardiac arrhythmias using fluorescent imaging of transmembrane potential and intracellular calcium in the intact heart

Zhenghong Lee, PhD  
(Case Western Reserve University)  
Professor, Radiology, Nuclear Medicine, University Hospitals-Case Medical Center  
Quantitative PET and SPECT imaging, multimodal image registration, 3D visualization, molecular imaging and small animal imaging systems

Kenneth Loparo, PhD  
(Case Western Reserve University)  
Professor, Electrical Engineering & Computer Science  
Stability and control of nonlinear and stochastic systems; systems biology

Mehran Mehregany, PhD  
(Massachusetts Institute of Technology)  
Professor, Electrical Engineering & Computer Science  
Micro/nano-electromechanical systems, silicon carbide semiconductor technology and microsystems, wireless health

Pedram Mohseni, PhD  
(University of Michigan)  
Associate Professor, Electrical Engineering & Computer Science  
Biomicrosystems, biomedical microtelemetry, biological-electronic interfaces, microelectronics for neurotechnology and wireless integrated sensing/actuating systems

George F. Muschler, MD  
(Northwestern University)  
Professor, Molecular Medicine, Orthopaedic Surgery, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)  
Bone biology, skeletal reconstruction, aging, osteoporosis

Raymond F. Muzic, Jr., PhD  
(Case Western Reserve University)  
Professor, Radiology, Biomedical Engineering, Oncology; University Hospitals-Case Medical Center  
Quantitative analysis of biomedical imaging data, physiologic modeling, optimal experiment design, assessment of new radiopharmaceuticals, imaging response to therapy, and in vivo quantification of receptor concentration

Ela Plow, PhD PT  
(University of Minnesota)  
Assistant Professor, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)  
Neurological recovery in clinical rehabilitation, neural mechanisms of Functional Electrical Stimulation (FES)-based rehabilitative technique; tailored brain stimulation, tailored rehabilitation, patient specific treatments, functional neuroimaging, Transcranial Magnetic Stimulation (TMS), Transcranial Direct Current Stimulation (TDCS), Diffusion Tensor Imaging (DTI)

Tarun Podder, PhD  
(University of Hawaii)  
Associate Professor, Radiation Oncology  
Student mentoring and faculty collaboration

Anand Ramamurthi, PhD  
(Oklahoma State University)  
Associate Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)  
Artificial heart valves, tissue engineering, biomaterials, thrombosis
<table>
<thead>
<tr>
<th>Name</th>
<th>Degree</th>
<th>University/Institution</th>
<th>Position</th>
<th>Research Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Julie Renner</td>
<td>PhD</td>
<td>(Purdue University)</td>
<td>Assistant Professor</td>
<td>Development of protein engineered materials for use in and study of electrochemical systems</td>
</tr>
<tr>
<td>Clare Rimnac</td>
<td>PhD</td>
<td>(Lehigh University)</td>
<td>Professor, Mechanical and Aerospace Engineering</td>
<td>Orthopaedic implant performance and design, mechanical behavior of hard tissues</td>
</tr>
<tr>
<td>Mark S. Rzeszotarski</td>
<td>PhD</td>
<td>(Case Western Reserve University)</td>
<td>Professor, Radiology, MetroHealth Medical Center</td>
<td>Radiological imaging, computed tomography, medical education</td>
</tr>
<tr>
<td>Dawn Taylor</td>
<td>PhD</td>
<td>(Arizona State University)</td>
<td>Assistant Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine</td>
<td>Restoration of movement and function to paralysis victims through the application of electrical current to the peripheral nerves</td>
</tr>
<tr>
<td>Jeffrey Ustin</td>
<td>MD</td>
<td>(Stanford University School of Medicine)</td>
<td>Assistant Professor, Anesthesiology, University Hospitals</td>
<td>Synthetic platelet technology, robot assisted atrial fibrillation ablation, endotracheal tube technology</td>
</tr>
<tr>
<td>Jennell Vick</td>
<td>PhD</td>
<td>(University of Washington, Seattle)</td>
<td>Assistant Professor, Communication Sciences, Pediatrics, Biomedical Engineering</td>
<td>Motor control, collaboration with faculty and student mentoring</td>
</tr>
<tr>
<td>Albert L. Waldo</td>
<td>MD</td>
<td>(State University of New York, Downstate)</td>
<td>Professor, Medicine/Cardiology, University Hospitals-Case Medical Center</td>
<td>Cardiac electrophysiology and cardiac excitation mapping</td>
</tr>
<tr>
<td>Benjamin Walter</td>
<td>MD</td>
<td>(MCP-Hahnemann School of Medicine, Philadelphia)</td>
<td>Associate Professor, Neurology</td>
<td>Neuromodulation with deep brain stimulation, student committee member and advisor</td>
</tr>
<tr>
<td>Russell Wang</td>
<td>DDS, MSD</td>
<td>(Indiana University)</td>
<td>Associate Professor, Comprehensive Care, School of Dental Medicine</td>
<td>Dental implant design, instrumentation, bone regeneration, 3D printing of biomaterials, biomechanics of bone fracture, biomaterials for maxillofacial reconstruction</td>
</tr>
<tr>
<td>Gary Wnek</td>
<td>PhD</td>
<td>(University of Massachusetts, Amherst)</td>
<td>Professor, Macromolecular Science and Engineering</td>
<td>Synthetic mimics of nerve, collagen solvent processing and drug delivery from polymer fibers</td>
</tr>
<tr>
<td>Xiong Yu</td>
<td>PhD, P.E.</td>
<td>(Purdue University School of Civil Engineering)</td>
<td>Associate Professor, Civil Engineering</td>
<td>Materials and sensors innovations with emphasis on interdisciplinary innovation to improve intelligence and durability</td>
</tr>
<tr>
<td>Maciej Zborowski</td>
<td>PhD</td>
<td>(Polish Academy of Science)</td>
<td>Associate Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine</td>
<td>Membrane separation of blood proteins</td>
</tr>
<tr>
<td>Nicholas P. Ziats</td>
<td>PhD</td>
<td>(Case Western Reserve University)</td>
<td>Professor, Pathology, University Hospitals-Case Medical Center</td>
<td>Vascular grafts, vascular cells, blood vessels</td>
</tr>
<tr>
<td>Christian Zorman</td>
<td>PhD</td>
<td>(Case Western Reserve University)</td>
<td>Associate Professor, Electrical Engineering &amp; Computer Science</td>
<td>Development of enabling materials for micro- and nanosystems</td>
</tr>
</tbody>
</table>

Research Appointments

<table>
<thead>
<tr>
<th>Name</th>
<th>Degree</th>
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<th>Position</th>
<th>Research Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Musa L. Audu</td>
<td>PhD</td>
<td>(Case Western Reserve University)</td>
<td>Research Associate Professor</td>
<td>Human musculoskeletal modeling and development of control systems for rehabilitation of individuals with spinal cord injury and other balance disorders, design of rehabilitation devices for physically challenged individuals</td>
</tr>
<tr>
<td>Cong Truc Huynh</td>
<td>PhD</td>
<td>(Sungkyunkwan University)</td>
<td>Research Assistant Professor</td>
<td>Polymers and drug delivery systems, biomaterials for functional tissue regeneration</td>
</tr>
<tr>
<td>Oju Jeon</td>
<td>PhD</td>
<td>(Hanyang University)</td>
<td>Research Associate Professor</td>
<td>Development of biomaterials to create 3D bioprinted constructs for tissue engineering and regenerative medicine</td>
</tr>
<tr>
<td>Pubudu Peiris</td>
<td>PhD</td>
<td>(Cleveland State University)</td>
<td>Research Assistant Professor</td>
<td>Development of impactful therapeutic and diagnostic agents for hard-to-treat and lethal forms of cancer</td>
</tr>
<tr>
<td>Tina Vrabec</td>
<td>PhD</td>
<td>(Case Western Reserve University)</td>
<td>Research Assistant Professor</td>
<td>Novel waveforms, electrode designs, and electrode materials for control of the nervous system as applied to motor block, pain, and the autonomic system</td>
</tr>
</tbody>
</table>
Ethan Walker, MD, PhD  
(National Medical University; Institute of Tuberculosis & Pulmonology of the Academy of Medical Science of Ukraine)  
**Research Assistant Professor**  
Development of a live-time imaging technique to rapidly and reliably identify basal and squamous skin cancer in the margins of conventionally resected skin cancer samples that would significantly impact the quality of patient care

Xinning Wang, PhD  
(The Chinese University of Hong Kong)  
**Research Assistant Professor**  
Development of novel molecular image probes for the diagnosis of cancer, development of molecular cancer therapeutic approaches

Mei Zhang, PhD  
(Wuhan University)  
**Research Assistant Professor**  
Nanotechnology for cancer diagnosis and treatment, imaging and manipulation of tumor microenvironment, cancer immunotherapy, adoptive T cell immunotherapy

**Adjunct Faculty**

Niloy Bhadra, MD, PhD  
(Case Western Reserve University)  
**Adjunct Assistant Professor**  
Experimental and computational studies of high frequency waveforms for reversible conduction block of peripheral nerves, design, testing and implementation of neuroprosthetic systems for the upper limb

Kath Bogie, D. Phil  
(University of Oxford)  
**Adjunct Assistant Professor, Biomedical Engineering (VA Medical Center)**  
Wound prevention and treatment in individuals with paralysis and in the biomechanics of wheelchairs and seating for people with limited mobility

Michael Bruckman, PhD  
(University of South Carolina)  
**Adjunct Assistant Professor**  
Engineering viral nanoparticles for MRI detection of atherosclerosis in mice

Scott Bruder, MD, PhD  
(Case Western Reserve University)  
**Adjunct Professor**  
Advising MD/PhD students regarding careers in industry

Hossein Ghassemi, PhD  
(McGill University)  
**Adjunct Assistant Professor**  
Teaching, student mentoring and collaboration with faculty

Richard C. Burgess, MD, PhD  
(Case Western Reserve University)  
**Adjunct Professor of Biomedical Engineering (Neurological Computing, Cleveland Clinic)**  
Magnetoencephalography, electrophysiological monitoring, EEG processing, medical informatics

Andrew Cornwell, PhD  
(Case Western Reserve University)  
**Adjunct Assistant Professor**  
Electrical stimulation of the nervous system, especially for use in rehabilitation of neurological disorders

William J. Dupps, MD, PhD  
(The Ohio State University)  
**Adjunct Associate Professor (Cole Eye Institute and Biomedical Engineering, Cleveland Clinic)**  
Application of engineering tools to the diagnosis and management of biomechanical disorders such as keratoconus and glaucoma

Stephen Fening, PhD  
(Ohio University)  
**Adjunct Associate Professor**  
Patient care through translational research and commercialization

Jennifer Greene-Roos, PhD  
(Case Western Reserve University)  
**Adjunct Assistant Professor (Cleveland Cord Blood Center)**  
Umbilical cord monocytes for non-healing wounds and gene therapy to treat HIV infected lymphoma patients; collaboration with faculty and student mentoring

Elizabeth C. Hardin, PhD  
(University of Massachusetts)  
**Adjunct Assistant Professor of Biomedical Engineering, (VA Medical Center)**  
Neural prostheses and gait mechanics, improving gait performance with neural prostheses using strategies developed in conjunction with forward dynamics, musculoskeletal models

Thomas Hering, PhD  
(Case Western Reserve University)  
**Adjunct Associate Professor (Orthopaedic Surgery, Washington University)**  
Cartilage, extracellular matrix biochemistry and molecular biology; transcriptional regulation of chondrogenesis

Joseph Jankowski, PhD, MBA  
(Case Western Reserve University)  
**Adjunct Professor**  
Administration of multi-party translation and commercialization programs, intellectual property management, technology-based opportunity assessment, commercialization

Kevin L. Kilgore, PhD  
(Case Western Reserve University)  
**Adjunct Assistant Professor, Biomedical Engineering, Orthopaedics, (MetroHealth Medical Center)**  
Functional electrical stimulation; neuroprostheses

Nicola Lai, PhD  
(University of Pisa, Italy)  
**Adjunct Associate Professor (Old Dominion University)**  
Quantitative understanding of regulation of energy transfer and metabolism

Mary Laughlin, MD  
(State University of New York)  
**Adjunct Professor (Cleveland Cord Blood Center)**  
Development of monocytes, hematopoietic stem cells
Paul Marasco, PhD
(Vanderbilt University)
Adjunct Associate Professor
Neural plasticity, sensory neurophysiology, brain organization, sensory integration with prosthetic devices

Aaron S. Nelson, MD
(Medical College of Ohio)
Adjunct Assistant Professor, Medical Director, MiMvista Corporation (Cleveland, OH)
Multimodality and quantitative imaging for neurologic and cardiac disorders, oncology and radiation oncology

Marc Penn, MD, MD, PhD, FACC
(Case Western Reserve University)
Adjunct Professor (Director of Research, Summa Cardiovascular Institute, Summa Health System)
Strategies for cardiovascular cell therapy to treat cardiac dysfunction

Suguna Rachakonda, PhD, MBA
(University of Hyderabad)
Adjunct Assistant Professor
Consultation on technology commercialization

Todd Ritzman, MD
(The Ohio State University)
Adjunct Associate Professor
Pediatric orthopaedic surgery

Enrique Saldivar, PhD, MD
(University of California)
Adjunct Associate Professor
Teaching, student mentoring and collaboration with faculty

Antonie Van den Bogert, PhD
(University of Utrecht)
Adjunct Associate Professor (Orchard Kinetics, LLC)
Biomechanics, motion capture, computational modeling

Matthew Schiefer, PhD
(Case Western Reserve)
Adjunct Instructor
Teaching, student mentoring and collaboration with faculty

Andrew Shoffstall, PhD
(Case Western Reserve University)
Adjunct Assistant Professor
Teaching, student mentoring and collaboration with faculty

Matthew Williams, PhD
(Case Western Reserve University)
Adjunct Assistant Professor
Teaching, student mentoring and collaboration with faculty

Fredy R. Zypman, PhD
(Case Western Reserve University)
Adjunct Professor
Theoretical and computational applied physics, reconstruction of forces at the nanoscale from experimental atomic force microscopy measurements, and applications to electric and mechanical phenomena in soft matter including interactions in electrolytes; friction at the nanoscale; random systems

Undergraduate Programs

The Case Western Reserve undergraduate program leading to the Bachelor of Science in Engineering degree program with a major in Biomedical Engineering was established in 1972.

Some BS graduates are employed in industry and medical centers. Others continue graduate or professional studies in biomedical engineering and other fields. Students with engineering ability and an interest in medicine may consider the undergraduate biomedical engineering program as an exciting alternative to conventional premedical programs. In addition to the University general education requirements, the undergraduate program has three major components: (1) Engineering Core, (2) BME Core, and (3) BME Speciality Tracks. The Engineering Core provides a fundamental background in mathematics, sciences, and engineering. The BME Core integrates engineering with biomedical science to solve biomedical problems. Hands-on experience in BME is developed through undergraduate laboratory and project courses. In addition, by choosing BME Track Courses, the student can study a specific area in depth. This integrated program is designed to ensure that BME graduates are competent engineers.

The Bachelor of Science in Engineering degree program with a major in Biomedical Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Program Educational Objectives

At the undergraduate level, we direct our efforts toward two educational objectives that describe the performance of alumni 3-6 years after graduation.

1. Our graduates will successfully enter and complete post-baccalaureate advanced degree programs, including those in biomedical engineering.
2. Our graduates will obtain jobs in the biomedical arena and advance to positions of greater responsibility.

Student Outcomes

As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering with a major in Biomedical Engineering is designed so that students attain:

- An ability to apply knowledge of mathematics, science, and engineering appropriate to biomedical 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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- 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 ability to communicate the impact of engineering solutions in a global, economic, environmental, 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

### Bachelor of Science in Engineering

#### Major in Biomedical Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduATEST/degrees) and university general education requirements (http://bulletin.case.edu/undergraduATEST/degreeprograms), the major requires the following courses:

#### Required Courses

<table>
<thead>
<tr>
<th>Major Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EBME 201</strong></td>
</tr>
<tr>
<td><strong>EBME 202</strong></td>
</tr>
<tr>
<td><strong>EBME 306</strong> &amp; <strong>EBME 356</strong></td>
</tr>
<tr>
<td><strong>EBME 308</strong> &amp; <strong>EBME 358</strong></td>
</tr>
<tr>
<td><strong>EBME 309</strong> &amp; <strong>EBME 359</strong></td>
</tr>
<tr>
<td><strong>EBME 310</strong> &amp; <strong>EBME 360</strong></td>
</tr>
<tr>
<td><strong>EBME 370</strong></td>
</tr>
<tr>
<td><strong>EBME 380</strong></td>
</tr>
<tr>
<td>Plus one engineering, Mathematics or Natural Science Elective</td>
</tr>
<tr>
<td>Plus 8 Specialty Track Specialization Courses (see below)</td>
</tr>
<tr>
<td><strong>Total Units</strong></td>
</tr>
</tbody>
</table>

#### Natural Sciences, Mathematics or Statistics Elective

Candidates for the Bachelor of Science in Engineering degree must fulfill a Natural Sciences, Mathematics or Statistics requirement as part of the Engineering Core, which is designated by the major department. Biomedical Engineering majors may meet this requirement by taking one of the following statistics courses:

| **STAT 312** | Basic Statistics for Engineering and Science | 3 |
| **STAT 313** | Statistics for Experimenters | 3 |
| **STAT 332** | Statistics for Signal Processing | 3 |
| **STAT 333** | Uncertainty in Engineering and Science | 3 |

#### Biomedical Engineering Specialty Tracks

Majors in Biomedical Engineering choose a specialization track, with track specific courses.

Required courses for these tracks are presented in the tables below. These tracks provide the student with a solid background in a well-defined area of biomedical engineering. To meet specific educational needs, students may choose alternatives from among the suggested electives or design unique specialties. These options are flexible and subject to departmental guidelines and faculty approval.

Approval of technical electives (TE): Pre-approved TE are (listed below) need no further approval. Any 300-400 level course offered by a department in the Case School of Engineering may be approved as a TE by a student’s academic advisor. Any other course must be approved by petition to the BME Undergraduate Education Committee. Transfer and study abroad courses must be approved by the BME Program Representative. Courses should be chosen as TE’s that are consistent with the track and are consistent with student’s career plans. Students are encouraged to choose electives that form a thematic depth.

### Biomedical Devices and Instrumentation Track

| **ECE 245** | Electronic Circuits |
| **ECE 281** | Logic Design and Computer Organization |
| **ECE 309** | Electromagnetic Fields I |
| **ECE 344** | Electronic Analysis and Design |
| **Approved Tech Elective** | 3 |
| **Approved Tech Elective** | 3 |
| **Approved Tech Elective** | 3 |
| **Con-joiner course: choose one of the following courses:** | 3 |
| **EBME 320** | Medical Imaging Fundamentals |
| **EBME 327** | Bioelectric Engineering |

The following courses are pre-approved, technical electives for the Biomedical Devices and Instrumentation track.

| **Electronics:** |
| **ECE 321** | Semiconductor Electronic Devices |
| **ECE 322** | Integrated Circuits and Electronic Devices |
| **ECE 371** | Applied Circuit Design |
| **Software:** (note many of these courses require ECE 132 instead of ENGR 131) |
| **ECE 323** | Introduction to Data Structures |
| **ECE 331** | Signal Processing |
| **ECE 337** | Compiler Design |
| **ECE 338** | Intro to Operating Systems and Concurrent Programming |
| **ECE 340** | Algorithms |
| **ECE 351** | Communications and Signal Analysis |
| **ECE 354** | Digital Communications |

### Modeling/Simulation:

| **ECE 324** | Modeling and Simulation of Continuous Dynamical Systems |
| **ECE 346** | Engineering Optimization |
| **EBME 478** | Computational Neuroscience |

### Other:

<p>| <strong>EBME 401D</strong> | Biomedical Instrumentation and Signal Processing |
| <strong>EBME 407</strong> | Neural Interfacing |
| <strong>EBME 421</strong> | Bioelectric Phenomena |</p>
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 307</td>
<td>Biomechanical Prosthetic Systems</td>
</tr>
<tr>
<td>EBME 320</td>
<td>Medical Imaging Fundamentals</td>
</tr>
<tr>
<td>EBME 421</td>
<td>Bioelectric Phenomena</td>
</tr>
<tr>
<td>EECS 371</td>
<td>Applied Circuit Design</td>
</tr>
<tr>
<td>EECS 304</td>
<td>Control Engineering I with Laboratory</td>
</tr>
<tr>
<td>EECS 313</td>
<td>Signal Processing</td>
</tr>
<tr>
<td>EECS 341</td>
<td>Introduction to Database Systems</td>
</tr>
</tbody>
</table>

Please click here to download the example program of study for the Devices and Instrumentation Track. ([link](http://bulletin.case.edu/schoolofengineering/biomedicalengineering/Devices_Track_Template_2018.xls))

*Requirements for a minor in Electrical Engineering can be found here (p. 68). These can usually be satisfied by judiciously selecting technical electives. Consult your advisor.

**Biomaterials Track**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 223</td>
<td>Introductory Organic Chemistry I</td>
</tr>
<tr>
<td>EMAC 270</td>
<td>Introduction to Polymer Science and Engineering</td>
</tr>
<tr>
<td>EMAC 351</td>
<td>Physical Chemistry for Engineering</td>
</tr>
<tr>
<td>EMAC 352</td>
<td>Polymer Physics and Engineering</td>
</tr>
<tr>
<td>Approved Tech. Elective</td>
<td>3</td>
</tr>
<tr>
<td>Approved Tech. Elective</td>
<td>3</td>
</tr>
<tr>
<td>Approved Tech. Elective</td>
<td>3</td>
</tr>
<tr>
<td>Con-joiner course: choose one of the following courses:</td>
<td>3</td>
</tr>
<tr>
<td>EBME 316</td>
<td>Biomaterials for Drug Delivery</td>
</tr>
<tr>
<td>EBME 325</td>
<td>Introduction to Tissue Engineering</td>
</tr>
<tr>
<td>EBME 305</td>
<td>Materials for Prosthetics and Orthotics</td>
</tr>
</tbody>
</table>

The following courses are pre-approved, technical electives for the Biomaterials track.

**Polymeric Biomaterials**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 276</td>
<td>Polymer Properties and Design</td>
</tr>
<tr>
<td>EMAC 355</td>
<td>Polymer Analysis Laboratory</td>
</tr>
<tr>
<td>EMAC 370</td>
<td>Polymer Chemistry</td>
</tr>
<tr>
<td>EMAC 376</td>
<td>Polymer Engineering</td>
</tr>
<tr>
<td>EMAC 377</td>
<td>Polymer Processing</td>
</tr>
<tr>
<td>EMAC 303</td>
<td>Structure of Biological Materials</td>
</tr>
<tr>
<td>EBME 305</td>
<td>Materials for Prosthetics and Orthotics</td>
</tr>
<tr>
<td>EBME 350</td>
<td>Quantitative Molecular, Cellular and Tissue Bioengineering</td>
</tr>
<tr>
<td>EBME 406/EMAC 471</td>
<td>Polymers in Medicine</td>
</tr>
<tr>
<td>EBME 325</td>
<td>Introduction to Tissue Engineering</td>
</tr>
<tr>
<td>EBME 425</td>
<td>Tissue Engineering and Regenerative Medicine</td>
</tr>
</tbody>
</table>

**Hard Materials**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 160</td>
<td>Mechanical Manufacturing</td>
</tr>
<tr>
<td>EMSE 327</td>
<td>Thermodynamic Stability and Rate Processes</td>
</tr>
<tr>
<td>EMSE 335</td>
<td>Strategic Metals and Materials for the 21st Century</td>
</tr>
</tbody>
</table>

Please click here to download the example program of study for the Biomaterials Track ([link](http://bulletin.case.edu/schoolofengineering/biomedicalengineering/Biomaterials_Engg_Generic_Track_Template_gs.xlsx))

*Requirements for a minor in Polymer Science and Engineering can be found here (p. 119). These can usually be satisfied by judiciously selecting technical electives. Consult your advisor.

**Biomechanics Track**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 160</td>
<td>Mechanical Manufacturing</td>
</tr>
<tr>
<td>EMAE 181</td>
<td>Dynamics</td>
</tr>
<tr>
<td>ECIV 310</td>
<td>Strength of Materials</td>
</tr>
<tr>
<td>EMAE 260</td>
<td>Design and Manufacturing I</td>
</tr>
<tr>
<td>Approved Tech Elective</td>
<td>3</td>
</tr>
<tr>
<td>Approved Tech Elective</td>
<td>3</td>
</tr>
<tr>
<td>Approved Tech Elective</td>
<td>3</td>
</tr>
<tr>
<td>Co-joiner course:</td>
<td>3</td>
</tr>
<tr>
<td>EBME 307</td>
<td>Biomechanical Prosthetic Systems</td>
</tr>
</tbody>
</table>

The following courses are pre-approved, technical electives for the Biomechanics track.

**EMAE**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 250</td>
<td>Computers in Mechanical Engineering</td>
</tr>
<tr>
<td>EMAE 290</td>
<td>Computer-Aided Manufacturing</td>
</tr>
<tr>
<td>EMAE 363</td>
<td>Mechanical Engineering Modern Analysis Methods</td>
</tr>
<tr>
<td>EMAE 390</td>
<td>Advanced Manufacturing Technology</td>
</tr>
<tr>
<td>EMAE 370</td>
<td>Design of Mechanical Elements</td>
</tr>
<tr>
<td>EMAE 372</td>
<td>Structural Materials by Design</td>
</tr>
<tr>
<td>EMAE 350</td>
<td>Mechanical Engineering Analysis</td>
</tr>
<tr>
<td>EMAE 415</td>
<td>Introduction to Musculo-skeletal Biomechanics</td>
</tr>
<tr>
<td>EMAE 305</td>
<td>Materials for Prosthetics and Orthotics</td>
</tr>
<tr>
<td>EBME 402</td>
<td>Organ/Tissue Physiology and Systems Modeling</td>
</tr>
<tr>
<td>ECIV 420</td>
<td>Finite Element Analysis</td>
</tr>
<tr>
<td>EBME 398</td>
<td>Biomedical Engineering Research Experience I</td>
</tr>
<tr>
<td>EMSE 372</td>
<td>Structural Materials by Design</td>
</tr>
</tbody>
</table>
Please click here to download the example program of study for the Biomechanics Track (http://bulletin.case.edu/schoolofengineering/biomedicalengineering/BiomechanicalTrack_Generic.xls) *Requirements for a minor in Mechanical Design and Manufacturing Engineering can be found here (p. 119). These can usually be satisfied by judiciously selecting technical electives. Consult your advisor.

**Biomedical Computing and Analysis Track**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 302</td>
<td>Discrete Mathematics</td>
</tr>
<tr>
<td>EECS 233</td>
<td>Introduction to Data Structures</td>
</tr>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications</td>
</tr>
<tr>
<td>EECS 324</td>
<td>Modeling and Simulation of Continuous Dynamical Systems</td>
</tr>
</tbody>
</table>

Approved Tech. Elective 3

Approved Tech. Elective 3

Approved Tech. Elective 3

Co-joiner course: choose one of the following courses: 3

- EBM 307 Biomechanical Prosthetic Systems
- EBM 327 Bioelectric Engineering
- EBM 350 Quantitative Molecular, Cellular and Tissue Bioengineering
- EBM 361 Biomedical Image Processing and Analysis

The following courses are pre-approved, technical electives for the Biomedical Computing and Analysis track.

**Systems and Control**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 304</td>
<td>Control Engineering I with Laboratory</td>
</tr>
<tr>
<td>EECS 346</td>
<td>Engineering Optimization</td>
</tr>
<tr>
<td>EBM 300</td>
<td>Dynamics of Biological Systems: A Quantitative Introduction to Biology</td>
</tr>
<tr>
<td>EECS 350</td>
<td>Operations and Systems Design</td>
</tr>
<tr>
<td>EECS 352</td>
<td>Engineering Economics and Decision Analysis</td>
</tr>
<tr>
<td>EECS 391</td>
<td>Introduction to Artificial Intelligence</td>
</tr>
<tr>
<td>EBM 398</td>
<td>Biomedical Engineering Research Experience I</td>
</tr>
</tbody>
</table>

Biomedical Computing & Imaging

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
</tr>
<tr>
<td>EECS 293</td>
<td>Software Craftsmanship</td>
</tr>
<tr>
<td>EECS 313</td>
<td>Signal Processing</td>
</tr>
<tr>
<td>EECS 338</td>
<td>Intro to Operating Systems and Concurrent Programming</td>
</tr>
<tr>
<td>EECS 340</td>
<td>Algorithms</td>
</tr>
<tr>
<td>EECS 341</td>
<td>Introduction to Database Systems</td>
</tr>
<tr>
<td>EECS 343</td>
<td>Theoretical Computer Science</td>
</tr>
<tr>
<td>EECS 391</td>
<td>Introduction to Artificial Intelligence</td>
</tr>
<tr>
<td>EECS 394</td>
<td>Introduction to Information Theory</td>
</tr>
<tr>
<td>EBM 398</td>
<td>Biomedical Engineering Research Experience I</td>
</tr>
</tbody>
</table>

Please click here to download the example program of study for the Biomedical Computing And Analysis Track (http://bulletin.case.edu/schoolofengineering/biomedicalengineering/Biomedical_Computing_and_Analysis_Template_amr_edit.xls) *Requirements for a minor in Systems and Control Engineering can be found here (p. 68). These can usually be satisfied by judiciously selecting technical electives. Consult your advisor.

**Bachelor of Science in Engineering**

**Suggested Program of Study: Major in Biomedical Engineering**

The following is an example program of study. Variations depend on advance placements. Students should work with their advisors to map out an individual plan of study.

**First Year**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fall</td>
</tr>
<tr>
<td>EBM 105</td>
<td>Introduction to Biomedical Engineering</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 111</td>
<td>Principles of Chemistry for Engineers</td>
<td>4</td>
</tr>
<tr>
<td>MATH 121</td>
<td>Calculus for Science and Engineering I</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 131/EECS 132</td>
<td>Elementary Computer Programming</td>
<td>3</td>
</tr>
<tr>
<td>FSxx</td>
<td>SAGES First Seminar</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 145</td>
<td>Chemistry of Materials</td>
<td>4</td>
</tr>
<tr>
<td>MATH 122</td>
<td>Calculus for Science and Engineering II</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 121</td>
<td>General Physics I - Mechanics</td>
<td>4</td>
</tr>
<tr>
<td>USxx</td>
<td>SAGES University Seminar</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Year Total:</td>
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<td>18</td>
</tr>
</tbody>
</table>

**Second Year**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fall</td>
</tr>
<tr>
<td>EBM 201</td>
<td>Physiology-Biophysics I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 223</td>
<td>Calculus for Science and Engineering III</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 122</td>
<td>General Physics II - Electricity and Magnetism</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 225</td>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer</td>
<td>4</td>
</tr>
<tr>
<td>USxx</td>
<td>SAGES University Seminar</td>
<td>3</td>
</tr>
<tr>
<td>EBM 202</td>
<td>Physiology-Biophysics II</td>
<td>3</td>
</tr>
<tr>
<td>MATH 224</td>
<td>Elementary Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>ENGR 210</td>
<td>Introduction to Circuits and Instrumentation</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>One of the of following:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BME Track Course d</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Science elective</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Breadth elective</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
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<tr>
<td>Year Total:</td>
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<tr>
<td></td>
<td></td>
<td>17</td>
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</table>

**Third Year**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fall</td>
</tr>
<tr>
<td>EBM 306</td>
<td>Introduction to Biomedical Materials</td>
<td>4</td>
</tr>
<tr>
<td>EBM 356</td>
<td>Introduction to Biomaterials Engineering - Laboratory</td>
<td>3</td>
</tr>
</tbody>
</table>

Please click here to download the example program of study for the Biomedical Computing And Analysis Track (http://bulletin.case.edu/schoolofengineering/biomedicalengineering/Biomedical_Computing_and_Analysis_Template_amr_edit.xls)
Professional Communication for Engineers (ENGR 398)** 1
Professional Communication for Engineers (ENGL 398)** 2
Biomedical Signals and Systems (EBME 308) & Biomedical Signals and Systems Laboratory (EBME 358) 4
Breadth elective **, g 3
Principles of Biomedical Instrumentation (EBME 310) & Biomedical Instrumentation Laboratory (EBME 360) 4
Statics and Strength of Materials (ENGR 200)** 3
Modeling of Biomedical Systems (EBME 309) & Biomedical Computer Simulation Laboratory (EBME 359) 4
BME Track Course d 3
Breadth elective **, g 3
Year Total: 17 17

Fourth Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth elective **, g</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Principles of Biomedical Engineering Design (EBME 370)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>BME Track Course b</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>BME Track Course b</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Statistics d</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Engineering/Math/Science Elective e</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>BME Track Course b</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>BME Track Course b</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Breadth elective **, g</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Biomedical Engineering Design Experience (EBME 380)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>BME Track Course b</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Year Total:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Units in Sequence: 133

* University general education requirement
** Engineering general education requirement
a This optional course is limited to first-year students and is not required.
b Courses chosen depending on the BME specialty track as listed above
c At least one engineering, math or natural science elective
d SAGES BME Department Seminar, ENGL 398 Professional Communication for Engineers Professional Communication for Engineers and ENGR 398 Professional Communication for Engineers Professional Communication for Engineers must be taken together
e STAT 312 Basic Statistics for Engineering and Science, STAT 313 Statistics for Experimenters, STAT 332 Statistics for Signal Processing, STAT 333 Uncertainty in Engineering and Science fulfill the statistics requirement. Consult your advisor to determine the most appropriate class
f Biomedical Computing and Analysis track requires EECS 132 Introduction to Programming in Java

There are four required Breadth Electives. Depending on the specific specialty track, a fifth Breadth Elective may be taken.

Co-op and Internship Programs (http://engineering.case.edu/coop)
Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop. Alternatively or additionally, students may obtain employment as summer interns.

BS/MS Program

The BS/MS program is designed to allow highly qualified undergraduate students from the Case BME program to integrate B.S. courses and project work with M.S. courses and research. Nominally, the combined program can be completed in 5 years including 3 summers starting after the junior year. The BS/MS program can reduce the time required to receive an MS degree because up to three courses taken during the undergraduate program at Case can be "double counted" towards M.S. requirements and because a research project can begin before the completion of the B.S. degree. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatetudies/gradprofessional/accelerationtowardgraduatedegreertext).

Admission to the B.S./M.S. program is typically open to BME juniors from Case with a grade point average of 3.2 or higher. Students with slightly lower GPA but with significant research experience and a strong faculty champion can petition the GEC for admission. To be most effective, applications to the BS/MS program should be submitted before the end of Spring semester in the junior year. The final deadline for BS/MS admissions is August 1 before the senior year. This will enable the GEC sufficient time to review the application and allow students to make any required changes to their POS for fall semester.

In general, the following steps should be taken to apply to the BS/MS program:

1. See Advisor to discuss interests (typically in junior year or earlier).
2. See Dean Anderson the Undergraduate office to discuss intentions.
3. Complete a School of Graduate Studies application and submit to the Graduate Studies office for the program of interest (BME).
4. Complete a planned Program of Study form (must be signed by student, Faculty Advisor, Department Chair, and Dean of Undergraduate Studies). (see Appendix for BS/MS PPOS form)

Additional information for BME students:

1. An eligible BME faculty member (primary or secondary) must agree to serve as the M.S. research advisor and a primary BME faculty member (who might be the same person as the research advisor) must agree to be the academic advisor. Obtaining this agreement is the responsibility of the applying student. The BS/MS application must include letters of recommendation from both the research and
academic advisor that states that they agree to serve in these roles and that they support the BS/MS application.

2. The BME department does not guarantee financial support during the MS portion of this program. However, the GEC requires students and potential research advisors to discuss and agree to some financial arrangement. The letter of recommendation from the proposed research advisor must therefore indicate that the issue of financial support has been discussed and that some arrangement has been agreed upon. The details of this arrangement do not need to be included in the letter.

3. Complete a standard application to the School of Graduate Studies via the online application system.

4. Complete the BS/MS Planned Program of Study (PPOS) form (in Appendix VI or from the BME website bme.case.edu). Make sure to check the "BS/MS" box and to indicate which courses are to be double-counted (by checking the "double count" box next to the relevant courses on the POS).

5. Obtain an approval signature from the School of Undergraduate Studies on the proposed POS prior to submitting the package (below) to the department.

6. Prepare the application package that includes the following:
   - A current transcript
   - The proposed M.S. Program of Study. Make sure that the Program of Study specifies both the academic and research advisors and includes both of their signatures. This form also needs to indicate the courses that are intended to be "double counted".
   - Only graduate-level courses (400 or higher) can be double counted. This typically means that students should register for 400 level courses to satisfy undergraduate technical electives.
   - It is possible to "double count" three credit hours of EBME 398 Biomedical Engineering Research Experience I. To do this, three credit hours of EBME 651 Thesis M.S. (Thesis Option) or EBME 601 Research Projects (Non-Thesis Option) should replace EBME 398 Biomedical Engineering Research Experience I in the fall or spring of the senior year. You should register for EBME 651 Thesis M.S. or EBME 601 Research Projects (but NOT EBME 398 Biomedical Engineering Research Experience I). However, you must attend the meetings of EBME 398 Biomedical Engineering Research Experience I and also fulfill all of the course requirements for EBME 398 Biomedical Engineering Research Experience I.
   - A maximum of nine (9) credit hrs can be double counted. Typically, these are two 3-credit courses (400 level or high) + 3 credits of EBME 651 Thesis M.S. or EBME 601 Research Projects (in place of EBME 398 Biomedical Engineering Research Experience I).
   - Three (3) reference reports (in sealed envelopes), including letters from your proposed academic and research advisor(s).

7. Submit the proposed POS, transcript, and letters of recommendation to the BME Graduate Coordinator.

No admission decision will be made until the POS is approved by the GEC. After a positive recommendation by the GEC, a letter of conditional admission will be sent. The condition for admission is the submission of GRE scores within 2 months of completing the B.S. requirements.

The student cannot graduate from the B.S./M.S. program without official GRE scores. This is a BME requirement and not a CSE requirement. Note that it is strongly recommended that students plan to take the GRE exam in the Fall semester of their senior year to be eligible for pre-doctoral fellowships from the National Science Foundation or other sources.

**BS-MS Thesis Option**

- 21-hrs of course work and 9-hrs of EBME 651 Thesis M.S.
- Requirement for completion: 30-hrs and thesis defense

要求 for completion: 30-hrs and comprehensive examination

Students can double count 9 credits (up to 3 credits can be at the 300 level)

**BS-MS Non-Thesis Options**

1. **BS-MS Course Only Option**

- 30-hrs of course work
- Requirement for completion: 30-hrs and comprehensive examination

Students can double count 9 credits (up to 3 credits can be at the 300 level)

2. **BS-MS Project Option**

- 24 to 27-hrs of course work and 3 to 6-hrs of EBME 601 Research Projects

Students can double count 9 credits (up to 3 credits can be at the 300 level)

3. **BS-ME Practice Oriented Option**

- 18-hrs in engineering (5 courses and capstone projects)
- EPOM 400 Leadership and Interpersonal Skills
- EPOM 401 Introduction to Business for Engineers
- EPOM 403 Product and Process Design and Implementation
- EPOM 405 Applied Engineering Statistics (can be double-counted)
- EPOM 407 Engineering Economics and Financial Analysis
- EPOM 409 Master of Engineering Capstone Project

- 12-hrs (4 BME technical Courses)
- Graduation requirement: 30-hrs and a comprehensive examination

Students can double count 9 credits (up to 3 credits can be at the 300 level)

**Minor in Biomedical Engineering**

A minor in biomedical engineering is offered to students who have taken the Engineering (technical) Core requirements. The minor consists of an approved set of five EBME courses.

**Required Courses**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 201</td>
<td>Physiology-Biophysics I</td>
<td>3</td>
</tr>
</tbody>
</table>
Master of Science in Engineering with Specialization in Translational Health Technology

This Master's degree in Biomedical Engineering is designed to develop expertise in translating biomedical ideas into clinical implementation. This degree can be completed in one year for full-time students. It is offered by the Biomedical Engineering department in the Case School of Engineering and takes advantage of the large pool of expertise in Biotechnology on the campus of Case Western Reserve University. It combines aspects of bioengineering, marketing, entrepreneurship, and bioregulatory affairs with ethics and experimental design. The program will require students to take a minimum of 30 credits including a design project.

**Special Features:**
- Flexible program to accommodate a professional's schedule
- Lock-Step Program; Duration 1 year: August to August
- Projects can be done within the place of work

Visit [http://engineering.case.edu/Translational-Health-Technology/program-features](http://engineering.case.edu/Translational-Health-Technology/program-features)

**Prerequisite:** Biomedical Engineering Degree or equivalent or consent of program director.

**Course curriculum is as follows:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 491</td>
<td>Introduction to Translational Health Technology</td>
<td>2</td>
</tr>
<tr>
<td>PQHS 431</td>
<td>Statistical Methods I</td>
<td>3</td>
</tr>
<tr>
<td>BETH 503</td>
<td>Research Ethics and Regulation</td>
<td>3</td>
</tr>
<tr>
<td>EBME 473</td>
<td>Fundamentals of Clinical Information Systems</td>
<td>3</td>
</tr>
<tr>
<td>IIME 446</td>
<td>Models of Health Care Systems</td>
<td>1.5</td>
</tr>
<tr>
<td>IIME 447</td>
<td>Regulatory Affairs for the Biosciences</td>
<td>1.5</td>
</tr>
<tr>
<td>EBME 472</td>
<td>BioDesign</td>
<td>3</td>
</tr>
<tr>
<td>IIME 450</td>
<td>Engineering Entrepreneurship</td>
<td>3</td>
</tr>
<tr>
<td>EBME 695</td>
<td>Project M.S.</td>
<td>4</td>
</tr>
</tbody>
</table>

Total Units: 24

For the remaining 6 credit hours, students can choose from any 400 level engineering course or biomedical engineering course for which
prerequisites are met and approved by the student's advisor or a program director.

**Wireless Health**
The **MS degree in Biomedical Engineering** (BME) with a specialization in Wireless Health is a "course-only" program of study. Students who complete the 10-course, 30-credit course-only option will have the requisite knowledge to enter and advance the wireless health industry.

For more details, please refer to the Master's Degree (http://engineering.case.edu/sandiego/ms) information on the Case School of Engineering website.

**MD/MS Program**
The MD/MS program is available to qualified medical students from the Case School of Medicine and the Cleveland Clinic Lerner College of Medicine of Case Western Reserve University. Students in this program receive some credit for their medical school studies in completing the MS degree. There are specific admission requirements.

The MD/MS degree is open to Case School of Medicine students in the Cleveland Clinic Lerner College of Medicine (CCLCM) or the University Program (UP), which will award the MD component of the dual degree. An undergraduate degree in engineering is desirable for students entering this program, but other students with an adequate undergraduate preparation (calculus with differential equations, physics, chemistry, and electronic circuits) will be considered. Additional undergraduate courses in instrumentation and signals/systems would be helpful. Students with an insufficient background will be admitted conditionally until they take the remedial undergraduate courses. Remedial courses will not count toward the MS requirements.

Interested students should submit their applications through the BME department, as the department taking responsibility for program management. Students will normally apply to the 10 program during their first year of medical school. Students should submit their medical school application instead of a separate graduate school application, including MCAT scores instead of GRE scores. The application should include a letter specifying the intended track, the department/major field designation, and a statement of purpose for seeking the combined degree.

The MS requirements are the same as the rest of the Case School of Engineering Thesis Option MS degree, i.e., 30 credit hours including nine to twelve hours of thesis registration (EBME 651 Thesis M.S.). Please note that only Thesis Option is available to MS/MD students. Students must complete the normal MD requirements in either the UP or CCLCM Program. Portions of the medical school curriculum earn graded credit toward the MS portion of this degree. Specifically, students in the University Program register for Integrated Biological Science courses (IBIS 401 Integrated Biological Sciences I), as in the MD/PhD program. Students in the CCLCM Program enroll in the 6-credit IBIS 434 Integrated Biological Sciences in Medicine Process of Discovery course in the second year of the CCLCM curriculum. Six credit hours of these medical school courses are applied to the MS component of the dual degree. The balance of required formal courses (12-15 hours or 4-5 courses) must be graduate level engineering concentration courses that provide rigor and depth in a field of engineering relevant to the area of research. All courses must be listed on the BME Program of Study, which must be submitted and formally approved by the BME Graduate Education Committee and subsequently transmitted to the School of Graduate Studies. The Program of Study must be approved prior to registration for the second engineering course. Students must earn a minimum of a B grade in each graduate engineering course, and have a minimum overall GPA of 3.25.

**PhD Program in Biomedical Engineering**
The PhD program requires a minimum of 36 credit hours of courses beyond the BS degree. A student's overall Program of Study must clearly demonstrate adequate depth in a field of biomedical engineering relevant to the student's research area. There are 12 credit hours of required core courses, which include the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 401D</td>
<td>Biomedical Instrumentation and Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>EBME 433</td>
<td>Advanced Topics for Physiological Systems Analysis</td>
<td>4</td>
</tr>
<tr>
<td>EBME 602</td>
<td>Special Topics</td>
<td>1</td>
</tr>
<tr>
<td>CBIO 453</td>
<td>Cell Biology I</td>
<td>3</td>
</tr>
</tbody>
</table>

The following "breadth" courses are also required:

**Two semesters of:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 611</td>
<td>BME Departmental Seminar I</td>
</tr>
<tr>
<td>or EBME 612</td>
<td>BME Departmental Seminar II</td>
</tr>
</tbody>
</table>

**Two semesters of:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 613</td>
<td>Topic Seminars for NeuroEngineering Students</td>
</tr>
<tr>
<td>EBME 614</td>
<td>Topic Seminars for NeuroEngineering Students</td>
</tr>
<tr>
<td>EBME 615</td>
<td>Topic Seminars for Imaging Students</td>
</tr>
<tr>
<td>EBME 616</td>
<td>Topic Seminars for Imaging Students</td>
</tr>
<tr>
<td>EBME 617</td>
<td>Topic Seminars for Biomaterials Students</td>
</tr>
<tr>
<td>EBME 618</td>
<td>Topic Seminars for Biomaterials Students</td>
</tr>
<tr>
<td>EBME 619</td>
<td>Topic Seminars for Miscellaneous Biomedical Engineering Students</td>
</tr>
<tr>
<td>EBME 620</td>
<td>Topic Seminars for Miscellaneous Biomedical Engineering Students</td>
</tr>
<tr>
<td>EBME 570</td>
<td>Graduate Professional Development for Biomedical Engineers</td>
</tr>
</tbody>
</table>

**Three semesters of teaching experience:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 400T</td>
<td>Graduate Teaching I</td>
</tr>
</tbody>
</table>
The remaining courses can be chosen with significant flexibility to meet the career goals of the student and to satisfy the departmental requirements of depth and breadth. Programs of study must include one graduate level course in biomedical sciences and one course whose content is primarily mathematical, in addition to at least two courses with significant engineering content. More details on these requirements and accepted depth and breadth courses can be found in the Department of Biomedical Engineering’s Graduate Education Committee Handbook. Eighteen hours of EBME 701 Dissertation Ph.D. are also required. PhD programs of study are reviewed and must be accepted by the Graduate Education Committee, the department chair and the School of Graduate Studies.

MD/PhD Programs

Students with outstanding qualifications may apply to either of two MD/PhD programs. Students interested in obtaining a combined MD/PhD, with an emphasis on basic research in biomedical engineering, are strongly encouraged to explore the Medical Scientist Training Program (MSTP), administered by the School of Medicine. The MD/PhD programs require approximately 7-8 years of intensive study after the BS. Interested students should apply through the MSTP office in the Medical School.

Graduate Certificate

Graduate Certificates are discipline independent and intended to enable knowledgeable entry into the field of study. They are prescribed 3-course, 9-credit subsets of our MS degree offerings.

Wireless Health

Required Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME/EECS 480A</td>
<td>Introduction to Wireless Health</td>
<td>3</td>
</tr>
<tr>
<td>EBME/EECS 480B</td>
<td>The Human Body</td>
<td>3</td>
</tr>
<tr>
<td>EBME/EECS 480C</td>
<td>Biomedical Sensing Instrumentation</td>
<td>3</td>
</tr>
</tbody>
</table>

For more details, please refer to the Graduate Certificate [here](http://engineering.case.edu/sandiego/gc) on the Case School of Engineering - San Diego website.

Facilities

The Department of Biomedical Engineering has major facilities in both the Case School of Engineering and the School of Medicine. In the Case School of Engineering, the Wickenden Building provides office space for the majority of faculty, as well as extensive non-clinical research laboratories and centers. Also, a number of faculty have their offices and laboratories in the School of Medicine in the Biomedical Research Building and the Wolstein Building. In addition, many faculty also have major laboratory activities in the various medical centers in Cleveland.

Major interdisciplinary centers include: the Neural Engineering Center, the Case Center for Imaging Research (CCIR), the Center for Biomaterials, and the Center for Computational Imaging & Personalized Diagnostics. The Neural Engineering Center is a major facility for basic research and preclinical testing, with a focus on neural recording and controlling neural activity to increase our understanding of the nervous system and to develop neural prostheses. The Case Center for Imaging Research, located in the Department of Radiology at University Hospitals, has capabilities in imaging structure and function from the molecular level to the tissue-organ level, using many modalities, including ultrasound, MRI, CT, PET, SPECT, bioluminescence, and light. The CCIR has the ability for full translation of discoveries along a continuum from molecules to mice to man. The Center for Biomaterials includes laboratories for biomaterials microscopy, biopolymer and biomaterial interfaces, and molecular simulation. The Center for Computational Imaging & Personalized Diagnostics develops, evaluates, and applies novel quantitative image analysis, computer vision, signal processing, segmentation, multi-modal co-registration tools, pattern recognition, and machine learning tools for disease diagnosis, prognosis, and theragnosis in the context of breast, lung, prostate, head and neck, and brain tumors. The center is also developing new radiographic and radio-path-omic approaches to study correlations of disease markers across multiple length scales, modalities, and functionalities - from gene and protein expression to spectroscopy to digital pathology and to multi-parametric radiographic imaging. Also available are biomedical sensing laboratories that include facilities for electrochemical sensing, chemical measurements in individual cells, and minimally invasive physiological monitoring. High-fidelity patient simulation and clinical decision-making research are done in collaboration with the School of Nursing’s simulation center.

The FES (Functional Electrical Stimulation) Center, with laboratories at CWRU and in three medical centers, develops techniques for restoration of movement in paralysis, control of the nervous system, and implantable technology. The APT (Advanced Platform Technology) Center develops advanced technologies that serve the clinical needs of veterans and others with motor and sensory deficits, limb loss, and other disabilities.

The Case-Coulter Translational Research Partnership (CCTRP) is an endowed program that promotes translational research and supports collaborative translational research projects to address unmet or poorly met clinical needs. The overarching goal of the program is to improve patient care and accelerate the delivery of healthcare technology from academia to the marketplace. The CCTRP, in particular, fosters collaborations between clinicians and the CWRU Biomedical Engineering faculty to achieve its goals.

The Biomedical Engineering faculty and students have access to the many facilities and major laboratories of both the Case School of Engineering and School of Medicine. In addition, faculty have numerous collaborations at University Hospitals, MetroHealth Medical Center, Louis Stokes Cleveland VA Medical Center, and the Cleveland Clinic. These provide extensive research resources in a clinical environment for both undergraduate and graduate students.
Courses

**EBME 105. Introduction to Biomedical Engineering. 3 Units.**
This course introduces students to a wide variety of biomedical engineering fields including: biomaterials, biomechanics, biomedical devices & instrumentation, and biomedical computing & analysis. Emphasis is given to recognizing the difference between medical technology as a subject area vs. career tracks within which this subject area is: imagined, designed, fabricated and used. Students learn to distinguish the difference between how a scientist, an engineer, and a clinician are trained and interact with medical technology. Foundational topics like: engineering design, structure-function relationship, biomimicry, and biocompatibility are presented at an introductory level.

Students well served by this course include: freshmen trying to decide if they want to major in biomedical engineering, freshman who know they want to major in biomedical engineering but are not certain which track they wish to pursue, and upper classmen in non-biomedical engineering majors who are looking for deeper insight into what this fast growing field is about.

**EBME 201. Physiology-Biophysics I. 3 Units.**
Fundamental concepts of physiology from the cells to organ systems. Cell structure and function: DNA-RNA related enzyme/protein synthesis, membrane permeation (receptors/ channels/gates), cellular biochemistry and energetic metabolic functions. Essential systems-level concepts include endocrinology, immunology, cellular/capillary/interphase transport, regulation of fluid volume, solutes, and pH. Liver, renal and respiratory physiology. Basic concepts in thermodynamics, transport and kinetics provide a framework for quantitative analysis and modeling of systems physiology. Prereq: Must have declared major or minor in Biomedical Engineering.

**EBME 202. Physiology-Biophysics II. 3 Units.**
This course is an extension of EBME 201 that will include structure and function of (1) the nervous system, including vision, somatic and proprioceptive sensation, and control of movement, (2) skeletal and smooth muscle, (3) cardiac muscle and the cardiovascular system, and (4) the metabolic system. The material will be taught from a quantitative and functional perspective, with some examples of human pathophysiology. Prereq: EBME 201.

**EBME 300. Dynamics of Biological Systems: A Quantitative Introduction to Biology. 3 Units.**
This course will introduce students to dynamic biological phenomena, from the molecular to the population level, and models of these dynamical phenomena. It will describe a biological system, discuss how to model its dynamics, and experimentally evaluate the resulting models. Topics will include molecular dynamics of biological molecules, kinetics of cell metabolism and the cell cycle, biophysics of excitability, scaling laws for biological systems, biomechanics, and population dynamics. Mathematical tools for the analysis of dynamic biological processes will also be presented. Students will manipulate and analyze simulations of biological processes, and learn to formulate and analyze their own models. This course satisfies a laboratory requirement for the biology major. Offered as BIOL 300 and EBME 300.

**EBME 303. Structure of Biological Materials. 3 Units.**
Structure of proteins, nucleic acids, connective tissue and bone, from molecular to microscopic levels. An introduction to bioengineering biological materials and biomimetic materials, and an understanding of how different instruments may be used for imaging, identification and characterization of biological materials. Offered as: EBME 303 and EMAC 303. Recommended preparation: EBME 201, EBME 202, and EMAC 270.

**EBME 305. Materials for Prosthetics and Orthotics. 3 Units.**
A synthesis of skeletal tissue structure and biology, materials engineering, and strength of materials concepts. This course is centered on deepening the concept of biocompatibility and using it to pose and solve biomaterials problems. We cover: fundamental concepts of materials used for load bearing medical applications, wear, corrosion, and failure of implants. Structure and properties of hard tissues and joints are presented using a size hierarchy motif. Tools and analysis paradigms useful in the characterization of biomaterials are covered in the context of orthopedic and dental applications. Prereq: EBME 306 and EBME 370 or Requisites Not Met permission.

**EBME 306. Introduction to Biomedical Materials. 3 Units.**
Biomaterials design and application in different tissue and organ systems. The relationship between the physical and chemical structure of biomaterials, functional properties, and biological response. Recommended preparation: EBME 201 and EBME 202.

**EBME 307. Biomechanical Prosthetic Systems. 3 Units.**
Introduction to the basic biomechanics of human movement and applications to the design and evaluation of artificial devices intended to restore or improve movement lost due to injury or disease. Measurement techniques in movement biomechanics, including motion analysis, electromyography, and gait analysis. Design and use of upper and lower limb prostheses. Principles of neuroprostheses with applications to paralyzed upper and lower extremities. Recommended preparation: Consent of instructor and senior standing. Prereq: EBME 308.

**EBME 308. Biomedical Signals and Systems. 3 Units.**

**EBME 309. Modeling of Biomedical Systems. 3 Units.**
Mathematical modeling and computational methods applied to biomedical systems. Spatially lumped and distributed models of electrical, mechanical, and chemical processes applied to cells, tissues, organ, and whole-body systems. Prereq: EBME 202 and EBME 308. Coreq: EBME 359.

**EBME 310. Principles of Biomedical Instrumentation. 3 Units.**
Physical, chemical, and biological, and system principles for biomedical measurements. Modular blocks and system integration. Sensors for displacement, force, pressure, flow, temperature, biopotentials, chemical composition of body fluids and biomaterial characterization. Patient safety related to instrumentation will also be covered. Prereq: EBME 308. Coreq: EBME 360.

**EBME 316. Biomaterials for Drug Delivery. 3 Units.**
The teaching objective is to provide students with a basic understanding of the principles of design and engineering of well-defined molecular structures and architectures intended for applications in controlled release and organ-targeted drug delivery. The course will discuss the therapeutic basic of drug delivery based on drug pharmacodynamics and clinical pharmacokinetics. Biomaterials with specialized structural and interfacial properties will be introduced to achieve drug targeting and controlled release. Offered as EBME 316 and EBME 416. Prereq: EBME 306.
EBME 318. Biomedical Engineering Laboratory. 1 Unit.
Experiments for measurement, assisting, replacement, or control of various biomedical systems. Students choose a few lab experiences from a large number of offerings relevant to all BME sequences. Experiments are conducted primarily in faculty labs with 3-8 students participating. Recommended preparation: ENGR 210, Prereq: BME Major, EBME 201, EBME 202 and Prereq or Coreq: EBME 308.

EBME 320. Medical Imaging Fundamentals. 3 Units.
General principles, instrumentation, and biomedical applications of medical imaging. Topics include: x-ray, ultrasound, MRI, nuclear imaging, image reconstruction, and image quality. Recommended preparation: EBME 308, ENGR 210, and EBME 202 or equivalent.

EBME 325. Introduction to Tissue Engineering. 3 Units.
The goal of this course is to present students with a firm understanding of the primary components, design principles, and engineering concepts central to the field of tissue engineering. First, the biological principles of tissue formation during morphogenesis and wound repair will be examined. The cellular processes underlying these events will be presented with an emphasis on microenvironment regulation of cell behavior. Biomimetic approaches to controlling cell function and tissue formation via the development of biomaterial systems will then be investigated. Case studies of regeneration strategies for specific tissues will be presented in order to examine the different tissue-specific engineering strategies that may be employed. Special current topics in tissue engineering will also be covered. Recommended preparation: EBME 306, BIOL 362, and CHEM 223.

EBME 327. Bioelectric Engineering. 3 Units.

EBME 328. Biomedical Engineering R&D Training. 1 Unit.
This course will provide research and development in the laboratory of a mentoring faculty member. Varied R&D experiences will include activities in biomedical instrumentation, tissue engineering, imaging, drug delivery, and neural engineering. Each Student must identify a faculty mentor, and together they will create description of the training experience prior to the first class. Prereq: EBME 201 and EBME 202.

EBME 350. Quantitative Molecular, Cellular and Tissue Bioengineering. 3 Units.

EBME 356. Introduction to Biomaterials Engineering - Laboratory. 1 Unit.
This is a core BME Laboratory course directed at providing Biomedical Engineering undergraduate students ‘hands on’ experience in a component of biomaterials engineering, specifically, biocompatibility. To that end, the course will focus on blood compatibility (hemocompatibility) of biomaterials, by teaching students how to analyze the interaction of blood components (proteins, platelets, RBCs) on biomedical relevant coated versus uncoated polymer surfaces. The students will learn important characterization techniques like contact angle measurement, UV-Vis spectroscopy and optical microscopy in the context of characterizing blood interactions with materials. Prereq: EBME 201 and EBME 202. Prereq or Coreq: EBME 306.

EBME 358. Biomedical Signals and Systems Laboratory. 1 Unit.
Computational laboratory experiences with biomedical applications. Coreq: EBME 308.

EBME 361. Biomedical Image Processing and Analysis. 3 Units.
Principles of image processing and analysis with applications to clinical and biomedical research. Topics include image filtering, registration, morphological processing, segmentation, classification, and 3D image visualization. There will be interesting, realistic computer projects in Matlab. Offered as EBME 361 and EBME 461. Prereq: EBME 308.

EBME 370. Principles of Biomedical Engineering Design. 3 Units.
Students learn and implement the design process to produce working prototypes of medical devices with potential commercial value to meet significant clinical needs. Critical examination of contemporary medical problems is used to develop a specific problem statement. The class is divided into teams of 3 to 4 students. Each team integrates their knowledge and skills to design a device to meet their clinical need. Project planning and management, including resource allocation, milestones, and documentation, are required to ensure successful completion of projects within the allotted time and budget. Formal design reviews by a panel of advisors and outside medical device experts are required every four weeks. Every student is required to give oral presentations at each formal review and is responsible for formal documentation of the design process, resulting in an executive summary and complete design history file of the project. The course culminates with a public presentation of the team's device to a panel of experts. This course is expected to provide the student with a real-world, capstone design experience. Recommended preparation: EBME 310 Prereq: Senior standing or requisites not met permission.

EBME 380. Biomedical Engineering Design Experience. 3 Units.
This course is the culmination of the BME educational experience in which the student will apply acquired skills and knowledge to create a working device or product to meet a medical need. Students will learn how to apply engineering skills to solve problems and physically realize a project design. The course structure includes regular meetings with a faculty project advisor, regular reports of accomplished activity, hands on fabrication of devices, and several lectures from leading engineers from industry and academia that have first hand experience in applying the principles of design to Biomedical Engineering. Students will also provide periodic oral progress reports and a final oral presentation with a written design report. Counts as SAGES Senior Capstone. Prereq: EBME 370 and Senior standing or requisites not met permission.
EBME 398. Biomedical Engineering Research Experience I. 3 Units.
Biomedical engineering seniors can participate in a research project under the supervision of any qualified CWRU faculty member with the approval of a Primary BME faculty member. Guided by the supervising faculty member, each student develops and performs a research or design project. Students are encouraged to work with others in the faculty laboratory, but they must make a major contribution to the project. A research project is expected to include a significant engineering component, such as design and/or analysis. A design project must include a significant research component, such as applying the developed design to solve an actual biomedical problem. This course requires a final technical report and a short oral presentation by the student. In advance of registration, all students must submit a course proposal (see FORMS on the BME web site). This proposal must be approved by their research mentor and submitted via email for approval by the course instructor. This course can qualify as a technical elective if the project includes material pertinent to the student’s BME track and is approved in advance by the BME faculty member responsible for the BME track. To be approved as a technical elective, the project proposal should identify the new technical material the student will master, and a plan for assessing mastery.

EBME 399. Biomedical Engineering Research Experience II. 3 Units.
Continuation of EBME 398. Consent of Instructor required. Prereq: EBME 398.

EBME 400T. Graduate Teaching I. 0 Unit.
This will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to consist of direct student contact, but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational opportunity for the student. Recommended preparation: UNIV 400, BME Ph.D. student.

EBME 401D. Biomedical Instrumentation and Signal Processing. 3 Units.
Graduate students with various undergraduate backgrounds will learn the fundamental principles of biomedical measurements that integrate instrumentation and signal processing with problem-based hands-on experience. Recommended preparation: Undergraduate circuit and signal processing class.

EBME 402. Organ/Tissue Physiology and Systems Modeling. 4 Units.
Graduate students with various undergraduate backgrounds will learn the fundamental principles of organ and tissue physiology as well as systems modeling. Prereq: Graduate Status.

EBME 406. Polymers in Medicine. 3 Units.
This course covers the important fundamentals and applications of polymers in medicine, and consists of three major components: (i) the blood and soft-tissue reactions to polymer implants; (ii) the structure, characterization and modification of biomedical polymers; and (iii) the application of polymers in a broad range of cardiovascular and extravascular devices. The chemical and physical characteristics of biomedical polymers and the properties required to meet the needs of the intended biological function will be presented. Clinical evaluation, including recent advances and current problems associated with different polymer implants. Recommended preparation: EBME 306 or equivalent. Offered as EBME 406 and EMAC 471. Prereq: Graduate Standing.

EBME 407. Neural Interfacing. 3 Units.
Neural interfacing refers to the principles, methods, and devices that bridge the boundary between engineered devices and the nervous system. It includes the methods and mechanisms to get information efficiently and effectively into and out of the nervous system to analyze and control its function. This course examines advanced engineering, neurobiology, neurophysiology, and the interaction between all of them to develop methods of connecting to the nervous system. The course builds on a sound background in Bioelectric Phenomenon to explore fundamental principles of recording and simulation, electrochemistry of electrodes in biological tissue, tissue damage generated by electrical stimulation, materials and material properties, and molecular functionalization of devices for interfacing with the nervous system. Several examples of the state-of-art neural interfaces will be analyzed and discussed. Recommended preparation: EBME 401. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 410. Medical Imaging Fundamentals. 3 Units.
Physical principles of medical imaging. Imaging devices for x-ray, ultrasound, magnetic resonance, etc. Image quality descriptions. Patient risk. Recommended preparation: EBME 308 and EBME 310 or equivalent. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 416. Biomaterials for Drug Delivery. 3 Units.
The teaching objective is to provide students with a basic understanding of the principles of design and engineering of well-defined molecular structures and architectures intended for applications in controlled release and organ-targeted drug delivery. The course will discuss the therapeutic basic of drug delivery based on drug pharmacodynamics and clinical pharmacokinetics. Biomaterials with specialized structural and interfacial properties will be introduced to achieve drug targeting and controlled release. Offered as EBME 316 and EBME 416. Prereq: EBME 306 and PHRM 309 or graduate standing.

EBME 419. Applied Probability and Stochastic Processes for Biology. 3 Units.
Applications of probability and stochastic processes to biological systems. Mathematical topics will include: introduction to discrete and continuous probability spaces (including numerical generation of pseudo random samples from specified probability distributions), Markov processes in discrete and continuous time with discrete and continuous sample spaces, point processes including homogeneous and inhomogeneous Poisson processes and Markov chains on graphs, and diffusion processes including Brownian motion and the Ornstein-Uhlenbeck process. Biological topics will be determined by the interests of the students and the instructor. Likely topics include: stochastic ion channels, molecular motors and stochastic ratchets, actin and tubulin polymerization, random walk models for neural spike trains, bacterial chemotaxis, signaling and genetic regulatory networks, and stochastic predator-prey dynamics. The emphasis will be on practical simulation and analysis of stochastic phenomena in biological systems. Numerical methods will be developed using a combination of MATLAB, the R statistical package, MCell, and/or URDME, at the discretion of the instructor. Student projects will comprise a major part of the course. Offered as BIOL 319, EEECS 319, MATH 319, SYBB 319, BIOL 419, EBME 419, MATH 419, PHOL 419, and SYBB 419.
EBME 421. Bioelectric Phenomena. 3 Units.
The goal of this course is to provide working knowledge of the theoretical methods that are used in the fields of electrophysiology and bioelectricity for both neural and cardiac systems. These methods will be applied to describe, from a theoretical and quantitative perspective, the electrical behavior of excitable cells, the methods for recording their activity and the effect of applied electrical and magnetic fields on excitable issues. A team modeling project will be required. Recommended preparation: differential equations, circuits. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 425. Tissue Engineering and Regenerative Medicine. 3 Units.
This course will provide advanced coverage of tissue engineering with a focus on stem cell-based research and therapies. Course topics of note include stem cell biology and its role in development, modeling of stem cell function, controlling stem cell behavior by engineering materials and their microenvironment, stem cells’ trophic character, and state-of-the-art stem cell implementation in tissue engineering and other therapeutic strategies. Prereq: PhD student in an engineering program or EBME 325 or requisites not met permission.

EBME 426. Nanomedicine. 3 Units.

EBME 427. Movement Biomechanics and Rehabilitation. 3 Units.
Introduction to the basic biomechanics of human movement and applications to the design and evaluation of artificial devices intended to restore or improve movement lost due to injury or disease. Measurement techniques in movement biomechanics, including motion analysis, electromyography, and gait analysis. Design and use of upper and lower limb prostheses. Principles of neuroprostheses with applications to paralyzed upper and lower extremities. Term paper required. Recommended preparation: Consent of instructor and graduate standing. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 431. Physics of Imaging. 3 Units.
Description of physical principles underlying the spin behavior in MR and Fourier imaging in multi-dimensions. Introduction of conventional, fast, and chemical-shift imaging techniques. Spin echo, gradient echo, and variable flip-angle methods. Projection reconstruction and sampling theorems. Bloch equations, T1 and T2 relaxation times, rf penetration, diffusion and perfusion. Flow imaging, MR angiography, and functional brain imaging. Sequence and coil design. Prerequisite may be waived with consent of instructor. Recommended preparation: PHYS 122 or PHYS 124 or EBME 410. Offered as EBME 431 and PHYS 431.

EBME 432. Quantitative Analysis of Physiological Systems. 3 Units.

EBME 433. Advanced Topics for Physiological Systems Analysis. 4 Units.

EBME 440. Translational Research for Biomedical Engineers. 3 Units.
Translational Research (TR) in the Biomedical Engineering context means translating laboratory discoveries or developments into improved health care. Topics and activities include: Interdisciplinary teamwork and communication; Research ethics and human subjects protection; Regulation and oversight of human subjects and animal research; Clinical validation study design and biostatistics; Intellectual property, technology transfer and commercialization; Physician shadowing; Attending Grand Rounds and Morbidity-Mortality conferences; Preparing IRB and IACUC protocols; Final integrative project. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 447A. Rehabilitation for Scientists and Engineers. 0 Unit.
Medical, psychological, and social issues influencing the rehabilitation of people with spinal cord injury, stroke, traumatic brain injury, and limb amputation. Epidemiology, anatomy, pathophysiology and natural history of these disorders, and the consequences of these conditions with respect to impairment, disability, handicap, and quality of life. Students will directly observe the care of patients in each of these diagnostic groups throughout the full continuum of care starting from the acute medical and surgical interventions to acute and subacute rehabilitation, outpatient medical and rehabilitation management and finally to community re-entry.

EBME 447B. Rehabilitation for Scientists and Engineers. 3 Units.
Medical, psychological, and social issues influencing the rehabilitation of people with spinal cord injury, stroke, traumatic brain injury, and limb amputation. Epidemiology, anatomy, pathophysiology and natural history of these disorders, and the consequences of these conditions with respect to impairment, disability, handicap, and quality of life. Students will directly observe the care of patients in each of these diagnostic groups throughout the full continuum of care starting from the acute medical and surgical interventions to acute and subacute rehabilitation, outpatient medical and rehabilitation management and finally to community re-entry. Coreq: EBME 447A.

EBME 450. Molecular and Cellular Physiology. 3 Units.
This course covers cellular and molecular basics for graduate students with little or no prior biology background. The emphasis of EBME 451 is on the molecular and cellular mechanisms underlying physiological processes. Structure-function relationship will be addressed throughout the course. The primary goal of the course is to develop understanding of the principles of the physiological processes at molecular and cellular level and to promote independent thinking and ability to solve unfamiliar problems. This course is no longer a core course of the Biomedical Engineering graduate curriculum but serves as a fundamentals course to prepare students for the graduate cellular and molecular physiology core. Prereq: Graduate standing.
EBME 460. Advanced Topics in NMR Imaging. 3 Units.
Frontier issues in understanding the practical aspects of NMR imaging. Theoretical descriptions are accompanied by specific examples of pulse sequences, and basic engineering considerations in MRI system design. Emphasis is placed on implications and trade-offs in MRI pulse sequence design from real-world versus theoretical perspectives. Recommended preparation: EBME 431 or PHYS 431. Offered as EBME 460 and PHYS 460. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 461. Biomedical Image Processing and Analysis. 3 Units.
Principles of image processing and analysis with applications to clinical and biomedical research. Topics include image filtering, registration, morphological processing, segmentation, classification, and 3D image visualization. There will be interesting, realistic computer projects in Matlab. Offered as EBME 361 and EBME 461. Prereq: EBME 401.

EBME 465. Biomedical Optical Imaging. 3 Units.
Fundamentals of biomedical optics (biophotonics) with a focus on concepts and instrumentation behind light-based imaging of biological tissues. Topics include: essentials of optics and photonics, light-tissue interactions, optical imaging, conventional and advanced microscopies, optical coherence tomography. Course will include hands-on labs and demonstrations. Prereq: EBME 308 and (Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above) or Requisites Not Met permission.

EBME 467. Commercialization and Intellectual Property Management. 3 Units.
This interdisciplinary course covers a variety of topics, including principles of intellectual property and intellectual property management, business strategies and modeling relevant to the creation of start-up companies and exploitation of IP rights as they relate to biomedical-related inventions. The goal of this course is to address issues relating to the commercialization of biomedical-related inventions by exposing law students, MBA students, and Ph.D. candidates (in genetics and proteomics) to the challenges and opportunities encountered when attempting to develop biomedical intellectual property from the point of early discovery to the clinic and market. Specifically, this course seeks to provide students with the ability to value a given technological advance or invention holistically, focusing on issues that extend beyond scientific efficacy and include patient and practitioner value propositions, legal and intellectual property protection, business modeling, potential market impacts, market competition, and ethical, social, and healthcare practitioner acceptance. During this course, law students, MBA students, and Ph.D. candidates in genomics and proteomics will work in teams of five (two laws students, two MBA students and one Ph.D. candidate), focusing on issues of commercialization and IP management of biomedical-related inventions. The instructors will be drawn from the law school, business school, and technology-transfer office. Please visit the following website for more information: fusioninnovate.com. Offered as LAWS 5341, MGMT 467, GENE 367, GENE 467, EBME 467 and EEC5 467.

EBME 471. Principles of Medical Device Design and Innovation. 3 Units.
Translational research leading to medical device innovation is highly interdisciplinary, requiring a systematic, structured approach to bringing new medical technologies to market. This course provides the fundamental principles of the Biodesign innovation process, providing the student the essential tools to (A) identify unmet clinical needs, (B) create innovative medical device concepts that respond to a primary unmet need, and (C) understand the process for translating these concepts into the market. In short, the student learns the fundamental principles for the process of identify, invent, implement in the field of Biodesign.

EBME 472. BioDesign. 3 Units.
Medical device innovations that would have been considered science fiction a decade ago are already producing new standards of patient care. Innovation leading to lower cost of care, minimally invasive procedures and shorter recovery times is equally important to healthcare business leaders, educators, clinicians, and policy-makers. Innovation is a driver of regional economic development and wealth creation in organizational units ranging in size from the start-up to the Fortune 500 companies. In a broader context, the pace of translational research leading to product and service innovation is highly interdisciplinary, thus, new products and services result from team efforts, marked by a systematic, structured approach to bringing new medical technologies to market and impacting patient care. In this course we examine medical technology innovations in the context of (A) addressing unmet clinical needs, (B) the process of inventing new medical devices and instruments, and (C) subsequent implementation of these advances in patient care. In short, the student learns the process of "identify, invent, implement" in the field of BioDesign. Offered as EBME 472, IIME 472 and SYBB 472.

EBME 473. Fundamentals of Clinical Information Systems. 3 Units.
Technology has played a significant role in the evolution of medical science and treatment. While we often think about progress in terms of the practical application of, say, imaging to the diagnosis and monitoring of disease, technology is increasingly expected to improve the organization and delivery of healthcare services, too. Information technology plays a key role in the transformation of administrative support systems (finance and administration), clinical information systems (information to support patient care), and decision support systems (managerial decision-making). This introductory graduate course provides the student with the opportunity to gain insight and situational experience with clinical information systems (CIS). Often considered synonymous with electronic medical records, the "art" of CIS more fundamentally examines the effective use of data and information technology to assist in the migration away from paper-based systems and improve organizational performance. In this course we examine clinical information systems in the context of (A) operational and strategic information needs, (B) information technology and analytic tools for workflow design, and (C) subsequent implementation of clinical information systems in patient care. Legal and ethical issues are explored. The student learns the process of "plan, design, implement" through hands-on applications to select CIS problems, while at the same time gaining insights and understanding of the impacts placed on patients and health care providers. Offered as EBME 473, IIME 473 and SYBB 421.

EBME 474. Biotransport Processes. 3 Units.
Biomedical mass transport and chemical reaction processes. Basic mechanisms and mathematical models based on thermodynamics, mass and momentum conservation. Analytical and numerical methods to simulate in vivo processes as well as to develop diagnostic and therapeutic methods. Applications include transport across membranes, transport in blood, tumor processes, bioreactors, cell differentiation, chemotaxis, drug delivery systems, tissue engineering processes. Recommended preparation: EBME 350 or equivalent. Offered as EBME 474 and ECHE 474.
EBME 478. Computational Neuroscience. 3 Units.
Computer simulations and mathematical analysis of neurons and neural circuits, and the computational properties of nervous systems. Students are taught a range of models for neurons and neural circuits, and are asked to implement and explore the computational and dynamic properties of these models. The course introduces students to dynamical systems theory for the analysis of neurons and neural learning, models of brain systems, and their relationship to artificial and neural networks. Term project required. Students enrolled in MATH 478 will make arrangements with the instructor to attend additional lectures and complete additional assignments addressing mathematical topics related to the course. Recommended preparation: MATH 223 and MATH 224 or BIOL 300 and BIOL 306. Offered as BIOL 378, COGS 378, MATH 378, BIOL 478, EBME 478, EECS 478, MATH 478 and NEUR 478.

EBME 480A. Introduction to Wireless Health. 3 Units.
Study of convergence of wireless communications, microsystems, information technology, persuasive psychology, and health care. Discussion of health care delivery system, medical decision-making, persuasive psychology, and wireless health value chain and business models. Understanding of health information technology, processing of monitoring data, wireless communication, biomedical sensing techniques, and health monitoring technical approaches and solutions. Offered as EECS 480A and EBME 480A.

EBME 480B. The Human Body. 3 Units.
Study of structural organization of the body. Introduction to anatomy, physiology, and pathology, covering the various systems of the body. Comparison of elegant and efficient operation of the body and the related consequences of when things go wrong, presented in the context of each system of the body. Introduction to medical diagnosis and terminology in the course of covering the foregoing. Offered as EECS 480B and EBME 480B.

EBME 480C. Biomedical Sensing Instrumentation. 3 Units.
Study of principles, applications, and design of biomedical instruments with special emphasis on transducers. Understanding of basic sensors, amplifiers, and signal processing. Discussion of the origin of biopotential, and biopotential electrodes and amplifiers (including biotelemetry). Understanding of chemical sensors and clinical laboratory instrumentation, including microfluidics. Offered as EECS 480C and EBME 480C. Prereq: EECS/EBME 480A, EECS/EBME 480B

EBME 480D. The Health Care Delivery Ecosystem. 3 Units.
Health care delivery across the continuum of care in the United States, including health policy and reform, financing of care, comparative health systems, population health, public health, access to care, care models, cost and value, comparative effectiveness, governance, management, accountability, workforce, and the future. Discussions of opportunities and challenges for wireless health, integrated into the foregoing topics. Perspective on health care delivery in other countries. Offered as EECS 480D and EBME 480D.

EBME 480E. Wireless Communications and Networking. 3 Units.
Essentials of wireless communications and networking, including teletraffic engineering, radio propagation, digital and cellular communications, wireless wide-area network architecture, speech and channel coding, modulation schemes, antennas, security, networking and transport layers, and 4G systems. Hands-on learning of the anatomy of a cell phone, and a paired wireless health device and its gateway. Offered as EECS 480E and EBME 480E.

EBME 480F. Physicians, Hospitals and Clinics. 3 Units.
Rotation through one or more health care provider facilities for a first-hand understanding of care delivery practice, coordination, and management issues. First-hand exposure to clinical personnel, patients, medical devices and instruments, and organizational workflow. Familiarity with provider protocols, physician referral practices, electronic records, clinical decision support systems, acute and chronic care, and inpatient and ambulatory care. Offered as EECS 480F and EBME 480F.

EBME 480M. Introduction to Medical Informatics. 3 Units.
Current state and emerging trends in Medical Informatics (MI) and associated health information systems. Principles, data, data management, system interoperability, patient privacy, information security, electronic records, telehealth, regulatory issues, clinical decision support, mobile documentation, devices and wireless communications in healthcare. Impact of wireless technology on emerging health information systems and processes. Offered as EECS 480M and EBME 480M.

EBME 480O. Introduction to Health Information Technology Implementation. 3 Units.
Current state and emerging trends in the implementation and adoption of health information technology (HIT). Macroergonomics; Technology transfer and adoption; Systems adoption life cycle; Impact of regulation; Decision and work transformation; HIT specification and acquisition; Contracting issues; Implementation, use, and evaluation; Impact of wireless technology on emerging processes. Offered as EECS 480O and EBME 480O. Prereq: EBME 480M.

EBME 480P. Advanced Biomedical Instrumentation. 3 Units.
Analysis and design of biosensors in the context of biomedical measurements. Base sensors using electrochemical, optical, piezoelectric, and other principles. Binding equilibria, enzyme kinetics, and mass transport modalities. Adding the "bio" element to base sensors and mathematical aspects of data evaluation. Applications to clinical problems and biomedical research. Offered as EECS 480P and EBME 480P.

EBME 480Q. Regulatory Policy and Regulations. 3 Units.
Introduction of wireless health technologies: spectrum, licensed versus unlicensed; personal area networks; body area networks; ultra-wideband low energy level short-range radios; wireless local area networks; wide area networks. The Federal system: separation of powers; the executive branch and its departments; the Senate and its committees; the FCC; policy versus regulatory versus legislative. What is a medical device: FDA; classification system; radiation-emitting products; software; RF in medical devices; converged medical devices; international aspects. Regulation of health information technology and wireless health: American Recovery and Reinvestment Act; Patient Protection and Affordable Care Act; FCC/FDA MoU; CMS and Reimbursement; privacy and security. Offered as EECS 480Q and EBME 480Q.

EBME 480R. User Experience Engineering. 3 Units.
Social, cognitive, behavioral, and contextual elements in the design of healthcare technology and systems. User-centered design paradigm from a broad perspective, exploring dimensions of product user experience and learning to assess and modify the design of healthcare technology. Practical utilization of user centered design method and assessment techniques for approaching a design problem. Offered as EECS 480R and EBME 480R.
EBME 480S. Wireless Health Product Development. 3 Units.
Integrating application requirements, market data, concept formulation, design innovation, and manufacturing resources for creating differentiated wireless health products that delight the user. Learning user-centric product development best practices, safety, security and privacy considerations, and risk management planning. Understanding the regulatory process. Identifying and managing product development tradeoffs. Offered as EECS 480S and EBME 480S. Prereq: EBME 480R.

EBME 491. Introduction to Translational Health Technology. 2 Units.
Introduction to Translational Health Technology serves as the orientation and launch of the year-long Masters of Translational Health Technology Program. Sessions are designed to orient students to this fast-paced, lock-step, interdisciplinary program so they are adequately coached and prepared for the road ahead in the translation of leading-edge research into patient care. In addition to providing specific instructional elements, this course also helps set program expectations, norms, and metrics of successful student performance. The course of study includes invited capstone project presentations by the incumbent (prior year) students or other graduate students; such project discussions enable: (A) BME masters degree students completing their studies a chance to reflect on their research and project work and, (B) for new students completing orientation to develop first-hand experience with the process of inquiry and debate relating to the field of translational health technology.

EBME 500T. Graduate Teaching II. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to consist of direct student contact, but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational opportunity for the students. Recommended preparation: EBME 400T, BME Ph.D. student.

EBME 507. Motor System Neuroprostheses. 3 Units.
Fundamentals of neural stimulation and sensing, neurophysiology and pathophysiology of common neurological disorders, general implantation and clinical deployment issues. Specialist discussions in many application areas such as motor prostheses for spinal cord injury and stroke, cochlear implants, bladder control, stimulation for pain management, deep brain stimulation, and brain computer interfacing. Prereq: Graduate standing.

EBME 570. Graduate Professional Development for Biomedical Engineers. 1 Unit.
Students will be trained in topics including public speaking, grant writing, notebook management, professionalism, etc. Prereq: Graduate standing.

EBME 600T. Graduate Teaching III. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to consist of direct student contact, but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational opportunity for the students. Recommended preparation: EBME 500T, BME Ph.D. student.

EBME 601. Research Projects. 1 - 18 Units.

EBME 602. Special Topics. 1 - 18 Units.

EBME 611. BME Departmental Seminar I. .5 Unit.
Lectures by invited speakers on subjects of current interest in biomedical engineering. Students will be evaluated on reading and preparation of questions for select speakers, as well as weekly participation. Between this course and EBME 612 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters.

EBME 612. BME Departmental Seminar II. .5 Unit.
Lectures by invited speakers on subjects of current interest in biomedical engineering. Students will be evaluated on reading and preparation of questions for select speakers, as well as weekly participation. Between this course and EBME 611 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters.

EBME 613. Topic Seminars for NeuroEngineering Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in NeuroEngineering. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 614 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 614. Topic Seminars for NeuroEngineering Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in NeuroEngineering. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 613 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 615. Topic Seminars for Imaging Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Imaging. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 616 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 616. Topic Seminars for Imaging Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Imaging. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 615 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 617. Topic Seminars for Biomaterials Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 618 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 618. Topic Seminars for Biomaterials Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 617 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.
EBME 619. Topic Seminars for Miscellaneous Biomedical Engineering Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students on topics outside of NeuroEngineering, Imaging, and Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 620 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 620. Topic Seminars for Miscellaneous Biomedical Engineering Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students on topics outside of NeuroEngineering, Imaging, and Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 619 students must earn a minimum of 1 credit (2 semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 651. Thesis M.S.. 1 - 18 Units.

EBME 695. Project M.S.. 1 - 9 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in the EBME Plan B MS Program.

EBME 701. Dissertation Ph.D.. 1 - 9 Units.
Ph.D. candidates only. Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Department of Chemical and Biomolecular Engineering

The Department of Chemical and Biomolecular Engineering offers Bachelor of Science in Engineering, Master of Science, and Doctor of Philosophy degree programs. The department has twelve full-time faculty members, all of whom lead active research programs in advanced and emerging areas of chemical and biomolecular engineering.

Mission
The Department of Chemical and Biomolecular Engineering inspires learning and the pursuit of scholarly activities in chemical and biological engineering and related science and engineering disciplines. The Department offers educational programs and a research environment that enable our graduates to succeed in an evolving workplace, provides opportunities for students and faculty to advance knowledge at the highest levels of the profession, and addresses technological and personnel needs of industry, governments, and society.

Background
The profession of chemical engineering involves the analysis, design, operation, and control of processes that convert matter and energy to more useful forms, encompassing processes at all scales from the molecular to the megascale. Traditionally, chemical engineers are responsible for the production of basic chemicals, plastics, and fibers. However, today's chemical engineers are also involved in food and fertilizer production, synthesis of electronic materials, waste recycling, and power generation. Chemical engineers also develop new materials (ceramic composites and electronic chips, for example) as well as biochemicals and pharmaceuticals. The breadth of training in engineering and the sciences gives chemical engineers a particularly wide spectrum of career opportunities. Chemical engineers work in the chemical and materials related industries, in government, and are accepted by graduate schools in engineering, chemistry, medicine, and law.

Research
Research in the department is sponsored by a variety of state and federal agencies, by private industry, and by foundations. Current active research topics include:

Energy
- Novel energy storage systems for transportation, grid storage applications, and portable devices
- Energy efficient extraction and processing of materials
- Fuel cells and batteries
- Novel catalysts, electrocatalysts, and plasmas for conversion of gases to fuels
- Simulation, modeling, and fundamental characterization of transport and interfacial processes in electrochemical energy storage and conversion systems

Materials
- Advanced materials for electronic and electrochemical device applications
- Novel synthesis and deposition methods and reactor designs, including electrochemical and plasma reactors
- Novel characterization of materials and in situ reactor diagnostics
- Simulation and theory of materials properties
- Surface properties and interfacial phenomena
- Materials processing and engineering at molecular through macro scales
- Novel separations processes

Biomolecular Engineering
- Biosensors
- Cell and tissue engineering
- Biocatalysis and protein engineering

Faculty
Daniel Lacks, PhD
(Harvard University)
C. Benson Branch Professor of Chemical Engineering, Department Chair
Molecular simulation, statistical mechanics, triboelectric charging

Rohan N. Akolkar, PhD
(Case Western Reserve University)
F. Alex Nason Professor
Electrochemical phenomena in next-generation batteries, photovoltaics and semiconductor devices

John C. Angus, PhD
(University of Michigan)
Emeritus Professor
Chemical vapor deposition of diamond, electrochemistry of diamond, gallium nitride synthesis
Undergraduate Programs
The Bachelor of Science in Engineering degree program with a major in Chemical Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Program Educational Objectives
The undergraduate program in chemical engineering seeks to produce graduates who will:

1. be able to excel in professional careers across a broad range of industries
2. apply the knowledge, skills and ethical practice acquired through the chemical engineering curriculum to positively contribute to their profession and society
3. assume positions of responsibility and/or leadership in academia, industry, government, and business
4. succeed in post-graduate and professional degree programs

Student Outcomes
In preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Chemical Engineering is designed so that students attain:

- 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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- 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, economic, environmental, 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
# Bachelor of Science in Engineering

## Required Courses: Major in Chemical Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

### Major Required Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECHE 151</td>
<td>Introduction to Chemical Engineering at Case</td>
<td>1</td>
</tr>
<tr>
<td>ECHE 260</td>
<td>Introduction to Chemical Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 360</td>
<td>Transport Phenomena for Chemical Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECHE 361</td>
<td>Separation Processes</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 362</td>
<td>Chemical Engineering Laboratory</td>
<td>4</td>
</tr>
<tr>
<td>ECHE 363</td>
<td>Thermodynamics of Chemical Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 364</td>
<td>Chemical Reaction Processes</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 365</td>
<td>Measurements Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 367</td>
<td>Process Control</td>
<td>4</td>
</tr>
<tr>
<td>ECHE 398</td>
<td>Process Analysis and Design</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 399</td>
<td>Chemical Engineering Design Project</td>
<td>3</td>
</tr>
</tbody>
</table>

### Related Required Courses

- CHEM 223 Introductory Organic Chemistry I
- or CHEM 323 Organic Chemistry I
- CHEM 290 Chemical Laboratory Methods for Engineers
- or all of the following three courses:
  - CHEM 113 Principles of Chemistry Laboratory
  - CHEM 233 Introductory Organic Chemistry Laboratory I
  - CHEM 234 Introductory Organic Chemistry Laboratory II
- STAT 313 Statistics for Experimenters
- or STAT 312 Basic Statistics for Engineering and Science

### Technical Breadth Elective Sequences

A distinctive feature of the chemical engineering program is the three-course breadth elective sequence that enables a student to specialize in a technical or professional area that complements the chemical engineering core. A breadth elective sequence that has standing departmental approval are described below. Alternatively, students may design their own breadth elective sequence, which must be approved by the department.

#### Biochemical Engineering (Advisor: Dr. Baskaran)

- BIOL 301 Biotechnology Laboratory: Genes and Genetic Engineering
- BIOL 343 Microbiology (Spring)
- ECHE 340 Biochemical Engineering (Spring)
- Total Units 9

#### Computing (Advisor: Dr. Lacks)

- EECS 281 Logic Design and Computer Organization
- EECS 346 Engineering Optimization (Spring)
- One additional EECS course at 200 level or above
- Total Units 10-11

#### Electrochemical Engineering (Advisor: Dr. Landau)

- ECE 381 Electrochemical Engineering (Spring)
- ECE 383 Chemical Engineering Applied to Microfabrication and Devices (Fall)
- One additional course selected from:
  - EMSE 343 Processing of Electronic Materials
  - EECS 309 Electromagnetic Fields I (Fall)
  - ECE 321 Semiconductor Electronic Devices (Spring)
  - ECE 481 Corrosion Fundamentals
- Total Units 9

#### Electronic Materials (Advisor: Dr. Liu)

- ECE 383 Chemical Engineering Applied to Microfabrication and Devices (Fall)
- EECS 309 Electromagnetic Fields I (Fall)
- One additional course selected from:
- Total Units 9
### EMSE 343
Processing of Electronic Materials

### EECS 321
Semiconductor Electronic Devices (Spring)

**Total Units** 9

### Energy (Advisor: Dr. Savinell)

**ECHE 381**  
Electrochemical Engineering (Fall) 3

Two additional courses selected from approved energy course in Engineering, Physics, Chemistry, Management, or Law 6-7

**Total Units** 9-10

### Environmental Engineering (Advisor: Dr. Feke)

**ECIV 368**  
Environmental Engineering (Spring) 3

Two additional courses selected from: 6

- **ECIV 351**: Engineering Hydraulics and Hydrology
- **ECIV 361**: Water Resources Engineering (Fall)
- **ECIV 362**: Solid and Hazardous Waste Management (Spring)
- **ESTD 398**: Seminar in Environmental Studies (Fall)
- **EEPS 220**: Environmental Geology
- **EEPS 303**: Environmental Law
- **EEPS 321**: Hydrogeology
- **EECS 342**: Introduction to Global Issues (Fall)

**Total Units** 9

### Management/Entrepreneurship (Advisor: Dr. Savinell)

**ACCT 100**  
Introduction to Accounting for Non-Business Majors 3

Two additional courses selected from: 6

- **BAFI 355**: Corporate Finance (Fall)
  or **BAFI 341**: Money and Banking
- **BLAW 331**: Legal Environment of Management
- **ENTP 301**: Entrepreneurial Strategy
  or **ENTP 311**: Entrepreneurship and Wealth Creation
- **OPRE 301**: Operations Research and Supply Chain Management
- **MGMT 315**: International Management Institute

**Total Units** 9

### Polymer Science (Advisor: Dr. Akolkar)

**EMAC 270**  
Introduction to Polymer Science and Engineering (Fall) 3

Two additional courses selected from: 6

- **EMAC 276**: Polymer Properties and Design (Spring)
- **EMAC 376**: Polymer Engineering (Spring)
- **EMAC 377**: Polymer Processing (Spring)
- **EMAC 378**: Polymer Engineer Design Product (Spring)
- **EMAC 303**: Structure of Biological Materials

**Total Units** 9

### Pre-Medical (Advisor: Dr. Baskaran)

**CHEM 113**  
Principles of Chemistry Laboratory 2

**BIOL 214**  
Genes, Evolution and Ecology 3

**BIOL 214L**  
Genes, Evolution and Ecology Lab 1

**BIOL 215**  
Cells and Proteins 3

**BIOL 215L**  
Cells and Proteins Laboratory 1

**Total Units** 10

### Research (Advisor: Dr. Martin)

**ECHE 350**  
Undergraduate Research Project I (Fall) 3

**ECHE 351**  
Undergraduate Research Project II 3

An elective course approved by sequence advisor 3

**Total Units** 9

### Systems and Control (Advisor: Dr. Lacks)

**EECS 346**  
Engineering Optimization (Spring) 3

**EECS 281**  
Logic Design and Computer Organization (Fall) 4

**EECS 304**  
Control Engineering I with Laboratory (Spring) 3

**Total Units** 10

### BS/MS Advanced Study Sequence (Advisor: Dr. Martin)

Three 400-level 3-credit ECHE courses 9

**Total Units** 9

### Custom-Designed Sequence (Advisor: Dr. Lacks)

Students can design a custom breadth elective sequence, consisting of three courses (9 credits) that fit in one coherent technical or professional theme. The courses must be technical or professional courses (see footnote b) that are 200-level or higher, with at least one of the courses being 300-level or higher. These courses cannot be research or independent study courses. Students interested in this option should submit a petition to their advisor naming and explaining the coherent theme, why this theme complements the chemical engineering core for him/her, and how the three courses fit into this theme. The petition must be approved by the faculty of the Department of Chemical and Biomolecular Engineering.

---

**a** At most one course in this sequence may double count to satisfy the Materials, Science, or Physical Chemistry elective requirement. This double counting does not reduce the total credit hour requirement for the degree; there are no restrictions on the additional course(s) used to meet the total credit requirement.

**b** For the purpose of the sequences, “technical and professional courses” are defined as courses that would not satisfy the humanities and social sciences requirement of the Case School of Engineering; also excluded are courses in American Studies (AMST), Asian Studies (ASIA), Childhood studies (CHST), ethics (ETHS), Judaic studies (JDST), music (MUAP), education (EDUC), women’s and gender studies (WGST), Washington study program (WASH), and other courses deemed by the department to be of this genre.
Bachelor of Science in Engineering
Suggested Program of Study: Major in Chemical Engineering

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

**First Year**

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Physics I - Mechanics (PHYS 121)**c or Physics and Frontiers I - Mechanics (PHYS 123)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering I (MATH 121)**c or Calculus I (MATH 123)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>FSxx SAGES First Seminar*</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Introduction to Chemical Engineering at Case (ECHE 151)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**c or Physics and Frontiers II - Electricity and Magnetism (PHYS 124)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
<td>4</td>
<td></td>
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<tr>
<td>Calculus for Science and Engineering II (MATH 122)**c or Calculus II (MATH 124)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Elementary Computer Programming (ENGR 131)**</td>
<td>3</td>
<td></td>
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<tr>
<td>USxx SAGES University Seminar I*</td>
<td>3</td>
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</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
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<tr>
<td>Year Total:</td>
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<td>18</td>
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**Second Year**

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory Organic Chemistry I (CHEM 223)c or Organic Chemistry I (CHEM 323)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering III (MATH 223)**c or Calculus III (MATH 227)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Introduction to Chemical Systems (ECHE 260)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>USxx SAGES University Seminar II*</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Elementary Differential Equations (MATH 224)**c or Differential Equations (MATH 228)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Statistics for Experimenters (STAT 313) or Basic Statistics for Engineering and Science (STAT 312)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Thermodynamics of Chemical Systems (ECHE 363)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Science elective g</td>
<td>3</td>
<td></td>
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<tr>
<td>Breadth elective*</td>
<td>3</td>
<td></td>
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<tr>
<td>Year Total:</td>
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**Third Year**

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Phenomena for Chemical Systems (ECHE 360)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Process Control (ECHE 367)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Chemical Laboratory Methods for Engineers (CHEM 290)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Technical breadth elective sequence I e</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Separation Processes (ECHE 361)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Chemical Reaction Processes (ECHE 365)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Measurements Laboratory (ECHE 364)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGL 398)**</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Breadth elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Year Total:</td>
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<td>15</td>
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</table>

**Fourth Year**

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Engineering Laboratory (ECHE 362)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Process Analysis and Design (ECHE 398)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Materials elective h</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Technical breadth elective sequence II e</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Breadth elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Chemical Engineering Design Project (ECHE 399) j</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Statics and Strength of Materials (ENGR 200)**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Physical Chemistry elective j</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Technical breadth elective sequence III e</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Breadth elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Year Total:</td>
<td>16</td>
<td>15</td>
</tr>
</tbody>
</table>

Total Units in Sequence: 130

Hours required for graduation: 129-131 (depending on breadth elective sequence)

* University general education requirement
** Engineering general education requirement
† Higher number (advanced or honors) courses are available to students by invitation only.
e A three-course (9 credit hours minimum) breadth sequence, as described above.
g Science elective. One course chosen from:
- PHYS 221 Introduction to Modern Physics
- CHEM 224 Introductory Organic Chemistry II
  or any 300 level or higher lecture-based course in Chemistry, Physics, Biology or Biochemistry

Note: The course used to satisfy the Science elective cannot double count towards the Materials or Physical Chemistry Elective requirements.
Materials elective. One course chosen from:
- EMAC 270 Introduction to Polymer Science and Engineering
- EMSE 276 Polymer Properties and Design
- EMSE 276 Materials Properties and Design
- EMSE 343 Processing of Electronic Materials
- BIOL 307 Introduction to Biochemistry: From Molecules to Medical Science
- Or any 300 level or higher lecture-based course in Materials Science and Engineering or Macromolecular Science and Engineering

Note: The course used to satisfy the Materials elective cannot double count towards the Science or Physical Chemistry Elective requirements.

Biochemical Engineering Concentration

Biochemical engineering can be defined as the field of application of chemical engineering principles to systems that utilize biomolecules or bio-organisms to bring forth biotransformation. Biochemical engineering applications are versatile, ranging from waste-water treatment to production of therapeutic proteins. For the biochemical engineering concentration, students select the elective courses as described below, and take two additional courses:

Materials Elective: BIOL 307
Science Elective: BIOL 300
Physical Chemistry Elective: BIOL 334
Breadth Elective Sequence: Biochemical Engineering sequence (described above)

**Must also take**
- BIOL 308 Molecular Biology
- and one course selected from:
  - PHRM 309 Principles of Pharmacology
  - A course pre-approved by Prof. Baskaran

Pre-Medical Concentration

By using the flexibility provided by science and technical electives in the curriculum, students are able to pursue courses that provide the background needed for medical school. Students choose the following electives to meet the course requirements of most medical schools.

Materials Elective: BIOL 307
Science Elective: CHEM 224 or CHEM 324
Chemistry Labs: CHEM 113 and CHEM 233 and CHEM 234 instead of CHEM 290

Breadth Elective Sequence: Pre-Medical sequence (described above)

Co-op and Internship Programs (http://engineering.case.edu/coop)

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop. Alternatively or additionally, students may obtain employment as summer interns.

Five-Year Combined BS/MS Program

Outstanding undergraduate students have the opportunity to obtain an MS degree, with a thesis, in one additional year of study beyond the BS degree. (Normally, it takes two years beyond the BS to earn an MS degree.) In this program, an undergraduate student can take up to nine hours of graduate credit that simultaneously satisfies undergraduate degree requirements. Typically, students in this program start their research leading to the MS thesis in the fall semester of the senior year. The BS degree is awarded at the completion of the senior year. Application for admission to the five-year BS/MS program is made after completion of five semesters of coursework. Minimum requirements are a 3.2 grade point average and the recommendation of the department. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatesudies/gradprofessional/#accelerationtowardgraduatedegree).

Five-and-a-Half Year Cooperative BS/MS Program

The cooperative bachelor’s/master’s program enables outstanding students who are enrolled in the cooperative education program to earn an MS in one semester beyond the BS degree. Students complete six credits of a graduate project during the second co-op period and follow an Advanced Study elective sequence. Up to nine credits of graduate coursework can be used to satisfy both graduate and undergraduate requirements. At the end of the fifth year, the student receives the BS degree. Upon completion of an additional 12 credits of graduate work the following semester, the student receives the MS degree (non-thesis). Application for admission to the five-and-a-half-year co-op BS/MS program is made during the second semester of the junior year (this semester is taken in the fall of the fourth year). Minimum requirements are a 3.2 grade point average, satisfactory performance in the previous co-op assignment, and the recommendation of the department.

Minor in Chemical Engineering

The minor in chemical engineering is for students majoring in other disciplines. A minimum of 17 hours in chemical engineering courses are required for the minor. The required courses are:

- ENGR 225 Thermodynamics, Fluid Dynamics, Heat and Mass Transfer 4
- ECHE 260 Introduction to Chemical Systems 3
The degree of Doctor of Philosophy is awarded in recognition of deep understanding of related subjects together with a demonstration of the ability to perform independent research, to suggest new areas for research, and to communicate results in an acceptable manner. For students entering the PhD program with a BS degree, a total of 12 courses (36 credit hours) is required. Course requirements for students entering with MS degrees are adjusted to account for work done at other universities, but a minimum of 6 courses (18 credit hours) must be taken at CWRU. The course requirements for students entering with a BS degree are as follows:

<table>
<thead>
<tr>
<th>Core and Elective courses</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional Development courses</td>
<td>6</td>
</tr>
<tr>
<td>PhD thesis research</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total Units</strong></td>
<td>54</td>
</tr>
</tbody>
</table>

- Some of the graduate-level courses should be taken from a list of recommended courses that satisfy the Chemical Engineering core ‘units’ requirement. This list will be provided to the students upon admission to the program. For the PhD program, students should demonstrate that they have acquired a minimum of three core ‘units’ in each of the categories of Chemical Engineering Transport, Thermodynamics, Reactions and Applied Mathematics.

- Professional development is an integral part of the PhD program of study. The 6 professional development credits are acquired through courses in Chemical Engineering Communications (3 total credits), and by attending the Chemical Engineering Colloquium (3 total credits). All PhD students are required to assist in three teaching experiences as part of their degree requirements.

- Students in the PhD program are required to complete 18 credits of thesis research. Also, students who enter the PhD program must pass a First Proposition Oral Examination (with an accompanying written report) that tests a student’s ability to think creatively, grasp new research concepts, and discuss such concepts critically and comprehensively. The First Proposition Exam, typically taken in the Fall semester of the second year, serves as the qualifying examination for the PhD degree. A Second Proposition Exam focusing on the student’s own research topic is required by the end of the second year in the PhD program. All PhD students must satisfy the residency requirements of the university and the Case School of Engineering. In addition, at various points in the course of the dissertation research, students will be required to prepare reports and seminars on their work, and defend their dissertation. The Chemical and Biomolecular Engineering Graduate Student Handbook contains a more detailed description of the department’s PhD requirements and a time schedule for their completion.

The department anticipates that from time to time, special cases will arise which are exceptions to the above guidelines, e.g., a student may have taken a graduate-level course at another school. In these cases, the student must submit a statement with the Planned Program of Study justifying the departure from the guidelines and have it approved by the department.

### Facilities

The department is housed in the Albert W. Smith Building and portions of the Bingham Building on the Case Quadrangle. Professor Smith was chair of industrial chemistry at Case from 1911 to 1927. Under his leadership a separate course of study in chemical engineering was introduced at

<table>
<thead>
<tr>
<th>ECHE 360</th>
<th>Transport Phenomena for Chemical Systems</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plus two courses selected from the following:</td>
<td>6-7</td>
<td></td>
</tr>
<tr>
<td>ECHE 361</td>
<td>Separation Processes</td>
<td></td>
</tr>
<tr>
<td>ECHE 363</td>
<td>Thermodynamics of Chemical Systems</td>
<td></td>
</tr>
<tr>
<td>ECHE 364</td>
<td>Chemical Reaction Processes</td>
<td></td>
</tr>
<tr>
<td>ECHE 365</td>
<td>Measurements Laboratory</td>
<td></td>
</tr>
<tr>
<td>ECHE 367</td>
<td>Process Control</td>
<td></td>
</tr>
</tbody>
</table>

| Total Units | 17-18 |

### Graduate Programs

#### Master of Science Program

Each MS candidate must complete a minimum of 30 hours of graduate-level credits. These credits can be distributed in one of two ways, Plan A or Plan B.

<table>
<thead>
<tr>
<th>Plan A</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ECHE 401</td>
<td>Chemical Engineering Communications</td>
</tr>
<tr>
<td>ECHE 402</td>
<td>Chemical Engineering Communications II</td>
</tr>
<tr>
<td>Six graduate-level courses (^a)</td>
<td>18</td>
</tr>
<tr>
<td>MS thesis research</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total Units</strong></td>
<td>30</td>
</tr>
</tbody>
</table>

or

<table>
<thead>
<tr>
<th>Plan B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ECHE 401</td>
<td>Chemical Engineering Communications</td>
</tr>
<tr>
<td>ECHE 402</td>
<td>Chemical Engineering Communications II</td>
</tr>
<tr>
<td>Eight graduate-level courses (^a)</td>
<td>24</td>
</tr>
<tr>
<td>Project and/or Special Problems (^b)</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total Units</strong></td>
<td>30</td>
</tr>
</tbody>
</table>

\(^a\) Some of the graduate-level courses must be taken from a list of recommended courses that satisfy the Chemical Engineering core ‘units’ requirement. The list is maintained by the department. For the MS program, students should demonstrate that they have acquired a minimum of three core ‘units’ in each of the categories of Chemical Engineering Transport, Thermodynamics and Reactions. Elective courses should be technical graduate-level courses selected after consultation with the advisor.

\(^b\) In special cases, a student may be permitted to complete a 6 credit project. In this case, only seven graduate courses will be required.

Full-time MS students are expected to serve as a teaching assistant as part of their education. Also, at various points during their thesis research, students will be required to present seminars and reports on their progress.

### Doctor of Philosophy Program

The department of Chemical and Biomolecular Engineering is housed in the Albert W. Smith Building and portions of the Bingham Building on the Case Quadrangle. Professor Smith was chair of industrial chemistry at Case from 1911 to 1927. Under his leadership a separate course of study in chemical engineering was introduced at
Courses

ECHE 151. Introduction to Chemical Engineering at Case. 1 Unit.
An introduction to the profession of chemical engineering, its practice in industry, and review of the challenges and opportunities for the profession. The academic programs and curricular enhancements available to students majoring in chemical engineering at CWRU, including breadth sequence sequences and concentrations, undergraduate research, international study opportunities, cooperative education and internships, are presented. In addition to introducing the chemical engineering faculty and their research, a number of guest speakers representing the broad professional opportunities discuss career options with the students. Through lectures and discussions, students are also introduced to topics such as professionalism and ethics. Upperclassmen students conduct their co-op debriefing in the class, sharing experiences and initiating networking. In the lab/recitation section, students in smaller groups conduct experiments on chemical processes, spanning different aspects of the profession, and run computer-based simulations of those experiments. Analysis and discussion of the results will follow. Chemical engineering upperclassmen serve as teaching assistants.

ECHE 250. Honors Research I. 1 - 3 Units.
A special program which affords a limited number of students the opportunity to conduct research under the guidance of one of the faculty. At the end of the first semester of the sophomore year, students who have a strong interest in research are encouraged to discuss research possibilities with the faculty. Assignments are made based on mutual interest. Subject to the availability of funds, the faculty employs students throughout. Prereq: ENGR 225 and MATH 223.

ECHE 251. Honors Research II. 1 - 3 Units.
(See ECHE 250.) Recommended preparation: ECHE 250.

ECHE 260. Introduction to Chemical Systems. 3 Units.
Material and energy balances. Conservation principles and the elementary laws of physical chemistry applied to chemical processes. Developing skills in quantitative formulation and solution of word problems. Prereq: CHEM 111 and ENGR 145. Prereq or Coreq: MATH 122.

ECHE 305. Topics in Chemical Engineering. 1 - 3 Units.
Topics in chemical engineering will be covered in an independent study mode. Readings and homework assignments will be assigned. Students are graded on the basis of homework assignments and a final exam.

ECHE 340. Biochemical Engineering. 3 Units.
Chemical engineering principles applied to biological and biochemical systems and related processes. Microbiology and biochemistry linked with transport phenomena, kinetics, reactor design and analysis, and separations. Specific examples of microbial and enzyme processes of industrial significance. Recommended preparation: BIOL 307, BIOL 343 and ECHE 364, or permission of instructor.

ECHE 350. Undergraduate Research Project I. 3 Units.
This course affords a student the opportunity to conduct research under the guidance of one of the faculty, as part of the Chemical Engineering Research breadth elective sequence. Students who have a strong interest in research are encouraged to discuss research possibilities with the faculty. Assignments are made based on mutual interest. Prereq: ECHE 350.

ECHE 355. Quantitative Molecular, Cellular and Tissue Bioengineering. 3 Units.
Physical and chemical principles associated with kinetics and mass transport. Molecular-cellular components incorporated in quantitative analysis of cellular, tissue, and organ systems. Mathematical and computational modeling developed for diagnostic and therapeutic applications. Offered as EBME 350 and ECHE 355.

ECHE 360. Transport Phenomena for Chemical Systems. 4 Units.
Fundamentals of fluid flow, heat and mass transport from the microscopic and macroscopic perspectives. Applications to chemical systems, including steady and transient operations, convective and molecular (conduction and diffusion) effects, and interfacial transport. Design of unit operations (e.g., heat exchangers). Heat and mass transfer analogies. Vector/tensor analysis and dimensional analysis used throughout. Prereq: ENGR 225 and MATH 223.

ECHE 361. Separation Processes. 3 Units.
Analysis and design of separation processes involving distillation, extraction, absorption, adsorption, and membrane processes. Design problems and the physical and chemical processes involved in separation. Equilibrium stage, degrees of freedom in design, graphical and analytical design techniques, efficiency and capacity of separation processes. Prereq: ECHE 260. Prereq or Coreq: ECHE 363.

ECHE 362. Chemical Engineering Laboratory. 4 Units.
Experiments in the operation of separation and reaction equipment, including design of experiments, technical analysis, and economic analysis. Experiments cover distillation, liquid-liquid extraction, heat transfer, fluidized beds, control, membrane separations, and chemical and electrochemical reactors. Prereq: ECHE 260, ECHE 360, ECHE 361, ECHE 363 and ECHE 364.

ECHE 362D. Chemical Engineering Laboratory in Denmark. 4 Units.
Chemical Engineering Laboratory in Denmark. A version of ECHE 362 taught during the summer at DTU in Lyngby. Prereq: ECHE 260 and ECHE 360 and ECHE 361 and ECHE 363 and ECHE 364.
ECHE 363. Thermodynamics of Chemical Systems. 3 Units.
First law, second law, phase equilibria, phase rule, chemical reaction equilibria, and applications to engineering problems. Thermodynamic properties of real substances, with emphasis on solutions. Thermodynamic analysis of processes including chemical reactions. Prereq: ECHE 260 and Prereq or Coreq: ENGR 225.

ECHE 364. Chemical Reaction Processes. 3 Units.

ECHE 365. Measurements Laboratory. 3 Units.
Laboratory introduction to the measurement process in engineering. Matching measurements to approximate and exact physical models is stressed. Extraction of physical parameters and estimation of the errors in the parameter estimates is an important part of the course. Example projects cover steady and unsteady state heat transfer, momentum transfer, and the first law of thermodynamics. Recommended preparation: ECHE 360. Prereq: ECHE 260 and ENGR 225. Prereq or Coreq: ECHE 363.

ECHE 367. Process Control. 4 Units.
Theoretical and practical aspects of feedback control of chemical processes. The course involves extensive use of computer software with some exams taken using the computer. Short laboratories and Labview training are integrated into the course. Topics include: analysis of linear dynamical systems using Laplace transforms, derivation of unsteady state mathematical models of simple chemical processes, dynamic simulation of linear and nonlinear models, design of PID controllers by model inverse methods, tuning of controller to accommodate process model uncertainty, two degrees of freedom controllers, feed-forward and cascade control. The Labview training covers programming basics, interfacing to a data acquisition system, and incorporating control algorithms. Prereq or Coreq: MATH 224 and ECHE 260.

ECHE 372. Electrochemical Energy Storage. 3 Units.
Batteries and supercapacitors as part of renewable energy systems are introduced. Related fundamental electrochemistry concepts, materials and techniques are described. Challenges, current literature and future opportunities in energy storage will be discussed. Offered as ECHE 372 and ECHE 472. Prereq: Junior or Senior standing or Requisites Not Met permission.

ECHE 375. Process Analysis and Design. 3 Units.

ECHE 378. Electrical and Electronic Fundamentals. 3 Units.
Circuits, digital and analog fundamentals, operational amplifiers, diode and transistor fundamentals, fundamentals of data conversion, and fundamentals of control systems. Prereq: ECHE 367.

ECHE 381. Electrochemical Engineering. 3 Units.
Engineering aspects of electrochemical processes including current and potential distribution, mass transport and fluid mechanical effects. Examples from industrial processes including electroplating, industrial electrolysis, corrosion, and batteries. Recommended preparation: ECHE 260 or permission of instructor. Offered as ECHE 381 and ECHE 480.

ECHE 382. Electrochemical Processes and Devices. 3 Units.
The course addresses major industrial applications of electrochemical technology focusing on batteries and fuel-cells, corrosion and its abatement, electroplating, metal electrowinning (including aluminum, magnesium, titanium and lithium) and refining (copper), industrial electrolytic processes (chlorine), electrochemical separation processes (electrophoresis, osmosis, and dialysis), and electrochemical sensors. The processes and devices are surveyed, focusing on the underlying thermodynamic and transport principles. Approaches to overcome barriers are discussed and future prospects and barriers are critically analyzed.

ECHE 383. Chemical Engineering Applied to Microfabrication and Devices. 3 Units.
Silicon based microfabrication and micromachining require many chemical engineering technologies. Microfabricated devices such as sensors are also directly related to chemical engineering. The applications of chemical engineering principles to microfabrication and micromachining are introduced. Oxidation processing, chemical vapor deposition, etching and patterning techniques, electroplating and other technologies are discussed. Graduate students will submit an additional final project on some technical aspect of microfabrication technology or devices. Recommended preparation: ECHE 363 and ECHE 371. Offered as ECHE 383 and ECHE 483.

ECHE 384. Corrosion Fundamentals. 3 Units.
This course will cover fundamentals of corrosion, including thermodynamic and kinetic aspects of the electrochemical reactions leading to corrosion. Salient features of the various types of corrosion will be reviewed, with an emphasis on fundamental mechanisms. Electrochemical testing, corrosion monitoring and techniques to stifle corrosion will be discussed. After completion of this course, students will be able to classify corrosion systems, understand the mechanisms underlying corrosion, and outline strategies to design corrosion-resistant systems. Offered as ECHE 384 and ECHE 481.

ECHE 385. Process Analysis and Design. 3 Units.

ECHE 386. Corrosion Fundamentals. 3 Units.
The course will cover fundamentals of corrosion, including thermodynamic and kinetic aspects of the electrochemical reactions leading to corrosion. Salient features of the various types of corrosion will be reviewed, with an emphasis on fundamental mechanisms. Electrochemical testing, corrosion monitoring and techniques to stifle corrosion will be discussed. After completion of this course, students will be able to classify corrosion systems, understand the mechanisms underlying corrosion, and outline strategies to design corrosion-resistant systems. Offered as ECHE 384 and ECHE 481.

ECHE 387. Data Acquisition and LabVIEW Bootcamp. 1 Unit.
This course will introduce and implement basic data acquisition concepts and LabVIEW virtual instrumentation programming, providing hands-on experience with hardware and software. It is intended to help those with little or no data acquisition experience to get started on setting up data acquisition for their application. No prior experience with LabVIEW is required. Consult with the instructor for additional details. Offered as ECHE 377 and ECHE 477.

ECHE 388. Chemical Engineering Design Project. 3 Units.
Students work in small groups on projects in conjunction with external companies. The projects are defined by the company, and involve real issues current at the company. All projects will involve design (i.e., open ended problems with no one solution or route), an economic analysis, and will account for possible safety and environmental issues. The nature of the projects varies, depending on the needs of each company. There are no lectures for this course, and students are expected to work on their project for an amount appropriate for a 3-credit course (10 hrs/week). Recommended preparation: ECHE 362, ECHE 365, and ECHE 398. Counts as SAGES Senior Capstone. Prereq: ECHE 360, ECHE 361, ECHE 364, and ECHE 367.

ECHE 400T. Graduate Teaching I. 0 Unit.
All Ph.D. students are required to take this course. The experience includes elements from the following tasks: development of teaching or lecture materials, teaching recitation groups, providing laboratory assistance, tutoring, exam/quiz/homework preparation and grading, mentoring students. Recommended preparation: Entering Ph.D. student in Chemical Engineering.
ECHE 401. Chemical Engineering Communications. 1 Unit.
Introductory course in communication for Chemical Engineering graduate students: preparation of first proposal for thesis, preparation of technical reports and scientific papers, literature sources, reviewing proposals, and manuscripts for professional journals, and making effective technical presentations.

ECHE 402. Chemical Engineering Communications II. 2 Units.
This course is a continuation of ECHE 401 and is designed to develop skills in writing proposals for funding research projects. The federal requirements are reviewed for submitting proposals to the major granting agents including NSF, NIH and DoD. We will study strategies for developing fundable projects. Each student will submit a research proposal for a thesis project and do an oral presentation of the project.

ECHE 460. Thermodynamics of Chemical Systems. 3 Units.
Phase equilibria, phase rule, chemical reaction equilibria in homogeneous and heterogeneous systems, ideal and non-ideal behavior of fluids and solutions, thermodynamic analysis of closed and open chemical systems with applications. Recommended preparation: ECHE 363.

ECHE 461. Transport Phenomena. 3 Units.

ECHE 462. Chemical Reaction Engineering. 3 Units.

ECHE 464. Surfaces and Adsorption. 3 Units.
Thermodynamics of interfaces, nature of interactions across phase boundaries, capillary wetting properties of adsorbed films, friction and lubrication, flotation, detergency, the surface of solids, relation of bulk to surface properties of materials, non-catalytic surface reactions. Recommended preparation: CHEM 335 or equivalent.

ECHE 466. Colloid Science. 3 Units.

ECHE 469. Chemical Engineering Seminar. 0 Unit.
Distinguished outside speakers present current research in various topics of chemical engineering science. Graduate students also present technical papers based on thesis research.

ECHE 470. Graduate Research Colloquium. 5 Unit.
Outside speakers present lectures on their current research. Various topics in the areas of chemical engineering science, basic and applied chemistry, bioengineering, material science, and applied mathematics are covered in the lectures. Graduate students also present technical papers based on their own research. Students are graded on the submission of one-page summary reports on any two lectures.

ECHE 472. Electrochemical Energy Storage. 3 Units.
Batteries and supercapacitors as part of renewable energy systems are introduced. Related fundamental electrochemistry concepts, materials and techniques are described. Challenges, current literature and future opportunities in energy storage will be discussed. Offered as ECHE 372 and ECHE 472. Prereq: Graduate standing or Requisites Not Met permission.

ECHE 474. Biotransport Processes. 3 Units.
Biomedical mass transport and chemical reaction processes. Basic mechanisms and mathematical models based on thermodynamics, mass and momentum conservation. Analytical and numerical methods to simulate in vivo processes as well as to develop diagnostic and therapeutic methods. Applications include transport across membranes, transport in blood, tumor processes, bioreactors, cell differentiation, chemotaxis, drug delivery systems, tissue engineering processes. Recommended preparation: EBME 350 or equivalent. Offered as EBME 474 and ECHE 474.

ECHE 475. Chemical Engineering Analysis. 3 Units.

ECHE 477. Data Acquisition and LabVIEW Bootcamp. 1 Unit.
This course will introduce and implement basic data acquisition concepts and LabVIEW virtual instrumentation programming, providing hands-on experience with hardware and software. It is intended to help those with little or no data acquisition experience to get started on setting up data acquisition for their application. No prior experience with LabVIEW is required. Consult with the instructor for additional details. Offered as ECHE 377 and ECHE 477.

ECHE 478. Membrane Separations. 3 Units.
Membranes can be used to perform chemical engineering separations with applications in water treatment, energy and human health. This course will provide an overview of membrane separations including mass transfer in porous media, membrane fabrication and design. Topics will include: microfiltration, ultrafiltration, nanofiltration, reverse osmosis, forward osmosis, pressure retarded osmosis, dialysis, and electro-dialysis. Special applications of membranes in fuel cells, batteries, ion-exchange media and gas separations can be addressed based on the interests of the enrolled students. Prereq: Graduate Standing or Requisites Not Met permission.

ECHE 480. Electrochemical Engineering. 3 Units.
Engineering aspects of electrochemical processes including current and potential distribution, mass transport and fluid mechanical effects. Examples from industrial processes including electroplating, industrial electrolysis, corrosion, and batteries. Recommended preparation: ECHE 260 or permission of instructor. Offered as ECHE 381 and ECHE 480.

ECHE 481. Corrosion Fundamentals. 3 Units.
This course will cover fundamentals of corrosion, including thermodynamic and kinetic aspects of the electrochemical reactions leading to corrosion. Salient features of the various types of corrosion will be reviewed, with an emphasis on fundamental mechanisms. Electrochemical testing, corrosion monitoring and techniques to stifle corrosion will be discussed. After completion of this course, students will be able to classify corrosion systems, understand the mechanisms underlying corrosion, and outline strategies to design corrosion-resistant systems. Offered as ECHE 384 and ECHE 481.
ECHE 483. Chemical Engineering Applied to Microfabrication and Devices. 3 Units.
Silicon based microfabrication and micromachining require many chemical engineering technologies. Microfabricated devices such as sensors are also directly related to chemical engineering. The applications of chemical engineering principles to microfabrication and micromachining are introduced. Oxidation processing, chemical vapor deposition, etching and patterning techniques, electroplating and other technologies are discussed. Graduate students will submit an additional final project on some technical aspect of microfabrication technology or devices. Recommended preparation: ECHE 363 and ECHE 371. Offered as ECHE 383 and ECHE 483.

ECHE 486. Protein Engineering. 3 Units.
Imagine all of the amazingly complex functions that proteins play. For example, right now, hemoglobin is transporting oxygen around your body so you can be in this class. Now imagine what we could do to harness the power and specificity of proteins to make the world better. This is protein engineering. This course will provide an in-depth examination of protein engineering topics and their applications. In particular, this class will cover the design and expression of recombinant proteins, purification strategies, and the incorporation of non-natural amino acids using a bacterial system. Specifically, amino acid sequences that dictate well-defined secondary structures such as beta-sheets, alpha-helices, and leucine zippers will be studied. We will examine recent tissue engineering examples from the literature such as incorporation of bioactive sequences to promote specific cell response (e.g., cell adhesion sites and protease degradation sequences). In addition, this course will explore the application of protein engineering in drug delivery, electrochemical technology, sensors, and nanoparticle assembly. Current computational techniques for protein design and directed evolution methods will also be explored. This class will emphasize primary literature papers and will expose students to the newest technologies being developed in these fields. Finally, the role of thermodynamics and kinetics will be discussed throughout the class. Prereq: Graduate standing or requisites not met permission.

ECHE 500T. Graduate Teaching II. 0 Unit.
All Ph.D. students are required to take this course. The experience will include elements from the following tasks: development of teaching or lecture materials, teaching recitation groups, providing laboratory assistance, tutoring, exam/quiz/homework preparation and grading, mentoring students. Recommended preparation: Ph.D. student in Chemical Engineering.

ECHE 508. Seminar on Review of Literature on Research Topic. 3 Units.
Impactful research requires a deep and comprehensive understanding of the current state of research on the topic. A critical review of relevant background literature will help determine what is already known on the topic, how extensively the topic has already been studied, who are the experts active in the field, and the relevant key questions that deserve further exploration. A review of the literature that describes methodologies (both experimental and theoretical) used in prior studies or new approaches that could be adapted from other research areas can also lead to the effective pursuit of the research topic. Through this course, students will learn how to develop a plan for a literature review, conduct the literature review and monitor continuing developments in the field, and create an annotated bibliography appropriate to the research project.

ECHE 509. Seminar on Preparation of Articles for Publication in Journals. 3 Units.
This course is intended for advanced graduate students who have generated results at the stage of being ready to be written up for a journal article. The course will cover: understanding what findings warrant publication, factors affecting journal selection, formatting requirements of journals, publication-quality figures, appropriate material for each of the sections of the paper. During the course students will be putting together a manuscript based on their research that would eventually be submitted to a journal.

ECHE 580. Special Topics. 3 Units. 
Special topics in chemical engineering. Prereq: Consent of instructor.

ECHE 600T. Graduate Teaching III. 0 Unit.
Research course taken by Plan B M.S. students. Recommended preparation: plan B student in Chemical Engineering.

ECHE 601. Independent Study. 1 - 18 Units.

ECHE 651. Thesis M.S.. 1 - 18 Units.

ECHE 655. Project M.S.. 1 - 9 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in ECHE Plan B Program.

ECHE 701. Dissertation Ph.D.. 1 - 9 Units.
Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Department of Civil Engineering

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David Zeng, Frank H. Neff Professor and Chair  
xiangwu.zeng@case.edu

The Department of Civil Engineering offers programs of study in environmental, geotechnical, and structural engineering, construction engineering and management, and engineering mechanics. Civil engineers plan, design, and construct facilities for meeting the needs of modern society. Civil engineers also help to reduce the environmental impact of these designs to help make modern society more sustainable. Examples of such facilities are transportation systems, schools and office buildings, bridges, dams, land reclamation projects, water treatment and distribution systems, commercial buildings, and industrial plants. Civil engineers can choose from a broad spectrum of opportunities in industry and consulting practice as well as research and development in firms in which civil engineers often participate as owners or partners. Employment can be found among a wide variety of industrial, governmental, construction, and private consulting organizations. There is a large demand for civil engineers nationally. The program at Case Western Reserve University is built around small classes, good faculty-student relationships and advising, and a program flexible enough to meet students’ personal career goals.

The Department of Civil Engineering of the Case School of Engineering offers a Bachelor of Science in Engineering degree program with a
major in Civil Engineering with courses in almost all the traditional Civil Engineering subjects. The graduate program offers the Master of Science and Doctor of Philosophy degrees in areas of structural, geotechnical, environmental engineering, and engineering mechanics. A cooperative education program involving participating engineering firms is also available for both undergraduate and graduate students.

The Department’s active research programs provide opportunities for students to participate in projects related to design, analysis, and testing. Projects are in areas such as computational mechanics, probabilistic design, climatic adaption, risk assessment, bridges, dynamics and wind engineering, response of concrete and steel structures, fracture mechanics, blast engineering, structural health monitoring, foundation engineering, static and dynamic behavior of soils, earthquake engineering, pavement engineering, subsurface and ex situ remediation, urban hydraulics, contaminated sediments, infrastructure materials, and infrastructure systems optimization.

Mission
The Department of Civil Engineering has developed its own mission statement and educational objectives that are consistent with those of the Case School of Engineering. This process involved the entire Civil Engineering faculty and the Department’s Civil Engineering Advisory Committee and alumni. Assessing the Department’s mission and educational objectives is an ongoing process.

Our mission is to prepare students for leadership roles in Civil and Environmental Engineering. The Department provides facilities and research expertise to advance the state of the Civil Engineering profession within the mission of the Case School of Engineering. Students address problems building on solid technical foundations while taking advantage of advanced technologies. Our graduates adhere to high technical and ethical standards, in service to the public. Graduates are prepared for the pursuit of advanced learning in civil engineering and related fields, as well as for the practice of Civil and Environmental Engineering at the highest professional levels.

Research
Research underway in Civil Engineering includes work in analytical, design and experimental areas and is sponsored by industry, state, and federal government sources. Major areas of research interest are:

- Behavior of reinforced and prestressed concrete
- Wind engineering
- Earthquake analysis and design of structures
- Finite element methods
- Nondestructive Testing of Structures
- Passive control of the vibration of structures
- Transient response of nonlinear structures
- Blast loading of structures
- Fracture mechanics
- Multiscale simulation of nonlinear dynamic structural behavior
- Modeling of structural materials and structural systems
- High and low-cycle fatigue
- Geotechnical/Pavement Materials
- Static behavior of anisotropic clays and sands
- Soil liquefaction
- Centrifuge modeling of static and dynamic soil behavior
- Dynamic soil-structure interaction
- Non-destructive testing evaluation of soils and pavement materials
- Measurement of dynamic soil properties
- Design of Structures for High-Speed Vehicles
- Stability of tailings dams
- Environmentally conscious manufacturing
- Brownfields/structural remediation
- Environmental modeling and software development
- Geoenvironmental engineering
- Sediment remediation
- Environmental chemistry
- Bioremediation
- Structural health monitoring
- Transportation safety
- Infrastructure engineering
- Non-destructive Testing
- Sensor technology
- Smart materials
- Energy structures and geotechnology
- Biofuel development
- Urban hydraulics
- Soil contamination standards
- Intelligent infrastructure and transportation system
- Driver safety
- Building materials
- Environmental hazard and risk engineering
- Extreme dynamic load resistant design
- Multi-hazard and structural risk assessment
- Water and wastewater treatment
- Environmental remediation
- Fate and transport of environmental contaminants
- Environmental materials
- Climatic adaption

Faculty
Xiangwu (David) Zeng, PhD (Cambridge University)
Chair and Frank H. Neff Professor
Geotechnical earthquake engineering; centrifuge modeling; foundation vibration

YeongAe Heo, PhD (University of California, Davis)
Assistant Professor
Multi-scale numerical modeling and simulation for nonlinear dynamic behavior of structural materials and systems; Multi-hazard and risk engineering; risk-based extreme dynamic load resistant design for onshore and offshore structures and infrastructures; big data analysis application to structural engineering
Yue Li, PhD
(Georgia Institute of Technology)
Associate Professor
Probabilistic analysis, structural and systems reliability, multi-hazard assessment and mitigation, risk-informed decision making, resilient and sustainability civil infrastructure systems, earthquake engineering, wind engineering, impact of climate change and adaptation strategies.

Michael Pollino, PhD, SE, PE
(University at Buffalo)
Associate Professor
Structural engineering; seismic analysis and design, rehabilitation of structures and civil infrastructure, large scale experimental testing of structural systems and sub-assemblages, structural dynamics, steel structures

Kurt. R. Rhoads, PhD, PE
(Stanford University)
Assistant Professor
Environmental Engineering; Fate of organic pollutants, bio-remediation, algal biofuel development

Adel S. Saada, PhD, PE
(Princeton University)
Professor
Mechanics of materials; static and dynamic mechanical behavior of soils; foundation engineering

Katie P. Wheaton, M.S., P.E., S.E.
(Lehigh University)
Instructor
Structural engineering; steel, concrete, and wood structures; geomatics; CAD modeling.

Xiong (Bill) Yu, PhD, PE
(Purdue University)
Professor
Geotechnical engineering; infrastructure; construction material testing; information technology; intelligent infrastructure; energy geotechnology; sustainable design; sensors: structural health monitoring

Hui Chun (Judy) Zhang, PhD
(Georgia Institute of Technology)
Associate Professor
Environmental engineering, environmental chemistry, fate and transformation of emerging contaminants, redox transformation at mineral-water interface, absorption, advanced inorganic and polymer materials for contaminant removal, water and wastewater treatment, and groundwater and soil remediation

Adjunct Faculty

Terrance Cybulski, Adjunct
Philip Desantis, Adjunct
Dan Ghiozel, Adjunct
Troy Morgan, Adjunct
Mark D. Rokoff, Adjunct
Martin Schmidt, Adjunct

Lance Wanamaker, Adjunct
Erwin V. Zaretsky, Adjunct

Emeritus Faculty

J. Ludwig Figueroa, PhD
(University of Illinois)
Professor Emeritus

Dario A. Gasparini, PhD
(Massachusetts Institute of Technology)
Professor Emeritus

Arthur A. Hucklebridge, DEng, PE
(University of California Berkeley)
Professor Emeritus

Aaron Jennings, PhD, PE
(University of Massachusetts Amherst)
Professor Emeritus

Undergraduate Programs

The faculty of the Civil Engineering Department believes very strongly that undergraduate education should prepare students to be productive professional engineers. For this reason, particular emphasis in undergraduate teaching is placed on the application of engineering principles to the solution of problems. After completing a broad Civil Engineering core program, undergraduate students choose an elective sequence in one of the areas of civil engineering of particular interest, such as structural, geotechnical, or environmental engineering; construction engineering and management, or engineering mechanics.

In order to provide undergraduates with experience in the practice of Civil Engineering, the department attempts to arrange summer employment for students during the three summers between their semesters at Case Western Reserve University. By working for organizations in areas of design and construction, students gain invaluable knowledge about how the profession functions. This experience helps students gain more from their education and helps them be more competitive when seeking future employment.

A cooperative education program is also available. This allows the student to spend time an extended period of time working full-time in an engineering capacity with a contractor, consulting engineer, architect, or materials supplier during the course of his or her education. This learning experience is designed to integrate classroom theory with practical experience and professional development.

The curriculum has been designed so that students choose a sequence of four (4) or more approved elective courses. The sequence gives students the opportunity to pursue in more depth a particular area of practice in Civil Engineering. Samples of courses from which elective sequences may be chosen follow the Civil Engineering curriculum in this bulletin. In addition, all Civil Engineering students participate in a team senior capstone design course which provides them experience with solving multidisciplinary Civil Engineering problems.

Students enrolled in other majors may pursue a minor in civil engineering. A minimum of 15 credit hours of Civil Engineering courses and prior Department minor advisor approval are required.
Most classes in the Civil Engineering Department have an enrollment of fewer than 25 students to encourage the development of close professional relationships with the faculty. Students also have opportunities to gain practical experience as well as earn a supplemental income by assisting faculty members in consulting work or a funded research project.

The Bachelor of Science in Engineering degree program with a major in Civil Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Program Educational Objectives
1. Graduates of the program will enter the profession of Civil Engineering and advance to positions of greater responsibility and leadership, in line with ASCE Professional Grade Descriptions.
2. Graduates of the program will enter and successfully progress in, or complete, advanced degree programs within their fields of choice.
3. Graduates of the program will progress toward or complete professional registration and licensure.

Student Outcomes
As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Civil Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics (including differential equations) and science (including calculus-based physics and general chemistry) and one additional area of science.
- an ability to design and conduct experiments, as well as to analyze and interpret data in more than one area of civil engineering.
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
- an ability to function on multi-disciplinary teams.
- an ability to identify, formulate, and solve engineering problems.
- an understanding of professional and ethical responsibility and the role of civil engineers in providing for the safety and well-being of the general public.
- an ability to communicate effectively in written and oral form.
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, 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 and the design of functional civil engineering facilities.
- proficiency in probability and statistics, as applied to civil engineering design and planning issues.
- an understanding of professional practice issues, including the role of civil engineering design and management professionals in the construction process.
- an understanding of the importance of professional licensure and the ethical use of a professional license.

Bachelor of Science in Engineering
Required Courses: Major in Civil Engineering
In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/cedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

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<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>ECIV 160</td>
<td>Surveying and Computer Graphics</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 211</td>
<td>Civil Engineering Materials</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 310</td>
<td>Strength of Materials</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 320</td>
<td>Structural Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 322</td>
<td>Structural Design I</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 330</td>
<td>Soil Mechanics</td>
<td>4</td>
</tr>
<tr>
<td>ECIV 340</td>
<td>Construction Management</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 351</td>
<td>Engineering Hydraulics and Hydrology</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 360</td>
<td>Civil Engineering Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 368</td>
<td>Environmental Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 398</td>
<td>Civil Engineering Senior Project</td>
<td>3</td>
</tr>
</tbody>
</table>

Related Required Courses

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<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>EMAE 181</td>
<td>Dynamics</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 250</td>
<td>Computers in Mechanical Engineering</td>
<td>3</td>
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A minimum of four courses from one of the following technical elective sequences (or alternatives approved by the student’s academic advisor), two of which must be from Civil Engineering and two of which must be designated as design courses (indicated with an *)

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<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>ECIV 321</td>
<td>Matrix Analysis of Structures</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 323</td>
<td>Structural Design II</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 411</td>
<td>Elasticity, Theory and Applications</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 420</td>
<td>Finite Element Analysis</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 421</td>
<td>Advanced Topics in Reinforced Concrete Structures</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 422</td>
<td>Advanced Structural Steel Design</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 424</td>
<td>Structural Dynamics</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 425</td>
<td>Structural Design for Dynamic Loads</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 426</td>
<td>Probabilistic Analysis</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 430</td>
<td>Foundation Engineering</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 456</td>
<td>Intelligent Infrastructure Systems</td>
<td>(*)</td>
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</table>

Geotechnical Engineering

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECIV 323</td>
<td>Structural Design II</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 411</td>
<td>Elasticity, Theory and Applications</td>
<td>(*)</td>
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<tr>
<td>ECIV 420</td>
<td>Finite Element Analysis</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 430</td>
<td>Foundation Engineering</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 431</td>
<td>Special Topics in Geotechnical Engineering</td>
<td>(*)</td>
</tr>
<tr>
<td>ECIV 432</td>
<td>Mechanical Behavior of Soils</td>
<td>(*)</td>
</tr>
</tbody>
</table>
Computer use is an integral part of the Civil Engineering curriculum. From required courses in computer programming and numerical analysis to subsequent use and development of Civil Engineering programs, students experience the use of computers as a planning, analysis, design, and managerial tools.

All sequences are constructed to provide a balance of marketable skills and theoretical bases for further growth. With departmental approval other sequences can be developed to meet students’ needs.

### Bachelor of Science in Engineering

**Suggested Program of Study: Major in Civil Engineering**

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

### First Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Elementary Computer Programming (ENGR 131)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>FSXX SAGES First Seminar</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>PHED (two half semester classes)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>SAGES University Seminar I</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Chemistry of Materials (ENGR 145)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Calculus for Science and Engineering II (MATH 122)**</td>
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</tr>
<tr>
<td></td>
<td>General Physics I - Mechanics (PHYS 121)**</td>
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<td>PHED (two half semester classes)</td>
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### Second Year

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<tr>
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<td>SAGES University Seminar II</td>
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<tr>
<td></td>
<td>Surveying and Computer Graphics (ECIV 160)</td>
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</tr>
<tr>
<td></td>
<td>Computers in Mechanical Engineering (EMAE 250)</td>
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<tr>
<td></td>
<td>Statics and Strength of Materials (ENGR 200)**</td>
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<tr>
<td></td>
<td>Calculus for Science and Engineering III (MATH 223)**</td>
<td>3</td>
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<tr>
<td></td>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
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</tr>
<tr>
<td></td>
<td>Breadth elective</td>
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</tr>
<tr>
<td></td>
<td>Strength of Materials (ECIV 310)</td>
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<tr>
<td></td>
<td>Dynamics (EMAE 181)</td>
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<tr>
<td></td>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Elementary Differential Equations (MATH 224)**</td>
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### Third Year

<table>
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<tr>
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<th>Course Title</th>
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<tbody>
<tr>
<td></td>
<td>Breadth elective</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Civil Engineering Materials (ECIV 211)</td>
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</tr>
<tr>
<td></td>
<td>Structural Analysis I (ECIV 320)</td>
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</tr>
<tr>
<td></td>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
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<td></td>
<td>Professional Communication for Engineers (ENGR 398)**</td>
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<td></td>
<td>Professional Communication for Engineers (ENGL 398)**</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Structural Design I (ECIV 322)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Soil Mechanics (ECIV 330)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Engineering Hydraulics and Hydrology (ECIV 351)</td>
<td>3</td>
</tr>
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<td></td>
<td>Environmental Engineering (ECIV 368)</td>
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</tr>
<tr>
<td></td>
<td>Approved elective</td>
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</tr>
<tr>
<td></td>
<td>Year Total:</td>
<td>16</td>
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<tr>
<td></td>
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<td>16</td>
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</table>

### Fourth Year

<table>
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<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Breadth elective</td>
<td>3</td>
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<td></td>
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</tbody>
</table>
from the Department's areas of concentration are as follows:

Students enrolled in other majors may elect to pursue a minor in Civil Engineering requiring 15 credit hours. Course selections require the approval of a Civil Engineering minor advisor. Recommended courses from the Department's areas of concentration are as follows:

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Management (ECIV 340)</td>
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</tr>
<tr>
<td>Civil Engineering Senior Project (ECIV 398)</td>
<td>3</td>
</tr>
<tr>
<td>Approved elective&lt;sup&gt;b&lt;/sup&gt;</td>
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</tr>
<tr>
<td>Approved elective&lt;sup&gt;b&lt;/sup&gt;</td>
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</tr>
<tr>
<td>Breadth elective&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3</td>
</tr>
<tr>
<td>Civil Engineering Systems (ECIV 360)</td>
<td>3</td>
</tr>
<tr>
<td>Approved Natural Science Elective&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
</tr>
<tr>
<td>Approved elective&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3</td>
</tr>
<tr>
<td>Open elective&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3</td>
</tr>
<tr>
<td>Year Total:</td>
<td>15</td>
</tr>
</tbody>
</table>

Total Units in Sequence: 130

<sup>a</sup> University general education requirement

<sup>b</sup> Engineering general education requirement

<sup>c</sup> Must be an approved course in a traditional science other than chemistry or physics such as biology, astronomy, or geology.

---

**Co-op and Internship Programs** ([http://engineering.case.edu/coop](http://engineering.case.edu/coop))

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Civil Engineering students typically go on a Co-op following the 3rd academic year at CWRU but should discuss their plans for Co-op with their academic advisor as soon as possible. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition, but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop. Alternatively or additionally, students may obtain employment as summer interns.

**BS/MS Program**

The Department also encourages CWRU undergraduate students to make use of the university's BS/MS program to pursue advanced studies in Civil Engineering. Undergraduates should apply for the BS/MS program in their junior year so they are able to select senior electives that will also satisfy MS degree requirements. Up to 9 hours of senior electives may be counted in both the BS and MS program thus allowing the student to complete the MS degree in the fifth year of study. Fifth year tuition scholarships may also be available. For more information students should discuss the BS/MS program with their Academic Adviser and/or the department BS/MS program coordinator. Review the Office of Undergraduate Studies BS/MS program requirements here ([http://bulletin.case.edu/undergraduatestudies/gradprofessional/#accelerationtowardgraduatedegreetext](http://bulletin.case.edu/undergraduatestudies/gradprofessional/#accelerationtowardgraduatedegreetext)).

**Minor in Civil Engineering**

Students enrolled in other majors may elect to pursue a minor in Civil Engineering requiring 15 credit hours. Course selections require the approval of a Civil Engineering minor advisor. Recommended courses from the Department's areas of concentration are as follows:

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
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<tbody>
<tr>
<td>Engineering Mechanics</td>
<td></td>
</tr>
<tr>
<td>ECIV 160 Surveying and Computer Graphics</td>
<td></td>
</tr>
<tr>
<td>ECIV 211 Civil Engineering Materials</td>
<td></td>
</tr>
<tr>
<td>ECIV 310 Strength of Materials</td>
<td></td>
</tr>
<tr>
<td>ECIV 360 Civil Engineering Systems</td>
<td></td>
</tr>
<tr>
<td>ECIV 411 Elasticity, Theory and Applications</td>
<td></td>
</tr>
<tr>
<td>ECIV 420 Finite Element Analysis</td>
<td></td>
</tr>
<tr>
<td>Structural Engineering</td>
<td></td>
</tr>
<tr>
<td>ECIV 160 Surveying and Computer Graphics</td>
<td></td>
</tr>
<tr>
<td>ECIV 211 Civil Engineering Materials</td>
<td></td>
</tr>
<tr>
<td>ECIV 310 Strength of Materials</td>
<td></td>
</tr>
<tr>
<td>ECIV 320 Structural Analysis I</td>
<td></td>
</tr>
<tr>
<td>ECIV 321 Matrix Analysis of Structures</td>
<td></td>
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<tr>
<td>ECIV 322 Structural Design I</td>
<td></td>
</tr>
<tr>
<td>ECIV 323 Structural Design II</td>
<td></td>
</tr>
<tr>
<td>Geotechnical Engineering</td>
<td></td>
</tr>
<tr>
<td>ECIV 160 Surveying and Computer Graphics</td>
<td></td>
</tr>
<tr>
<td>ECIV 211 Civil Engineering Materials</td>
<td></td>
</tr>
<tr>
<td>ECIV 310 Strength of Materials</td>
<td></td>
</tr>
<tr>
<td>ECIV 330 Soil Mechanics</td>
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<tr>
<td>ECIV 360 Civil Engineering Systems</td>
<td></td>
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<tr>
<td>ECIV 430 Foundation Engineering</td>
<td></td>
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<tr>
<td>ECIV 433 Soil Dynamics</td>
<td></td>
</tr>
<tr>
<td>ECIV 437 Pavement Analysis and Design</td>
<td></td>
</tr>
<tr>
<td>Construction Engineering and Management</td>
<td></td>
</tr>
<tr>
<td>ECIV 160 Surveying and Computer Graphics</td>
<td></td>
</tr>
<tr>
<td>ECIV 211 Civil Engineering Materials</td>
<td></td>
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<tr>
<td>ECIV 340 Construction Management</td>
<td></td>
</tr>
<tr>
<td>ECIV 341 Construction Scheduling and Estimating</td>
<td></td>
</tr>
<tr>
<td>ECIV 360 Civil Engineering Systems</td>
<td></td>
</tr>
<tr>
<td>Environmental Engineering</td>
<td></td>
</tr>
<tr>
<td>ECIV 160 Surveying and Computer Graphics</td>
<td></td>
</tr>
<tr>
<td>ECIV 211 Civil Engineering Materials</td>
<td></td>
</tr>
<tr>
<td>ECIV 351 Engineering Hydraulics and Hydrology</td>
<td></td>
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<tr>
<td>ECIV 361 Water Resources Engineering</td>
<td></td>
</tr>
<tr>
<td>ECIV 362 Solid and Hazardous Waste Management</td>
<td></td>
</tr>
<tr>
<td>ECIV 368 Environmental Engineering</td>
<td></td>
</tr>
</tbody>
</table>

**Graduate Programs**

The MS and PhD programs in structural engineering, geotechnical engineering, engineering mechanics and environmental engineering prepare students for careers in industry, professional practice, research, and teaching. Experience has shown that job opportunities are excellent for students who receive advanced degrees in Civil Engineering from Case Western Reserve University. Recent advanced degree recipients have found positions in universities, consulting firms, state and federal agencies, aerospace firms, and the energy industry.

Each student's program of course work and research is tailored to his or her interests, in close consultation with a faculty advisor. For students
working toward the Master of Science degree, study plans may include a research-oriented thesis, a practice-oriented project, or courses only followed by a comprehensive exam. For students working toward the Doctor of Philosophy degree, a research dissertation is required.

Civil Engineering graduate students are also encouraged to review the CWRU School of Graduate Studies web page for additional details about University requirements for advanced degree programs.

Review the School of Graduate Studies MS and PhD degree requirements here (http://bulletin.case.edu/schoolorgraduatedestudies/academicrequirements).

Facilities

**Vanderhoof-Schouette Structural Laboratory**

The Vanderhoof-Schouette Structural Laboratory and Educational facility features a 2400 ft² cellular strong floor and a 28 ft. high, L-shaped cellular strong wall. The strong wall includes a vertical cell for testing tall specimens with loads up to 1000 kips. A 15-ton crane, a scissors lift, and a forklift truck are available for positioning specimens. A 95 gpm hydraulic pump powers servo-hydraulic actuators for applying static or dynamic loads. The laboratory has a variety of instrumentation and data acquisition equipment. Four 6 ft x 6 ft uni-axial shaking tables are available for seismic testing of small physical models.

**Environmental Engineering Laboratory**

This laboratory is one in a suite of laboratories that support Environmental Engineering teaching and research. The facilities include a teaching laboratory, an advanced instrumentation laboratory, an environmental research laboratory and an electronic classroom/software laboratory. The Environmental Engineering laboratory is equipped for conventional Standard Methods analysis of water, wastewater, soil, solid waste, and air samples (pH meters, furnaces, ovens, incubators, hoods, etc.) and for aerobic microbiology work. The lab also offers generous bench top space for student teams to explore laboratory procedures and provides direct access to research, instrumentation, and computational facilities.

**Environmental Biotechnology Laboratory**

This laboratory is equipped for culturing, processing, and analyzing microorganisms for remediation and biofuel research. Algae are cultivated in a Conviron A1000 growth chamber with programmable temperature and light controls. A Labcomp laminar-flow biocabinet and a Uamato autoclave are used for microbial culturing. Two refrigerated centrifuges, including a microcentrifuge, are available for culture separation. The laboratory is also equipped for molecular analyses with a thermal cycler and regulated temperature baths, with a New Brunswick incubated orbital shaker, a New Brunswick ultra-low temperature freezer and a Panasonic microwave oven.

**Geotechnical Engineering Laboratories**

The new state of the art Geotechnical Engineering Laboratories and Educational Facilities offer an ideal environment for teaching and research:

The Frank Gerace Undergraduate Laboratory has a complete array of modern units for characterizing and testing soils. Such units lend themselves to automated data acquisition and processing.

The Richard A. Saada Intelligent Geosystems Laboratory houses innovative interdisciplinary research including sensor and non-destructive technologies such as Time Domain Reflectometry (TDR), ultrasonics, fiber optic sensors, smart and functional materials, multiphysics processes in porous materials, etc.

The Saada Family Geotechnical Laboratory has a full array of strength and deformation testing units; notable are automated triaxial units for generalized extension and compression tests, units permitting simultaneous application of hydrostatic, axial and torsional static and dynamic loads, units by means of which one dimensional consolidation in the triaxial cell can be achieved, and various pore pressure, force and deformation measuring devices. Also available is a longitudinal and torsional resonant column device and a large size oedometer equipped with bender elements.

A 20g-tons fully automated centrifuge with a servo-hydraulic earthquake shaker is in operation.

The Warren C. Gibson library has a large array of reference materials, conference proceedings and internet connection to the University library and other sources of technical information.

**Haptic Research Laboratory**

The haptic interface laboratory hosts two state-of-the-art driving simulators. It provides holistic driving simulations for advanced research, education and training in the area of transportation safety, human perception and human-machine interface.

**Neff Civil Engineering Undergraduate Computer Laboratory**

This laboratory provides Civil Engineering students with access to all the computer resources needed for both course work and research. The laboratory is supplemented by other facilities provided by the university. All of the computers in the Neff lab can act as independent workstations or provide access via a fiber optic link to other campus computers.

**Civil Engineering Study Lounge**

This study area is designed to supplement the computer laboratories with a quiet workplace for individual or group study.

**ASCE Lounge**

Provides a student controlled venue for hosting American Society of Civil Engineers (ASCE) student chapter activities.

**Miller Library**

The Miller Library named in honor of Graig J. Miller, a former Civil Engineering faculty member, acts as both a library and as the Department’s premier meeting space.

**Vose Room**

The department also shares use of the Vose Room equipment for meetings and video conferencing.

**Courses**

**ECIV 160. Surveying and Computer Graphics. 3 Units.**

Principles and practice of surveying; error analysis, topographic mapping, introduction to photogrammetry and GIS; principles of graphics; computer-aided-drafting. Laboratory.
ECIV 211. Civil Engineering Materials. 3 Units.

ECIV 300. Undergraduate Research. 3 Units.
Research conducted under the supervision of a sponsoring Civil Engineering faculty member. Research can be done on an independent topic or as part of an established on-going research activity. The student will prepare a written report on the results of the research. Course may fulfill one technical elective requirement.

ECIV 310. Strength of Materials. 3 Units.

ECIV 320. Structural Analysis I. 3 Units.

ECIV 321. Matrix Analysis of Structures. 3 Units.
Matrix formulation and computer analysis (MATLAB recommended) for statically indeterminate linear structural systems; Stiffness method (direct/displacement method); Potential Energy Method; Development of element equations for 1D axial and flexural members and 2D triangle element; Transformation between local to global coordinates; Development of displacement fields (linear function for axial members and cubic function for flexural members); Shape function concept in approximation; Introduction to elasticity, finite element analysis and nonlinear structural analysis. Recommended preparation: Linear Algebra. Prereq: ECIV 320 and EMAE 250.

ECIV 322. Structural Design I. 3 Units.

ECIV 323. Structural Design II. 3 Units.

ECIV 324. Timber and Masonry Design. 3 Units.
Introduction to wood material. Design for timber beams and columns to resist vertical and lateral loads. Design of nailed and bolted connections. Introduction to masonry materials and design of wall. Prereq: ECIV 322.

ECIV 330. Soil Mechanics. 4 Units.
The physical, chemical, and mechanical properties of soils. Soil classification, capillarity, permeability, and flow nets. One dimensional consolidation, stress and settlement analysis. Shear strength, stability of cuts, and design of embankments, retaining walls and footings. Standard laboratory tests performed for the determination of the physical and mechanical properties of soils. Laboratory. Recommended preparation: ECIV 310.

ECIV 340. Construction Management. 3 Units.
Selected topics in construction management including specifications writing, contract documents, estimating, materials and labor, bidding procedures and scheduling techniques. The course is augmented by guest lecturers from local industries.

ECIV 341. Construction Scheduling and Estimating. 3 Units.
The focus is on scheduling, and estimating and bidding for public and private projects. This includes highways as well as industrial and building construction. The use of computers with the latest software in estimating materials, labor, equipment, overhead and profit is emphasized. Recommended preparation: ECIV 340 and consent of instructor.

ECIV 351. Engineering Hydraulics and Hydrology. 3 Units.
Application of fluid statics and dynamics to Civil Engineering Design. Hydraulic machinery, pipe network analysis, thrust, hammer, open channel flow, sewer system design, culverts, flow gauging, retention/detention basin design. Applied hydrology, hydrograph analysis and hydraulic routing will also be introduced. Recommended preparation: Concurrent enrollment in ENGR 225.

ECIV 360. Civil Engineering Systems. 3 Units.
Introduction to probability and statistics. Discrete and continuous random variables, probability distributions, bivariate data, probabilistic analysis of systems, and reliability analysis. Introduction to engineering economics. Interest rates and equivalence, present worth, rate of return analysis, depreciation, and inflation.

ECIV 361. Water Resources Engineering. 3 Units.
Water doctrine, probabilistic analysis of hydrologic data, common and rare event analysis, flood forecasting and control, reservoir design, hydrologic routing, synthetic streamflow generation, hydroelectric power, water resource quality, water resources planning. Recommended preparation: ECIV 351.

ECIV 362. Solid and Hazardous Waste Management. 3 Units.

ECIV 368. Environmental Engineering. 3 Units.
Principle and practice of environmental engineering. Water and waste water engineering unit operations and processes including related topics from industrial waste disposal, air pollution and environmental health.

ECIV 396. Civil Engineering Special Topics I. 1 - 3 Units.
Special topics in civil engineering in which a regular course is not available. Conferences and report.

ECIV 397. Civil Engineering Topics II. 3 Units.
Special topics in civil engineering in which a regular course is not available. Conferences and report.

ECIV 398. Civil Engineering Senior Project. 3 Units.
A project emphasizing research and/or design must be completed by all civil engineers. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Counts as SAGES Senior Capstone.
ECIV 400T. Graduate Teaching I. 0 Unit.
This series of three courses will provide Ph.D. students with practical experience in teaching at the University level and will expose them to effective teaching methods. Each course assignment will be organized in coordination with the student’s dissertation advisor and the department chairperson. Assignments will successively require more contact with students, with duties approaching the teaching requirements of a faculty member in the Ph.D. student’s area of study. Prereq: Ph.D. students in Civil Engineering.

ECIV 411. Elasticity, Theory and Applications. 3 Units.

ECIV 420. Finite Element Analysis. 3 Units.
Theory and application of the finite element method. Approximation theory as the basis for finite element methods. The formulations for a variety of finite elements in one, two, and three dimensions. The modeling and analysis of structural components and systems using planar, solid, and plate elements. Implementations of element formulations using Matlab. An advanced finite element analysis program will be used for analysis of structural problems. Recommended preparation: ECIV 321 is a prerequisite for structural engineering students. Background in advanced mechanics and numerical analysis of structures is required for this course. If you have not completed these courses, please discuss with the instructor. Prereq: Graduate Standing or ECIV 321.

ECIV 421. Advanced Topics in Reinforced Concrete Structures. 3 Units.
Group project-based course to design and evaluate multistory reinforced concrete structures according to the US building design codes (ACI318, ASCE7, ASCE41), including inelastic behavior of plain concrete, reinforced concrete, and reinforcing steel; inelastic rebar buckling and slip behavior; reinforcement design under various loads; design evaluation criteria at member level and system level; nonlinear static structural analysis method (Pushover analysis) for RC frames under dynamic lateral forces using an open source code (OpenSees). Prereq: Graduate Standing or ECIV 321, ECIV 322 and ECIV 323.

ECIV 422. Advanced Structural Steel Design. 3 Units.
Selected topics in structural steel design including plastic design, torsion, lateral buckling, torsional-flexural buckling, frame stability, plate girders, and connections, including critical review of current design specifications relating to these topics. Recommended preparation: ECIV 322.

ECIV 424. Structural Dynamics. 3 Units.
Modeling of structures as single and multidegree of freedom dynamic systems. The eigenvalue problem, damping, and the behavior of dynamic systems. Deterministic models of dynamic loads such as wind and earthquakes. Analytical methods, including modal, response spectrum, time history, and frequency domain analyses. Recommended preparation: ECIV 321 and consent of instructor.

ECIV 425. Structural Design for Dynamic Loads. 3 Units.
Structural design problems in which dynamic excitations are of importance. Earthquake, wind, blast, traffic, and machinery excitations. Human sensitivity to vibration, mechanical behavior of structural elements under dynamic excitation, earthquake response and earthquake-resistant design, wind loading, damping in structures, hysteretic energy dissipation, and ductility requirements. Recommended preparation: ECIV 424.

ECIV 426. Probabilistic Analysis. 3 Units.

ECIV 427. Environmental Organic Chemistry. 3 Units.
This is an advanced course focusing on examination of processes that effect the behavior and fate of anthropogenic organic contaminants in aquatic environments. The lectures will focus on intermolecular interactions and thermodynamic principles governing the kinetics of some of the important chemical and physicochemical transformation reactions of organic contaminants. Recommended Preparation: One semester of Organic chemistry or prior approval of the instructor.

ECIV 430. Foundation Engineering. 3 Units.

ECIV 431. Special Topics in Geotechnical Engineering. 3 Units.

ECIV 432. Mechanical Behavior of Soils. 3 Units.
Soil statics and stresses in a half space-tridimensional consolidation and sand drain theory; stress-strain relations and representations with rheological models. Critical state and various failure theories and their experimental justification for cohesive and noncohesive soils. Laboratory measurement of rheological properties, pore water pressures, and strength under combined stresses. Laboratory. Recommended preparation: ECIV 330.

ECIV 433. Soil Dynamics. 3 Units.

ECIV 434. Field Instrumentation and In situ Testing. 3 Units.

ECIV 437. Pavement Analysis and Design. 3 Units.
ECIV 450. Environmental Engineering Chemistry. 3 Units.
Fundamentals of inorganic, organic, and physical chemistry with emphasis on the types of problems encountered in the environmental engineering field. Equilibria among liquid, gaseous, and solid phases; kinetics to the extent that time permits. A strong mathematical approach is taken in solving the equilibrium and kinetic problems presented. Equilibrium speciation software for solution of more complex problems. Topics that will be covered in the course include chemical equilibrium, acid/base reactions, mathematical problem solving approach, graphical approaches, titration curves, solubility of gases and solids, buffering systems, numerical solution of equilibrium problems, thermodynamics, oxidation-reduction reactions, principles of quantitative chemistry and analytical techniques, introduction to the use of analytical instrumentation, and chemical kinetics. Prereq: ECIV 368 or requisites not met permission.

ECIV 456. Intelligent Infrastructure Systems. 3 Units.
Topics on smart infrastructure systems; smart materials fabrication, embedded sensing technology for infrastructure condition monitoring, the system models for infrastructural condition diagnosing and adaptive controlling, and spatial-temporal integrated infrastructure management system.

ECIV 461. Environmental Engineering Biotechnology. 3 Units.
Process design fundamentals for biological reactors applied to environmental engineering processes, including wastewater treatment, bioremediation, and bioenergy production. Topics include mass balances, methane fermentation, fixed-growth reactors, molecular biology tools, and reactor models. Recommended preparation: ECIV 368 Environmental Engineering.

ECIV 500T. Graduate Teaching II. 0 Unit.
This series of three courses will provide Ph.D. students with practical experience in teaching at the University level and will expose them to effective teaching methods. Each course assignment will be organized in coordination with the student's dissertation advisor and the department chairperson. Assignments will successively require more contact with students, with duties approaching the teaching requirements of a faculty member in the Ph.D. student's area of study. Prereq: Ph.D. student in Civil Engineering.

ECIV 500T. Graduate Teaching II. 0 Unit.

ECIV 560. Environmental Engineering Chemistry. 3 Units.
Fundamentals of inorganic, organic, and physical chemistry with emphasis on the types of problems encountered in the environmental engineering field. Equilibria among liquid, gaseous, and solid phases; kinetics to the extent that time permits. A strong mathematical approach is taken in solving the equilibrium and kinetic problems presented. Equilibrium speciation software for solution of more complex problems. Topics that will be covered in the course include chemical equilibrium, acid/base reactions, mathematical problem solving approach, graphical approaches, titration curves, solubility of gases and solids, buffering systems, numerical solution of equilibrium problems, thermodynamics, oxidation-reduction reactions, principles of quantitative chemistry and analytical techniques, introduction to the use of analytical instrumentation, and chemical kinetics. Prereq: ECIV 368 or requisites not met permission.

ECIV 561. Environmental Engineering Biotechnology. 3 Units.
Process design fundamentals for biological reactors applied to environmental engineering processes, including wastewater treatment, bioremediation, and bioenergy production. Topics include mass balances, methane fermentation, fixed-growth reactors, molecular biology tools, and reactor models. Recommended preparation: ECIV 368 Environmental Engineering.

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ECIV 561. Environmental Engineering Biotechnology. 3 Units.
Process design fundamentals for biological reactors applied to environmental engineering processes, including wastewater treatment, bioremediation, and bioenergy production. Topics include mass balances, methane fermentation, fixed-growth reactors, molecular biology tools, and reactor models. Recommended preparation: ECIV 368 Environmental Engineering.

Data Science and Analytics / Applied Data Science
Bachelor of Science in Data Science and Analytics
Administered by the Department of Electrical Engineering and Computer Science (p. 68)
Glennan Building (7071)
http://engineering.case.edu/eecs/
Phone: 216.368.3800, Fax: 216.368.6888
Alexis R. Abramson, PhD, Interim Chair
The Bachelor of Science degree program in Data Science and Analytics provides our students with a broad foundation in the field and the instruction, skills, and experience needed to understand and handle large amounts of data that transform thinking about a collection of vast amounts of data into one that focuses on the data's conversion to actionable information. The degree program has a unique focus on real-world data and real-world applications.

This major is one of the first undergraduate programs nationwide with a unique curriculum that includes mathematical modeling, informatics, data analytics, visual analytics and project-based applications - all elements of the future emerging field of data science.

Minor in Applied Data Science (ADS)
Administered by the Department of Electrical Engineering and Computer Science (p. 137)
312 White Building (7204)
http://engineering.case.edu/eecs/
Phone: 216.368.4230, Fax: 216.368.3209
Roger French, EMSE / CSE Faculty Director (ADS)
The Minor in Applied Data Science (https://case.edu/datascience) is based in the Case School of Engineering and includes faculty from schools across the university. The minor is directed to students studying in the domains of Engineering and Physical Sciences (including Energy and Manufacturing, Astronomy, Geology, Physics), Health (including Translational and Clinical), and Business (including Finance, Marketing, and Economics). Successful completion of the minor requirements leads to a "Minor in Applied Data Science" for the graduating student. The minor represents that the students have developed knowledge of the
essential elements of Data Science and Analytics in the area of their major (their domain of expertise).

**Bachelor of Science in Data Science and Analytics**

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

### Major Requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 111</td>
<td>Principles of Chemistry for Engineers</td>
<td>4</td>
</tr>
<tr>
<td>DSCI 133</td>
<td>Introduction to Data Science and Engineering for Majors</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 234</td>
<td>Structured and Unstructured Data</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 341</td>
<td>Introduction to Databases: DS Major</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 342</td>
<td>Introduction to Data Science Systems</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 343</td>
<td>Introduction to Data Analysis</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 344</td>
<td>Scalable Parallel Data Analysis</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 345</td>
<td>Files, Indexes and Access Structures for Big Data</td>
<td>3</td>
</tr>
<tr>
<td>EECS 132</td>
<td>Introduction to Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>EECS 302</td>
<td>Discrete Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>EECS 340</td>
<td>Algorithms</td>
<td>3</td>
</tr>
<tr>
<td>EECS 393</td>
<td>Software Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ENGL 398</td>
<td>Professional Communication for Engineers</td>
<td>2</td>
</tr>
<tr>
<td>ENGR 398</td>
<td>Professional Communication for Engineers</td>
<td>1</td>
</tr>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications</td>
<td>3</td>
</tr>
<tr>
<td>MATH 121</td>
<td>Calculus for Science and Engineering I</td>
<td>4</td>
</tr>
<tr>
<td>MATH 122</td>
<td>Calculus for Science and Engineering II</td>
<td>4</td>
</tr>
<tr>
<td>MATH 223</td>
<td>Calculus for Science and Engineering III</td>
<td>3</td>
</tr>
<tr>
<td>MATH 224</td>
<td>Elementary Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 121</td>
<td>General Physics I - Mechanics</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 122</td>
<td>General Physics II - Electricity and Magnetism</td>
<td>4</td>
</tr>
</tbody>
</table>

Core courses provide our students with a strong background in signal processing, systems, and analytics. Students are required to develop depth in at least one of the following technical areas: signal processing, systems, and analytics. Each data science and analytics student must complete the following requirements:

### Technical Elective Requirement

Each student must complete 8 courses (24 credit-hours) of approved technical electives. Technical electives shall be chosen to fulfill the probability/statistics elective (1 course), the computer and data security elective (1 course), the depth requirement (3 courses), and 3 courses otherwise chosen to increase the student's understanding of data science and analytics. Technical electives not used to satisfy the probability/statistics elective, the computer and data security elective, or the depth requirement are more generally defined as any course related to the principles and practice of data science and analytics. This includes all DSCI courses at the 200 level and above and can include courses from other programs. All non-DSCI technical electives must be approved by the student's academic advisor.

### Depth Requirement

Each student must show a depth of competence in one technical area by taking at least three courses from one of the following three areas. Additional courses, beyond those that are listed, may be approved by the student's academic advisor.

#### Area I: Signal Processing

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>EECS 313</td>
<td>Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
</tr>
</tbody>
</table>

#### Area II: Systems

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 325</td>
<td>Computer Networks I</td>
<td>3</td>
</tr>
<tr>
<td>or EECS 425</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EECS 338</td>
<td>Intro to Operating Systems and Concurrent Programming</td>
<td>4</td>
</tr>
<tr>
<td>EECS 600</td>
<td>Special Topics (Cloud Computing)</td>
<td>1-18</td>
</tr>
</tbody>
</table>

#### Area III: Analytics

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSCI 390</td>
<td>Machine Learning for Big Data</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 391</td>
<td>Data Mining for Big Data</td>
<td>3</td>
</tr>
<tr>
<td>EECS 339</td>
<td>Web Data Mining</td>
<td>3</td>
</tr>
<tr>
<td>EECS 346</td>
<td>Engineering Optimization</td>
<td>3</td>
</tr>
<tr>
<td>EECS 440</td>
<td>Machine Learning</td>
<td>3</td>
</tr>
<tr>
<td>EECS 442</td>
<td>Causal Learning from Data</td>
<td>3</td>
</tr>
</tbody>
</table>

### Computer and Data Security Elective Requirement

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 444</td>
<td>Computer Security</td>
<td>3</td>
</tr>
<tr>
<td>MATH 408</td>
<td>Introduction to Cryptology</td>
<td>3</td>
</tr>
</tbody>
</table>

### Statistics Requirement

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 380</td>
<td>Introduction to Probability</td>
<td>3</td>
</tr>
<tr>
<td>STAT 325</td>
<td>Data Analysis and Linear Models</td>
<td>3</td>
</tr>
</tbody>
</table>

### Design Requirement

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSCI 398</td>
<td>Engineering Projects I</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 399</td>
<td>Engineering Projects II</td>
<td>3</td>
</tr>
</tbody>
</table>

### Suggested Program of Study: Bachelor of Science in Data Science and Analytics

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

#### First Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES First Year Seminar*</td>
<td>4</td>
</tr>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)</td>
<td>4</td>
</tr>
</tbody>
</table>
Calculus for Science and Engineering I (MATH 121) 4
Introduction to Programming in Java (EECS 132) 3
PHED (2 half semester courses)* 0
SAGES University Seminar* 3
General Physics I - Mechanics (PHYS 121) 4
Calculus for Science and Engineering II (MATH 122) 4
Introduction to Data Science and Engineering for Majors (DSCI 133) 3
PHED (2 half semester courses)* 0
Open Elective 3
Year Total: 15 17

Second Year

SAGES University Seminar* 3
General Physics II - Electricity and Magnetism (PHYS 122) 4
Calculus for Science and Engineering III (MATH 223) 3
Structured and Unstructured Data (DSCI 234) 3
Discrete Mathematics (EECS 302) 3
Introduction to Databases: DS Major (DSCI 341) 3
Elementary Differential Equations (MATH 224) 3
Algorithms (EECS 340) 3
Breadth elective** 3
Probability/Statistics Electivea 3
Year Total: 16 15

Third Year

Introduction to Data Science Systems (DSCI 342) 3
Software Engineering (EECS 393) 3
Breadth elective** 3
Introduction to Data Analysis (DSCI 343) 3
Introduction to Linear Algebra for Applications (MATH 201) 3
Professional Communication for Engineers (ENGL 398) 2
Professional Communication for Engineers (ENGR 398) 1
Scalable Parallel Data Analysis (DSCI 344) 3
Computer and Data Security Electiveb 3
Files, Indexes and Access Structures for Big Data (DSCI 345) 3
Technical Electivec 3
Year Total: 15 15

Fourth Year

Technical Electivec 3
Technical Electivec 3
DSCI 398 Senior Project I 4
Technical Electivec 3
Breadth elective** 3

Breadth elective** 3
DSCI Technical electivec 3
DSCI 399 Senior Project II 4
Technical electived 3
Open elective 3
Year Total: 16 16

Total Units in Sequence: 125

* University general education requirement
** Engineering general education requirement
a Probability and statistics elective (MATH 380 Introduction to Probability, STAT 325 Data Analysis and Linear Models)
b Computer and data security elective (EECS 444 Computer Security, MATH 408 Introduction to Cryptology)
c Technical electives in signal processing, systems, and analytics (see lists of approved courses under program requirements)
d Technical electives

Minor in Applied Data Science (ADS)

Elements of the Minor:
The minor is structured so that the students who qualify for the minor have a working understanding of the basic ADS tools and their application in their domain area. This includes:

- Data Management: datastores, sources, streams;
- Distributed Computing: local computer, distributed computing (such as Hadoop), or other cloud computing;
- Informatics, Ontology, Query: including search, data assembly, annotation; and
- Statistical Analytics: tools such as R statistics and high-level scripting languages (such as Python).

The data types found in these domains are diverse. They include time series and spectral data for Energy and Astronomy, and sensor and production data and image and volumetric data for Manufacturing. In Health, Translational ADS includes Genomic, Proteomic, and other Omics data, while Clinical ADS includes patient data, medical data, physiological time series, and mobile data. Business data types include stock and other financial market data for Finance, time series and cross-section data for Economics, and operations and consumer behavior data for Marketing.

Students will develop comprehensive experience in the steps of data analysis.

- Define the Applied Data Science questions.
- Identify, locate, and/or generate the necessary data, including defining the ideal data set and variables of interest, determining and obtaining accessible data and cleaning the data in preparation for analysis.
- Exploratory data analysis to start identifying the significant characteristics of the data and information it contains.
- Statistical modeling and prediction, including interpretation of results, challenging results, and developing insights and actions.
Course syllabus and requirements include:

- Synthesizing the results in the context of the domain and the initial questions, and writing this up.
- The creation of reproducible research, including code, datasets, documentation, and reports, which are easily transferable and verifiable.

The ADS minor curriculum
The curriculum is based on five 3-credit courses, with one class chosen from each of Levels 1 through Level 5, which cover the spectrum of learning needed to achieve domain area expertise in data science and analytics. The courses are chosen to be both cross-cutting, i.e., intermixing students from across the university in the fundamental concepts such as scripting and statistics (Levels 1, 2, and 4), and domain-focused (Levels 3 and 5). For the Level 4 undergraduate research course, the research topic will be approved by the minor advisor, and will also be a 3-credit project. This will provide minor students both the domain focused learning they need, and a broadening perspective on applications, methods, and uses of ADS in other domains.

Courses Counted Toward Minor Requirements
Established courses included in the Minor are found in Case School of Engineering (Materials Science, Electrical Engineering and Computer Science, Manufacturing), College of Art & Science (Mathematics, Astronomy, Philosophy); School of Medicine, School of Nursing, and Weatherhead School of Management (Marketing, Finance, Operations, and Economics).

The courses that meet the requirements for the Minor can also be taken by students to meet requirements in Major programs, and therefore serve a dual purpose in our academic offerings. However, each program, department, and school may have its own criteria on whether a given course could be “double counted” towards major and minor requirements.

Level 5:
- BAFI 361 Empirical Analysis in Finance 3
- ECON 327 Advanced Econometrics 3
- MKMR 308 Measuring Marketing Performance 3
- MKMR 310 Marketing Analytics 3
- SYBB 459 Bioinformatics for Systems Biology 3

Level 4:
- ASTR 369 Undergraduate Research 1 - 3
- DSCI 352 Applied Data Science Research 3
- EMSE 325 Undergraduate Research in Materials Science and Engineering 1 - 3
- SYBB 387 Undergraduate Research in Systems Biology 1 - 3

Level 3:
- DSCI 351 Exploratory Data Science 3
- MKMR 201 Marketing Management 3
- SYBB 311A Survey of Bioinformatics: Technologies in Bioinformatics 1
- SYBB 311B Survey of Bioinformatics: Data Integration in Bioinformatics 1
- SYBB 311C Survey of Bioinformatics: Translational Bioinformatics 1
- SYBB 421 Fundamentals of Clinical Information Systems 3

Courses

DSCI 133. Introduction to Data Science and Engineering for Majors. 3 Units.
This course is an introduction to data science and analytics. In the first half of the course, students will develop a basic understanding of how to manipulate, analyze and visualize large data in a distributed computing environment, with an appreciation of open source development, security and privacy issues. Case studies and team project assignments in the second half of the course will be used to implement the ideas. Topics covered will include: Overview of large scale parallel and distributed (cloud) computing; file systems and file i/o; open source coding and distributed versioning, data query and retrieval; basic data analysis; visualization; data security, privacy and provenance. Prereq: ENGR 131 or EECS 132.

DSCI 134. Introduction to Applied Data Science. 3 Units.
This course is an introduction to data science and analytics. In the first half of the course, students will develop a basic understanding of how to manipulate, analyze and visualize large data in a distributed computing environment, with an appreciation of open source development, security and privacy issues. In the second half of the course, students will gain experience in data manipulation and analysis using scripted programming languages such as Python.
DSCI 234. Structured and Unstructured Data. 3 Units.
This course is an introduction to types of data and their representation, storage, processing and analysis. The course has three parts. In the first part of the course, students will develop a basic understanding and the ability to represent, store, process and analyze structured data. Structured data include catalogs, records, tables, logs, etc., with a fixed dimension and well-defined meaning for each data point. Suitable representation and storage mechanisms include lists and arrays. Relevant techniques include keys, hashes, stacks, queues and trees. In the second part of the course, students will develop a basic understanding and the ability to represent, store, process and analyze semi-structured data. Semi-structured data include texts, web pages and networks, without a dimension and structure, but with well-defined meaning for each data point. Suitable representation and storage mechanisms include trees, graphs and RDF triples. Relevant techniques include XML, YAML, JSON, parsing, annotation, language processing. In the third part of the course, students will develop a basic understanding and the ability to represent, store, process and analyze unstructured data. Unstructured data include images, video, and time series data, without neither a fixed dimension and structure, nor well-defined meaning for individual data points. Suitable representation and storage mechanisms include large matrices, EDF, DICOM. Relevant techniques include feature extraction, segmentation, clustering, rendering, indexing, and visualization. Prereq: DSCI 133.

DSCI 330. Cognition and Computation. 3 Units.
An introduction to (1) theories of the relationship between cognition and computation; (2) computational models of human cognition (e.g. models of decision-making or concept creation); and (3) computational tools for the study of human cognition. All three dimensions involve data science: theories are tested against archives of brain imaging data; models are derived from and tested against datasets of e.g., financial decisions (markets), legal rulings and findings (juries, judges, courts), legislative actions, and healthcare decisions; computational tools aggregate data and operate upon it analytically, for search, recognition, tagging, machine learning, statistical description, and hypothesis testing. Offered as COGS 330, COGS 430, DSCI 330 and DSCI 430.

DSCI 341. Introduction to Databases: DS Major. 3 Units.
Database management become a central component of a modern computing environment, and, as a result, knowledge about database systems has become an essential part of education in computer science and data science. This course is an introduction to the nature and purpose of database systems, fundamental concepts for designing, implementing and querying a database and database architectures. Weeks 1-6 provide an overview of basic database systems concepts including database design, database systems architecture, and database querying, using relational model and SQL as query language. Weeks 7-10 Objects, Semi structured data, XML and RDF basics. Weeks 11-14 provide an overview of more advanced topics including Database System Architectures (Parallel Databases and Distributed Databases), and Data Warehousing and Information Retrieval. Prereq: DSCI 234 or EECS 233.

DSCI 342. Introduction to Data Science Systems. 3 Units.
An introduction to the software and hardware architecture of data science systems, with an emphasis on Operating Systems and Computer Architecture that are relevant to Data Sciences systems. At the end of the course, the student should understand the principles and architecture of storage systems, file systems (especially HDFS), memory hierarchy, and GPU. The student should have carried out projects in these areas, and should be able to critically compare various design decisions in terms of capability and performance. Prereq: DSCI 234.

DSCI 343. Introduction to Data Analysis. 3 Units.
In this class we will give a broad overview of data analysis techniques, covering techniques from data mining, machine learning and signal processing. Students will also learn about probabilistic representations, how to conduct an empirical study and support empirical hypotheses through statistical tests, and visualize the results. Course objectives: -Expose students to different analysis approaches. -Understand probabilistic representations and inference mechanisms. -Understand how to create empirical hypotheses and how to test them. Prereq: EECS 340 and DSCI 234.

DSCI 344. Scalable Parallel Data Analysis. 3 Units.
This course provides an introduction to scalable and parallel data analysis using the most common frameworks and programming tools in the age of big data. Covered topics include parallel programming models, parallel hardware architectures, multi-threaded, multi-core programming, cluster computing and GPU programming. The course is designed to provide a heavily hands-on experience with several programming assignments. Prereq: DSCI 342.

DSCI 345. Files, Indexes and Access Structures for Big Data. 3 Units.
Database management become a central component of a modern computing environment, and, as a result, knowledge about database systems has become an essential part of education in computer science and data science. This course is an introduction to the nature and purpose of database systems, fundamental concepts for designing, implementing and querying a database and database architectures. Objectives: -An expert knowledge of basic data structures, basic searching, sorting, methods, algorithm techniques, (such as greedy and divide and conquer) -In-depth knowledge on Search and Index Structures for large, heterogeneous data including multidimensional data, high dimensional data and data in metric spaces (e.g., sequences, images), on different search methods (e.g. similarity searching, partial match, exact match), and on dimensionality reduction techniques. Prereq: DSCI 234 or EECS 233.

DSCI 351. Exploratory Data Science. 3 Units.
In this course, we will learn data science and analysis approaches to identify statistically significant relationships and better model and predict the behavior of these systems. We will assemble and explore real-world datasets, perform clustering and pair plot analyses to investigate correlations, and logistic regression will be employed to develop associated predictive models. Results will be interpreted, visualized and discussed. We will introduce basic elements of statistical analysis using R Project open source software for exploratory data analysis and model development. R is an open-source software project with broad abilities to access machine-readable open-data resources, data cleaning and munging functions, and a rich selection of statistical packages, used for data analytics, model development and prediction. This will include an introduction to R data types, reading and writing data, looping, plotting and regular expressions, so that one can start performing variable transformations for linear fitting and developing structural equation models, while exploring for statistically significant relationships. The M section of DSCI 351 is for students focusing on Materials Data Science. Offered as DSCI 351, DSCI 351M and DSCI 451. Prereq: (ENGR 131 or EECS 132 or DSCI 134) and (STAT 312R or STAT 201R or SYBB 310 or PQHS/EPBI 431).
DSCI 351M. Exploratory Data Science. 3 Units.
In this course, we will learn data science and analysis approaches to identify statistically significant relationships and better model and predict the behavior of these systems. We will assemble and explore real-world datasets, perform clustering and pair plot analyses to investigate correlations, and logistic regression will be employed to develop associated predictive models. Results will be interpreted, visualized and discussed. We will introduce basic elements of statistical analysis using R Project open source software for exploratory data analysis and model development. R is an open-source software project with broad abilities to access machine-readable open-data resources, data cleaning and munging functions, and a rich selection of statistical packages, used for data analytics, model development and prediction. This will include an introduction to R data types, reading and writing data, looping, plotting and regular expressions, so that one can start performing variable transformations for linear fitting and developing structural equation models, while exploring for statistically significant relationships. The M section of DSCI 351 is for students focusing on Materials Data Science. Offered as DSCI 351, DSCI 351M and DSCI 451. Prereq: (ENGR 131 or EECS 132 or DSCI 134) and (STAT 312R or STAT 201R or SYBB 310 or PQHS/EPBI 431).

DSCI 352. Applied Data Science Research. 3 Units.
This is a project based data science research class, in which project teams identify a research project under the guidance of a domain expert professor. The research is structured as a data analysis project including the 6 steps of developing a reproducible data science project, including 1: Define the ADS question, 2: Identify, locate, and/or generate the data 3: Exploratory data analysis 4: Statistical modeling and prediction 5: Synthesizing the results in the domain context 6: Creation of reproducible research, Including code, datasets, documentation and reports. During the course special topic lectures will include Ethics, Privacy, Openness, Security, Ethics. Value. The M section of DSCI 352 is for students focusing on Materials Data Science. Offered as DSCI 352, DSCI 352M and DSCI 452. Prereq: (DSCI 133 or DSCI 134 or ENGR 131 or EECS 132) and (STAT 312R or STAT 201R or SYBB 310 or PQHS/EPBI 431 or OPRE 207) and (DSCI 351 or (SYBB 311A and SYBB 311B and SYBB 311C and SYBB 311D) or SYBB 321 or MKMR 201).

DSCI 352M. Applied Data Science Research. 3 Units.
This is a project based data science research class, in which project teams identify a research project under the guidance of a domain expert professor. The research is structured as a data analysis project including the 6 steps of developing a reproducible data science project, including 1: Define the ADS question, 2: Identify, locate, and/or generate the data 3: Exploratory data analysis 4: Statistical modeling and prediction 5: Synthesizing the results in the domain context 6: Creation of reproducible research, Including code, datasets, documentation and reports. During the course special topic lectures will include Ethics, Privacy, Openness, Security, Ethics. Value. The M section of DSCI 352 is for students focusing on Materials Data Science. Offered as DSCI 352, DSCI 352M and DSCI 452. Prereq: (DSCI 133 or DSCI 134 or ENGR 131 or EECS 132) and (STAT 312R or STAT 201R or SYBB 310 or PQHS/EPBI 431 or OPRE 207) and (DSCI 351 or (SYBB 311A and SYBB 311B and SYBB 311C and SYBB 311D) or SYBB 321 or MKMR 201).

DSCI 353. Data Science: Statistical Learning, Modeling and Prediction. 3 Units.
In this course, we will use an open data science tool chain to develop reproducible data analyses useful for inference, modeling and prediction of the behavior of complex systems. In addition to the standard data cleaning, assembly and exploratory data analysis steps essential to all data analyses, we will identify statistically significant relationships from datasets derived from population samples, and infer the reliability of these findings. We will use regression methods to model a number of both real-world and lab-based systems producing predictive models applicable in comparable populations. We will assemble and explore real-world datasets, use pair-wise plots to explore correlations, perform clustering, self-similarity, and logistic regression develop both fixed-effect and mixed-effect predictive models. We will introduce machine-learning approaches for classification and tree-based methods. Results will be interpreted, visualized and discussed. We will introduce the basic elements of data science and analytics using R Project open source software. R is an open-source software project with broad abilities to access machine-readable open-data resources, data cleaning and assembly functions, and a rich selection of statistical packages, used for data analytics, model development, prediction, inference and clustering. For students with little prior R experience, we’ll introduce resources to learn R data types, reading and writing data, looping, plotting and regular expressions. With this background, it becomes possible to start performing variable transformations for linear regression fitting and developing structural equation models, fixed-effects and mixed-effects models along with other statistical learning techniques, while exploring for statistically significant relationships. The class will be structured to have a balance of theory and practice. We’ll split class into Foundation and Practicum a) Foundation: lectures, presentations, discussion b) Practicum: coding, demonstrations and hands-on data science work. Offered as DSCI 353, DSCI 353M and DSCI 453.
DSCI 353M. Data Science: Statistical Learning, Modeling and Prediction. 3 Units.

In this course, we will use an open data science tool chain to develop reproducible data analyses useful for inference, modeling and prediction of the behavior of complex systems. In addition to the standard data cleaning, assembly and exploratory data analysis steps essential to all data analyses, we will identify statistically significant relationships from datasets derived from population samples, and infer the reliability of these findings. We will use regression methods to model a number of both real-world and lab-based systems producing predictive models applicable in comparable populations. We will assemble and explore real-world datasets, use pair-wise plots to explore correlations, perform clustering, self-similarity, and logistic regression develop both fixed-effect and mixed-effect predictive models. We will introduce machine-learning approaches for classification and tree-based methods. Results will be interpreted, visualized and discussed. We will introduce the basic elements of data science and analytics using R Project open source software. R is an open-source software project with broad abilities to access machine-readable open-data resources, data cleaning and assembly functions, and a rich selection of statistical packages, used for data analytics, model development, prediction, inference and clustering. For students with little prior R experience, we’ll introduce resources to learn R data types, reading and writing data, looping, plotting and regular expressions. With this background, it becomes possible to start performing variable transformations for linear regression fitting and developing structural equation models, fixed-effects and mixed-effects models along with other statistical learning techniques, while exploring for statistically significant relationships. The class will be structured to have a balance of theory and practice. We’ll split class into Foundation and Practicum a) Foundation: lectures, presentations, discussion b) Practicum: coding, demonstrations and hands-on data science work. Offered as DSCI 353, DSCI 353M and DSCI 453.

DSCI 390. Machine Learning for Big Data. 3 Units.

Machine learning is a sub-field of Artificial Intelligence that is concerned with the design and analysis of algorithms that "learn" and improve with experience. While the broad aim behind research in this area is to build systems that can simulate or even improve on certain aspects of human intelligence, algorithms developed in this area have become very useful in analyzing and predicting the behavior of complex systems. Machine learning algorithms have been used to guide diagnostic systems in medicine, recommend interesting products to customers in e-commerce, play games at human championship levels, and solve many other very complex problems. This course is an introduction to algorithms for machine learning and their implementation in the context of big data. We will study different learning settings, the different algorithms that have been developed for these settings, and learn about how to implement these algorithms and evaluate their behavior in practice. We will also discuss dealing with noise, missing values, scalability properties and talk about tools and libraries available for these methods. At the end of the course, you should be able to: --Understand when to use machine learning algorithms; --Understand, represent and formulate the learning problem; --Apply the appropriate algorithm(s) or tools, with an understanding of the tradeoffs involved including scalability and robustness; --Correctly evaluate the behavior of the algorithm when solving the problem. Prereq: DSCI 234 and DSCI 343.

DSCI 391. Data Mining for Big Data. 3 Units.

With the unprecedented rate at which data is being collected today in almost all fields of human endeavor, there is an emerging economic and scientific need to extract useful information from it. Data mining is the process of automatic discovery of patterns, changes, associations and anomalies in massive databases, and is a highly interdisciplinary field representing the confluence of several disciplines, including database systems, data warehousing, machine learning, statistics, algorithms, data visualization, and high-performance computing. This course is an introduction to the commonly used data mining techniques. In the first part of the course, students will develop a basic understanding of the basic concepts in data mining such as frequent pattern mining, association rule mining, basic techniques for data preprocessing such as normalization, regression, and classic matrix decomposition methods such as SVD, LU, and QR decompositions. In the second part of the course, students will develop a basic understanding of classification and clustering and be able to apply classic methods such as k-means, hierarchical clustering methods, nearest neighbor methods, association based classifiers. In the third part of the course, students will have a chance to study more advanced data mining applications such as feature selection in high-dimensional data, dimension reduction, and mining biological datasets. Prereq: DSCI 234 and DSCI 343.

DSCI 430. Cognition and Computation. 3 Units.

An introduction to (1) theories of the relationship between cognition and computation; (2) computational models of human cognition (e.g. models of decision-making or concept creation); and (3) computational tools for the study of human cognition. All three dimensions involve data science: theories are tested against archives of brain imaging data; models are derived from and tested against datasets of e.g., financial decisions (markets), legal rulings and findings (juries, judges, courts), legislative actions, and healthcare decisions; computational tools aggregate data and operate upon it analytically, for search, recognition, tagging, machine learning, statistical description, and hypothesis testing. Offered as COGS 330, COGS 430, DSCI 330 and DSCI 430.

DSCI 451. Exploratory Data Science. 3 Units.

In this course, we will learn data science and analysis approaches to identify statistically significance relationships and better model and predict the behavior of these systems. We will assemble and explore real-world datasets, perform clustering and pair plot analyses to investigate correlations, and logistic regression will be employed to develop associated predictive models. Results will be interpreted, visualized and discussed. We will introduce basic elements of statistical analysis using R Project open source software for exploratory data analysis and model development. R is an open-source software project with broad abilities to access machine-readable open-data resources, data cleaning and munging functions, and a rich selection of statistical packages, used for data analytics, model development and prediction. This will include an introduction to R data types, reading and writing data, looping, plotting and regular expressions, so that one can start performing variable transformations for linear fitting and developing structural equation models, while exploring for statistically significant relationships. The M section of DSCI 351 is for students focusing on Materials Data Science. Offered as DSCI 351, DSCI 351M and DSCI 451.
DSCI 452. Applied Data Science Research. 3 Units.
This is a project based data science research class, in which project teams identify a research project under the guidance of a domain expert professor. The research is structured as a data analysis project including the 6 steps of developing a reproducible data science project, including 1: Define the ADS question, 2: Identify, locate, and/or generate the data 3: Exploratory data analysis 4: Statistical modeling and prediction 5: Synthesizing the results in the domain context 6: Creation of reproducible research, including code, datasets, documentation and reports. During the course special topic lectures will include Ethics, Privacy, Openness, Security, Ethics. Value. The M section of DSCI 352 is for students focusing on Materials Data Science. Offered as DSCI 352, DSCI 352M and DSCI 452.

DSCI 453. Data Science: Statistical Learning, Modeling and Prediction. 3 Units.
In this course, we will use an open data science tool chain to develop reproducible data analyses useful for inference, modeling and prediction of the behavior of complex systems. In addition to the standard data cleaning, assembly and exploratory data analysis steps essential to all data analyses, we will identify statistically significant relationships from datasets derived from population samples, and infer the reliability of these findings. We will use regression methods to model a number of both real-world and lab-based systems producing predictive models applicable in comparable populations. We will assemble and explore real-world datasets, use pair-wise plots to explore correlations, perform clustering, self-similarity, and logistic regression develop both fixed-effect and mixed-effect predictive models. We will introduce machine-learning approaches for classification and tree-based methods. Results will be interpreted, visualized and discussed. We will introduce the basic elements of data science and analytics using R Project open source software. R is an open-source software project with broad abilities to access machine-readable open-data resources, data cleaning and assembly functions, and a rich selection of statistical packages, used for data analytics, model development, prediction, inference and clustering.

For students with little prior R experience, we’ll introduce resources to learn R data types, reading and writing data, looping, plotting and regular expressions. With this background, it becomes possible to start performing variable transformations for linear regression fitting and developing structural equation models, fixed-effects and mixed-effects models along with other statistical learning techniques, while exploring for statistically significant relationships. The class will be structured to have a balance of theory and practice. We’ll split class into Foundation and Practicum a) Foundation: lectures, presentations, discussion b) Practicum: coding, demonstrations and hands-on data science work. Offered as DSCI 353, DSCI 353M and DSCI 453.
communications skills to become leaders in creating the new techniques and technologies which will advance their fields. To achieve this goal, the department offers a wide range of technical specialties consistent with the breadth of electrical engineering and computer science, including recent developments in the field. Because of the rapid pace of advancement in these fields, our degree programs emphasize a broad and foundational science and technology background that equips students for future developments. Our programs include a wide range of electives and our students are encouraged to develop individualized programs which can combine many aspects of electrical engineering and computer science.

Research
The research thrusts of the Electrical Engineering and Computer Science department include:

1. Micro/Nano Systems
2. Electronics and Instrumentation
3. Robotics and Haptics
4. Embedded Systems, including VLSI, FPGA
6. Bioinformatics and Systems Biology
7. Machine Learning and Data Mining
8. Computer Networks and Distributed Systems
9. Secure and Reliable Software
10. Energy Systems, including Wind and Power Grid Management/Control
11. Gaming, Simulation, Optimization
12. Medical Informatics and Wireless Health

EECS participates in a number of groundbreaking collaborative research and educational programs, including the Microelectromechanical Systems Research Program, the Center for Computational Genomics, graduate program in Systems Biology and Bioinformatics, the Clinical & Translational Science Collaborative, the Great Lakes Energy Institute, and the VA Center for Advanced Platform Technology.

Electrical, Computer, and Systems Engineering Division
Marc Buchner, PhD
(Michigan State University)
Associate Professor
Computer gaming and simulation, virtual reality, software-defined radio, wavelets, joint time-frequency analysis

M. Cenk Cavusoglu, PhD
(University of California, Berkeley)
Associate Chair, Professor
Robotics, systems and control theory, and human-machine interfaces; with emphasis on medical robotics, haptics, virtual environments, surgical simulation, and bio-system modeling and simulation

Vira Chankong, PhD
(Case Western Reserve University)
Associate Professor
Large-scale optimization; logic-based optimization; multi-objective optimization; optimization applications in radiation therapy treatment planning, medical imaging, manufacturing and production systems, and engineering design problems

Philip Feng, PhD
(California Institute of Technology)
Associate Professor
Nanoelectromechanical systems (NEMS), energy-efficient devices, advanced materials & devices engineering, bio/chemical sensors & biomedical microsystems, RF/microwave devices & circuits, low-noise measurement & precision instruments

Michael Fu, PhD
(Case Western Reserve University)
Assistant Professor
Neuro-rehabilitation and motor-relearning, with emphasis on virtual environments, neuromuscular electrical stimulation, robotics, psychophysics, haptic interfaces, and brain-machine interfaces

Roberto Fernandez Galan, PhD
(Humboldt Universität)
Assistant Professor
Systems Biology, Signal Processing and Data Analysis, Computational Neuroscience and Electrophysiology

Mario Garcia-Sanz, DrEng
(University of Navarra, Spain)
Professor
Robust and nonlinear control, quantitative feedback theory, multivariable control, dynamic systems, systems modeling and identification; energy innovation, wind energy, spacecraft, electrical, mechanical, environmental and industrial applications

Evren Gurkan-Cavusoglu, PhD
(Middle East Technical University)
Assistant Professor
Health Informatics, HCI, Visualization

Gregory S. Lee, PhD
(University of Washington)
Assistant Professor
Haptic devices, including low-power design and effects on perception; applications to robotic surgery and telesurgery; secure teleoperation

Pan Li, PhD
(University of California, Los Angeles)
Assistant Professor
Health Informatics, HCl, Visualization

Ming-Chun Huang, PhD
(University of California, Los Angeles)
Assistant Professor
Health Informatics, HCl, Visualization

Wei Lin, PhD
(Washington University in St. Louis)
Professor
Nonlinear control, dynamic systems and homogeneous systems theory, H-infinity and robust control, adaptive control, system parameter estimation and fault detection, nonlinear control applications to under-actuated mechanical systems, biologically-inspired systems and systems biology
Kenneth A. Loparo, PhD  
(Case Western Reserve University)  
*Nord Professor of Engineering*

Stability and control of nonlinear and stochastic systems; fault detection, diagnosis, and prognosis; recent applications work in advanced control and failure detection of rotating machines, signal processing for the monitoring and diagnostics of physiological systems, and modeling, analysis, and control of power and energy systems

Behnam Malakooti, PhD, PE  
(Purdue University)  
*Professor*

Design and multi-objective optimization, manufacturing/production/operations systems, intelligent systems and networks, artificial neural networks, biological systems, intelligent decision making

Soumyajit Mandal, PhD  
(Massachusetts Institute of Technology)  
*Assistant Professor*

Integrated Circuits and Systems, Nuclear Magnetic Resonance (NMR) Sensors

Mehran Mehregany, PhD  
(Massachusetts Institute of Technology)  
*Goodrich Professor of Engineering Innovation*

Research and development at the intersections of micro/nano-electromechanical systems, semiconductor silicon carbide and integrated circuits

Pedram Mohseni, PhD  
(University of Michigan)  
*Professor*

Biomedical microsystems, bioelectronics, wireless neural interfaces, CMOS interface circuits for MEMS, low-power wireless sensing/actuating microsystems

Wyatt S. Newman, PhD, PE  
(Massachusetts Institute of Technology)  
*Professor*

Mechatronics, high-speed robot design, force- and vision-based machine control, artificial reflexes for autonomous machines, rapid prototyping, agile manufacturing, mobile robotic platforms

Christos Papachristou, PhD  
(Johns Hopkins University)  
*Professor*

VLSI design and CAD, computer architecture and parallel processing, design automation, embedded system design

Marija Prica, PhD  
(Carnegie Mellon University)  
*Assistant Professor*

Energy, Optimization, Protection

Daniel Saab, PhD  
(University of Illinois at Urbana-Champaign)  
*Associate Professor*

Computer architecture, VLSI system design and test, CAD design automation

Sree N. Sreenath, PhD  
(University of Maryland)  
*Professor*

Systems biology complexity research (modeling, structural issues, and simulation); cell signaling, population behavior, and large-scale behavior; global issues and sustainable development

Christian A. Zorman, PhD  
(Case Western Reserve University)  
*Professor*

Materials and processing techniques for MEMS and NEMS, wide bandgap semiconductors, development of materials and fabrication techniques for polymer-based MEMS and bioMEMS

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**Computer Science Division**

Erman Ayday, PhD  
(Georgia Institute of Technology)  
*Assistant Professor*

Cryptography, Network Security, Trust and Reputation Management, Big Data Analytics

Harold S. Connamacher, PhD  
(University of Toronto)  
*Assistant Professor*

Constraint satisfaction problems, graph theory, random structures, and algorithms

Chris Fietkiewicz, PhD  
(Case Western Reserve University)  
*Assistant Professor*

Applied and theoretical neuroscience, neuronal modeling, signal processing and signal analysis, electrophysiology, applications to epilepsy and respiratory control

Mehmet Koyuturk, PhD  
(Purdue University)  
*Professor*

Bioinformatics and computational biology, computational modeling and algorithm development for systems biology, integration, mining and analysis of biological data, algorithms for distributed systems

Michael Lewicki, PhD  
(California Institute of Technology)  
*Professor*

Computational perception and scene analysis, visual representation and processing, auditory representation and analysis

Jing Li, PhD  
(University of California, Riverside)  
*Associate Chair, Professor*

Computational biology and bioinformatics, statistical genomics and functional genomics, systems biology, algorithms

Vincenzo Liberatore, PhD  
(Rutgers University)  
*Associate Professor*

Distributed systems, Internet computing, randomized algorithms
H. Andy Podgurski, PhD  
(University of Massachusetts, Amherst)  
Professor  
Software engineering methodology and tools, especially use of data  
mining, machine learning, and program analysis techniques in software  
testing, fault detection and localization, reliable engineering and software  
security, electronic medical records, privacy

Michael Rabinovich, PhD  
(University of Washington)  
Professor  
Computer networks, Internet performance evaluation, databases, utility  
computing

Soumya Ray, PhD  
(University of Wisconsin, Madison)  
Associate Professor  
Artificial intelligence, machine learning, reinforcement learning,  
automated planning, applications to interdisciplinary problems including  
medicine and bioinformatics

Xusheng Xiao, PhD  
(North Carolina State University)  
Assistant Professor  
Software Engineering, Computer Security

Secondary Faculty Appointments
Alexis R. Abramson, PhD  
(University of California, Berkeley)  
Interim Chair, Electrical Engineering and Computer Science  
Milton and Tamar Maltz Professor of Energy Innovation, Mechanical and  
Aerospace Engineering

Kathryn Daltorio, PhD  
(Case Western Reserve University)  
Assistant Professor

Dominique Durand, Ph.D.  
(University of Toronto)  
Professor

Mark Griswold, PhD  
(University of Würzburg, Germany)  
Professor, Radiology

Fulai Jin, PhD  
(Univ of California, Los Angeles)  
Assistant Professor

Thomas LaFramboise, PhD  
(University of Illinois)  
Associate Professor, Genetics

Anant Madabhushi, Ph.D.  
(University of Pennsylvania)  
Secondary Professor

Elizabeth Madigan, PhD  
(Case Western Reserve University)  
Professor, Frances Payne Bolton School of Nursing

Roger D. Quinn, PhD  
(Virginia Polytechnic Institute and State University)  
Professor, Mechanical and Aerospace Engineering

Satya S. Sahoo, PhD  
(Wright State University)  
Assistant Professor, Center for Clinical Investigations

Nicole Sieberlich, PhD  
(University of Würzburg, Germany)  
Associate Professor, Biomedical Engineering

Peter Thomas, PhD  
(University of Chicago)  
Associate Professor, Mathematics, Applied Mathematics, and Statistics

Xiong (Bill) Yu, PhD, PE  
(Purdue University)  
Professor, Civil Engineering

Research Faculty
Farhad Kaffashi, PhD  
(Case Western Reserve University)  
Research Assistant Professor  
Signal processing of physiological time series data, systems and control

Adjunct Faculty Appointments
Michael Adams, PhD  
(Case Western Reserve University)  
Adjunct Assistant Professor

Mark A. Allman, MSEE  
(Ohio University)  
Adjunct Instructor

Nicholas Barendt, MSEE  
(Case Western Reserve University)  
Adjunct Sr. Instructor

Gurkan Bebek, Ph.D.  
(Case Western Reserve University)  
Adjunct Instructor

Swarup Bhunia, Ph.D.  
(Purdue University)  
Adjunct Associate Professor

Michael S. Branicky, ScD, PE  
(Massachusetts Institute of Technology)  
Adjunct Professor

Mahdi Cheraghchi, Ph.D.  
(Swiss Federal Institute of Technology)  
Adjunct Assistant Professor

Robert Eckman, MBA, PMP, CISSP  
(University of Phoenix)  
Adjunct Instructor
Lev Gonick, Ph.D.
(York University, Toronto)
Adjunct Professor

John C. Hoag, Ph.D.
(The Ohio State University)
Adjunct Associate Professor

Suparerk Janjarasjitt, PhD
(Case Western Reserve University)
Adjunct Assistant Professor

Eamon Johnson, PhD
(Case Western Reserve University)
Adjunct Instructor

David Kazdan, Ph.D.
(Case Western Reserve University)
Adjunct Assistant Professor

John R. Miller, Ph.D.
(Massachusetts Institute of Technology)
Adjunct Professor

Srinivas Raghavan, PhD
(Ohio State University)
Adjunct Professor

Gideon Samid, PhD
(Israel Institute of Technology)
Adjunct Assistant Professor

Shivakumar Sastry, PhD
(Case Western Reserve University)
Adjunct Associate Professor

William L. Schultz, PhD, PE
(Case Western Reserve University)
Adjunct Associate Professor

Marvin S. Schwartz, PhD
(Case Western Reserve University)
Adjunct Professor

Lawrence Sears
(Case Western Reserve University)
Adjunct Instructor

Amit Sinha, PhD
(Case Western Reserve University)
Adjunct Assistant Professor

Theodore Theofrastous, JD
(Case Western Reserve University)
Adjunct Instructor

Peter J. Tsivitse, PhD
(Case Western Reserve University)
Adjunct Professor

Francis G. Wolff, Ph.D.
(Case Western Reserve University)
Adjunct Associate Professor

Olaf Wolkenhauer, PhD
(UMIST, Manchester)
Adjunct Professor

Qing-rong Jackie Wu, PhD
(Mayo Graduate School)
Adjunct Professor

Guo-Qiang "GQ" Zhang, Ph.D.
(Cambridge University)
Adjunct Professor

Xiang Zhang, PhD
(University of North Carolina at Chapel Hill)
Adjunct Associate Professor

Hongping Zhao, PhD
(Lehigh University)
Adjunct Associate Professor

Active Emeritus Faculty

George W. Ernst, PhD
(Carnegie Institute of Technology)
Emeritus Professor

Learning problem solving strategies, artificial intelligence, expert systems, program verification

Dov Hazony, PhD
(University of California, Los Angeles)
Emeritus Professor

Network synthesis, ultrasonics, communications

Francis "Frank" L. Merat, PhD, PE
(Case Western Reserve University)
Emeritus Professor

Computer and robot vision, digital image processing, sensors, titanium capacitors and power electronics; RF and wireless systems; optical sensors; engineering education

Gultekin Ozsoyoglu, PhD
(University of Alberta, Canada)
Emeritus Professor

Graph databases and data mining problems in metabolic networks, metabolomics, and systems biology, bioinformatics, web data mining

Z. Meral Ozsoyoglu, PhD
(University of Alberta, Canada)
Emeritus Professor

Database systems, database query languages and optimization, data models, index structures, bioinformatics, medical informatics

Lee J. White, PhD
(University of Michigan)
Emeritus Professor

Software testing; regression testing, GUI testing, specification-based testing, testing of object-oriented software

Undergraduate Programs

The EECS department offers programs leading to degrees in:

1. Data Science and Analytics (Bachelor of Science)
2. Electrical Engineering (Bachelor of Science in Engineering)
3. Systems and Control Engineering (Bachelor of Science in Engineering)
4. Computer Engineering (Bachelor of Science in Engineering)
5. Computer Science (Bachelor of Science, Bachelor of Arts)

These programs provide students with a strong background in the fundamentals of mathematics, science, and engineering. Students can use their technical and open electives to pursue concentrations in bioelectrical engineering, complex systems, automation and control, digital systems design, embedded systems, micro/nano systems, robotics and intelligent systems, signal processing and communications, and software engineering. In addition to an excellent technical education, all students in the department are exposed to societal issues, ethics, professionalism, and have the opportunity to develop leadership and creativity skills.

Bachelor of Science in Data Science and Analytics

The Bachelor of Science degree program in Data Science and Analytics provides our students with a broad foundation in the field and the instruction, skills, and experience needed to understand and handle large amounts of data that transform thinking about a collection of vast amounts of data into one that focuses on the data’s conversion to actionable information. The degree program has a unique focus on real-world data and real-world applications.

This major is one of the first undergraduate programs nationwide with a unique curriculum that includes mathematical modeling, informatics, data analytics, visual analytics and project-based applications - all elements of the future emerging field of data science.

An undergraduate minor in Applied Data Science (p. 137) is administered in the Materials Science and Engineering Department.

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

### Major Requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 111</td>
<td>Principles of Chemistry for Engineers</td>
<td>4</td>
</tr>
<tr>
<td>DSCI 133</td>
<td>Introduction to Data Science and Engineering for Majors</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 234</td>
<td>Structured and Unstructured Data</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 341</td>
<td>Introduction to Databases: DS Major</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 342</td>
<td>Introduction to Data Science Systems</td>
<td>3</td>
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<tr>
<td>DSCI 343</td>
<td>Introduction to Data Analysis</td>
<td>3</td>
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<tr>
<td>DSCI 344</td>
<td>Scalable Parallel Data Analysis</td>
<td>3</td>
</tr>
<tr>
<td>DSCI 345</td>
<td>Files, Indexes and Access Structures for Big Data</td>
<td>3</td>
</tr>
<tr>
<td>EECS 132</td>
<td>Introduction to Programming in Java</td>
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<tr>
<td>EECS 302</td>
<td>Discrete Mathematics</td>
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</tr>
<tr>
<td>EECS 340</td>
<td>Algorithms</td>
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</tbody>
</table>

Core courses provide our students with a strong background in signal processing, systems, and analytics. Students are required to develop depth in at least one of the following technical areas: signal processing, systems, and analytics. Each data science and analytics student must complete the following requirements:

### Technical Elective Requirement

Each student must complete 8 courses (24 credit hours) of approved technical electives. Technical electives shall be chosen to fulfill the probability/statistics elective (1 course), the computer and data security elective (1 course), the depth requirement (3 courses), and 3 courses otherwise chosen to increase the student's understanding of data science and analytics. Technical electives not used to satisfy the probability/statistics elective, the computer and data security elective, or the depth requirement are more generally defined as any course related to the principles and practice of data science and analytics. This includes all DSCI courses at the 200 level and above and can include courses from other programs. All non-DSCI technical electives must be approved by the student's academic advisor.

### Depth Requirement

Each student must show a depth of competence in one technical area by taking at least three courses from one of the following three areas. Additional courses, beyond those that are listed, may be approved by the student’s academic advisor.

#### Area I: Signal Processing

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>EECS 246</td>
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<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
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#### Area II: Systems

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<td>EECS 325</td>
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<td>EECS 425</td>
<td>Computer Networks I</td>
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<td>EECS 338</td>
<td>Intro to Operating Systems and Concurrent Programming</td>
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<tr>
<td>EECS 600</td>
<td>Special Topics (Cloud Computing)</td>
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#### Area III: Analytics

<table>
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<tr>
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<tr>
<td>DSCI 390</td>
<td>Machine Learning for Big Data</td>
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<tr>
<td>DSCI 391</td>
<td>Data Mining for Big Data</td>
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## Computer and Data Security Elective Requirement

- **EECS 444** Computer Security 3
- **MATH 408** Introduction to Cryptology 3

## Statistics Requirement

- **MATH 380** Introduction to Probability 3
- **STAT 325** Data Analysis and Linear Models 3

## Design Requirement

- **DSCI 398** Engineering Projects I
- **DSCI 399** Engineering Projects II

### Suggested Program of Study: Bachelor of Science in Data Science and Analytics

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS [http://sis.case.edu](http://sis.case.edu).

#### First Year

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#### Fourth Year

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<tr>
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</table>

Total Units in Sequence: 125

- **a** Probability and statistics elective (MATH 380 Introduction to Probability, STAT 325 Data Analysis and Linear Models)
- **b** Computer and data security elective (EECS 444 Computer Security, MATH 408 Introduction to Cryptology)
- **c** Technical electives in signal processing, systems, and analytics (see lists of approved courses under program requirements)
- **d** Technical electives

The Bachelor of Science degree program in Data Science and Analytics (p. 58) is based in the Department of Electrical Engineering and Computer Science in the Case School of Engineering.

### Applied Data Science Minor

An undergraduate minor in applied data science (p. 137) is administered in the Materials Science and Engineering Department.

A complete list of DSCI (p.  ) courses may be found on the courses tab of the Data Sciences section of the General Bulletin.
Bachelor of Science in Electrical Engineering

The Bachelor of Science in Engineering degree program with a major in Electrical Engineering provides our students with a broad foundation in electrical engineering through combined classroom and laboratory work which prepares our students for entering the profession of electrical engineering, as well as for further study at the graduate level.

The Bachelor of Science in Engineering degree program with a major in Electrical Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Mission

The educational mission of the electrical engineering program is to graduate students who have fundamental technical knowledge of their profession and the requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies that will advance the general field of electrical engineering.

Program Educational Objectives

1. Graduates will be successful professionals obtaining positions appropriate to their background, interests, and education.
2. Graduates will use continuous learning opportunities to improve and enhance their professional skills.
3. Graduates will demonstrate leadership in their profession.

Student Outcomes

As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Electrical Engineering is designed so that students attain:

• 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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
• 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 engineering solutions in a global, economic, environmental, 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

Core courses provide our students with a strong background in signals and systems, computers, electronics (both analog and digital), and semiconductor devices. Students are required to develop depth in at least one of the following technical areas: signals and systems, solid state, computer hardware, computer software, control, circuits, robotics, and biomedical applications. Each electrical engineering student must complete the following requirements:

Major in Electrical Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatemajors/ee) and university general education requirements (http://bulletin.case.edu/undergraduatemajors/degree), the major requires the following courses:

Major Requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 245</td>
<td>Electronic Circuits</td>
</tr>
<tr>
<td>EECS 246</td>
<td>Signals and Systems</td>
</tr>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
</tr>
<tr>
<td>EECS 309</td>
<td>Electromagnetic Fields I</td>
</tr>
<tr>
<td>EECS 313</td>
<td>Signal Processing</td>
</tr>
<tr>
<td>EECS 321</td>
<td>Semiconductor Electronic Devices</td>
</tr>
</tbody>
</table>

Core courses provide our students with a strong background in signals and systems, computers, electronics (both analog and digital), and semiconductor devices. Students are required to develop depth in at least one of the following technical areas: signals and systems, solid state, computer hardware, computer software, control, circuits, robotics, and biomedical applications. Each electrical engineering student must complete the following requirements:

Technical Elective Requirement

Each student must complete eighteen (18) credit hours of approved technical electives. Technical electives shall be chosen to fulfill the depth requirement (see next) and otherwise increase the student’s breadth of understanding of electrical engineering. Technical electives not used to satisfy the depth requirement are more generally defined as any course related to the principles and practice of electrical engineering. This includes all EECS courses at the 300 level and above and can include courses from other programs. All non-EES technical electives must be approved by the student’s academic advisor.

Depth Requirement

Each student must show a depth of competence in one technical area by taking at least three courses from one of the following areas. This depth requirement may be met using a combination of the above core courses and a selection of open and technical electives. Alternative depth areas may be considered by petition to the program faculty.

Area I: Signals & Control

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 304</td>
<td>Control Engineering I with Laboratory</td>
</tr>
<tr>
<td>EECS 313</td>
<td>Signal Processing</td>
</tr>
<tr>
<td>EECS 351</td>
<td>Communications and Signal Analysis</td>
</tr>
<tr>
<td>EECS 354</td>
<td>Digital Communications</td>
</tr>
<tr>
<td>EECS 374</td>
<td>Advanced Control and Energy Systems</td>
</tr>
<tr>
<td>EECS 375</td>
<td>Applied Control</td>
</tr>
<tr>
<td>EECS 490</td>
<td>Digital Image Processing</td>
</tr>
<tr>
<td>MATH 307</td>
<td>Linear Algebra</td>
</tr>
</tbody>
</table>
Area II: Computer Software

EECS 233  Introduction to Data Structures  4
EECS 293  Software Craftsmanship  4
EECS 302  Discrete Mathematics  3
EECS 338  Intro to Operating Systems and Concurrent Programming  4
EECS 340  Algorithms  3
EECS 373  Modern Robot Programming  3
EECS 391  Introduction to Artificial Intelligence  3
EECS 393  Software Engineering  3
EECS 473  Modern Robot Programming  3

Area III: Solid State

PHYS 221  Introduction to Modern Physics  3
EECS 321  Semiconductor Electronic Devices  4
EECS 322/415  Integrated Circuits and Electronic Devices  3
EECS 422  Solid State Electronics II  3

Area IV: Circuits

EECS 245  Electronic Circuits  4
EBME 310  Principles of Biomedical Instrumentation  3
EECS 326  Instrumentation Electronics  3
EECS 344  Analytical Electronics and Design  3
EECS 371  Applied Circuit Design  3
EECS 426  MOS Integrated Circuit Design  3

Area V: Computer Hardware

EECS 281  Logic Design and Computer Organization  4
EECS 301  Digital Logic Laboratory  2
EECS 314  Computer Architecture  3
EECS 315  Digital Systems Design  4
EECS 316  Computer Design  3
EECS 318  VLSI/CAD  4

Area VI: Biomedical Applications

EBME 201  Physiology-Biophysics I (and 2 of the following 4 courses)  3
EBME 310  Principles of Biomedical Instrumentation  3
EBME 320  Medical Imaging Fundamentals  3
EBME 327  Bioelectric Engineering  3
EBME 401D  Biomedical Instrumentation and Signal Processing  3

Area VII: Robotics

EECS 246  Signals and Systems  4
EECS 275  Fundamentals of Robotics  4
EECS 304  Control Engineering I with Laboratory  3
EECS 376  Mobile Robotics  4
EECS 373  Modern Robot Programming  3
EECS 473  Modern Robot Programming  3

EECS 484  Computational Intelligence I: Basic Principles  3
EECS 489  Robotics I  3

Statistics Requirement

STAT 332  Statistics for Signal Processing*  3

* STAT 333 Uncertainty in Engineering and Science may be substituted with approval of advisor

Design Requirement

EECS 398  Engineering Projects I  4
EECS 399  Engineering Projects II  3

In consultation with a faculty advisor, a student completes the program by selecting technical and open elective courses that provide in-depth training in one or more of a spectrum of specialties, such as, control, signal processing, electronics, integrated circuit design and fabrication, and robotics. With the approval of the advisor, a student may emphasize other specialties by selecting elective courses from other programs or departments.

Additionally, math and statistics classes are highly recommended as an integral part of the student’s technical electives to prepare for work in industry and government and for graduate school. The following math/statistics classes are recommended and would be accepted as approved technical electives:

- MATH 201 Introduction to Linear Algebra for Applications
- MATH 330 Introduction to Scientific Computing
- MATH 380 Introduction to Probability
- STAT 412 Statistics for Design and Analysis in Engineering and Science

Other Math/Statistics may be used as technical electives with the approval of the student’s academic advisor.

Many courses have integral or associated laboratories in which students gain “hands-on” experience with electrical engineering principles and instrumentation. Students have ready access to the teaching laboratory facilities and are encouraged to use them during nonscheduled hours in addition to the regularly scheduled laboratory sessions. Opportunities also exist for undergraduate student participation in the wide spectrum of research projects being conducted in the department.

Suggested Program of Study: Major in Electrical Engineering

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

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<th>First Year</th>
<th>Units</th>
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<tr>
<td>SAGES First Year Seminar*</td>
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<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
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<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
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<td>Elementary Computer Programming (ENGR 131)**</td>
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Spring

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<tr>
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<td>Calculus for Science and Engineering I (MATH 121)**</td>
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<td>Open elective</td>
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SAGES University Seminar* 3
General Physics I - Mechanics (PHYS 121)**,b 4
Calculus for Science and Engineering II (MATH 122)** 4
Chemistry of Materials (ENGR 145)** 4
PHED (2 half semester courses)c 0
Year Total: 18 15

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<td>General Physics II - Electricity and Magnetism (PHYS 122)**,b</td>
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<td>Calculus for Science and Engineering III (MATH 223)**</td>
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<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
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<td>Logic Design and Computer Organization (EECS 281)</td>
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<td>SAGES University Seminar*</td>
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<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
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<td>Elementary Differential Equations (MATH 224)**</td>
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<td>Statics and Strength of Materials (ENGR 200)**</td>
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<td>Approved technical elective</td>
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Total Units in Sequence: 128

** University general education requirement
** Engineering general education requirement
b Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics and PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics I - Mechanics and PHYS 122 General Physics II - Electricity and Magnetism.
c Students may replace STAT 332 Statistics for Signal Processing with STAT 333 Uncertainty in Engineering and Science if approved by their advisor.
d Technical electives will be chosen to fulfill the depth requirement and otherwise increase the student’s understanding of electrical engineering. Courses used to satisfy the depth requirement must come from the department’s list of depth areas and related courses. Technical electives not used to satisfy the depth requirement are more generally defined as any course related to the principles and practice of electrical engineering. This includes all EECS courses at the 200 level and above, and can include courses from other programs. All non-EECS technical electives must be approved by the student’s advisor.
e B.S./M.S. students may double count EECS 651 Thesis M.S. to fulfill the EECS 399 Engineering Projects II requirement.
f CO-OP students may obtain design credit for EECS 399 Engineering Projects II if their co-op assignment included significant design responsibility; however, the student is still responsible for such course obligations as reports, presentations, and ethics assignments. Design credit and fulfillment of remaining course responsibilities are arranged through the course instructor.
g At least 10 of the 14 required Electrical Engineering courses (EECS 281 Logic Design and Computer Organization, EECS 245 Electronic Circuits, EECS 246 Signals and Systems, EECS 309 Electromagnetic Fields I, EECS 313 Signal Processing, EECS 321 Semiconductor Electronic Devices, EECS 398 Engineering Projects I, EECS 399 Engineering Projects II and the six technical electives) in the Electrical Engineering B.S. program must be satisfied by courses in the EECS department.

**Double Major: Systems and Control Engineering & Electrical Engineering**

The department also offers a double major in Systems and Control Engineering and Electrical Engineering. Students pursuing the Bachelor of Science in Engineering degree program with a major in Electrical Engineering can take the following courses as technical and open electives to earn a second major in Systems and Control Engineering:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 216</td>
<td>Fundamental System Concepts (SC)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>EECS 304</td>
<td>Control Engineering I with Laboratory (EE, Area I: Signals &amp; Control) and (SC)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>EECS 305</td>
<td>Control Engineering I Laboratory (This is the additional 1 credit-hour course needed (SC))</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
The department also offers a minor in electronics for students in the College of Arts and Sciences. This program requires the completion of 31 credit hours, of which 10 credit hours may be used to satisfy portions of the College of Arts and Sciences. This program requires the completion of 31 credit hours, of which 10 credit hours may be used to satisfy portions of the College of Arts and Sciences. This program requires the completion of 31 credit hours, of which 10 credit hours may be used to satisfy portions of the College of Arts and Sciences. This program requires the completion of 31 credit hours, of which 10 credit hours may be used to satisfy portions of the College of Arts and Sciences. This program requires the completion of 31 credit hours, of which 10 credit hours may be used to satisfy portions of the College of Arts and Sciences.

### Cooperative Education Program

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop.

Alternatively or additionally, students may obtain employment as summer interns.

### BS/MS Program in Electrical Engineering

The department encourages highly motivated and qualified students to apply for admission to the five-year BS/MS Program in the junior year. This integrated program, which permits up to 9 credit hours of graduate level coursework to be counted towards both BS and MS degree requirements (including an option to substitute MS thesis work for EECS 399 Engineering Projects II, the second senior project). It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduestudies/gradprofessional/accelerationtowardgraduatedegreehardtex).

### Minor in Electrical Engineering

Students enrolled in degree programs in other engineering departments can have a minor specialization by completing the following courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>EECS 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>EECS 309</td>
<td>Electromagnetic Fields I</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Approved technical elective</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td><strong>Total Units</strong></td>
<td><strong>18</strong></td>
</tr>
</tbody>
</table>

### Minor in Electronics

The department also offers a minor in electronics for students in the College of Arts and Sciences. This program requires the completion of 31 credit hours, of which 10 credit hours may be used to satisfy portions of the students’ skills and distribution requirements. The following courses are required for the electronics minor:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 125</td>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci</td>
<td>4</td>
</tr>
<tr>
<td>MATH 126</td>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci II</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 115</td>
<td>Introductory Physics I</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 116</td>
<td>Introductory Physics II</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 131</td>
<td>Elementary Computer Programming</td>
<td>3</td>
</tr>
<tr>
<td>ENGR 210</td>
<td>Introduction to Circuits and Instrumentation</td>
<td>4</td>
</tr>
<tr>
<td>EECS 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><strong>Total Units</strong></td>
<td><strong>31</strong></td>
</tr>
</tbody>
</table>

### Bachelor of Science in Systems and Control Engineering

The Bachelor of Science in Engineering degree program with a major in Systems and Control Engineering provides our students with the basic concepts, analytical tools, and engineering methods which are needed in analyzing and designing complex technological and non-technological systems. Problems relating to modeling, simulation, decision-making, control, and optimization are studied. Some examples of systems problems which are studied include: modeling and analysis of complex biological systems, computer control of industrial plants, developing world models for studying environmental policies, and optimal planning and management in large-scale systems. In each case, the relationship and interaction among the various components of a given system must be modeled. This information is used to determine the best way of coordinating and regulating these individual contributions to achieve the overall goal of the system.

The Bachelor of Science in Engineering with a major in Systems and Control Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

### Mission

The mission of the Systems and Control Engineering program is to provide internationally recognized excellence for graduate and undergraduate education and research in systems analysis, design, and control. These theoretical and applied areas require cross-disciplinary concepts, analytical tools, and engineering methods which are needed in analyzing and designing complex technological and non-technological systems. Problems relating to modeling, simulation, decision-making, control, and optimization are studied. Some examples of systems problems which are studied include: modeling and analysis of complex biological systems, computer control of industrial plants, developing world models for studying environmental policies, and optimal planning and management in large-scale systems. In each case, the relationship and interaction among the various components of a given system must be modeled. This information is used to determine the best way of coordinating and regulating these individual contributions to achieve the overall goal of the system.

### Program Educational Objectives

1. Graduates apply systems methodology to multi-disciplinary projects that include technical, social, environmental, and/or economic factors.
2. Graduates use systems understanding, thinking and problem-solving skills to analyze and design systems or processes that respond to technical and societal needs.
3. Graduates use teamwork, leadership, communication, and management skills to facilitate multidisciplinary projects that bring together practitioners of various engineering fields in an effective, professional, and ethical manner.

### Student Outcomes

- an ability to apply knowledge of mathematics, science, and engineering
Major in Systems and Control Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduastudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

### Major Requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 216</td>
<td>Fundamental System Concepts</td>
<td>3</td>
</tr>
<tr>
<td>EECS 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>EECS 304</td>
<td>Control Engineering I with Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>EECS 305</td>
<td>Control Engineering I Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EECS 313</td>
<td>Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>EECS 324</td>
<td>Modeling and Simulation of Continuous Dynamical Systems</td>
<td>3</td>
</tr>
<tr>
<td>EECS 342</td>
<td>Introduction to Global Issues</td>
<td>3</td>
</tr>
<tr>
<td>EECS 346</td>
<td>Engineering Optimization</td>
<td>3</td>
</tr>
<tr>
<td>EECS 352</td>
<td>Engineering Economics and Decision Analysis</td>
<td>3</td>
</tr>
<tr>
<td>OPRE 432</td>
<td>Computer Simulation</td>
<td>3</td>
</tr>
<tr>
<td>EECS 399</td>
<td>Engineering Projects II</td>
<td>3</td>
</tr>
</tbody>
</table>

Fifteen hours of approved technical electives including at least 9 hours of approved courses to constitute a depth of study

### Breadth Requirement

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications</td>
<td>3</td>
</tr>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
</tr>
</tbody>
</table>

### Statistics Requirement

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>* STAT 333 Uncertainty in Engineering and Science may be substituted with approval of advisor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Design Requirement

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 398</td>
<td>Engineering Projects I</td>
<td>4</td>
</tr>
</tbody>
</table>

### Depth Requirement

Each student must show a depth of competence in one technical area by taking at least three courses from one of the three tracks/program concentration areas, namely energy systems, control systems and data analytics, listed below:

**Track 1: Energy Systems**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 368</td>
<td>Power System Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>EECS 369</td>
<td>Power System Analysis II</td>
<td>3</td>
</tr>
<tr>
<td>EECS 370</td>
<td>Smart Grid</td>
<td>3</td>
</tr>
<tr>
<td>EECS 374</td>
<td>Advanced Control and Energy Systems</td>
<td>3</td>
</tr>
<tr>
<td>EECS 375</td>
<td>Applied Control</td>
<td>3</td>
</tr>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
</tbody>
</table>

**Track 2: Control Systems**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 375</td>
<td>Applied Control</td>
<td>3</td>
</tr>
<tr>
<td>EECS 374</td>
<td>Advanced Control and Energy Systems</td>
<td>3</td>
</tr>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
</tbody>
</table>

Technical Elective from the Energy Systems or Data Analytics tracks 3

**Track 3: Data Analytics**

- DSCI 343 Introduction to Data Analysis 3

  **"Core Tools" list:**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 339</td>
<td>Web Data Mining</td>
<td>3</td>
</tr>
<tr>
<td>STAT 325</td>
<td>Data Analysis and Linear Models</td>
<td>3</td>
</tr>
<tr>
<td>STAT 326</td>
<td>Multivariate Analysis and Data Mining</td>
<td>3</td>
</tr>
<tr>
<td>EECS 435</td>
<td>Data Mining</td>
<td>3</td>
</tr>
<tr>
<td>EECS 452</td>
<td>Random Signals</td>
<td>3</td>
</tr>
<tr>
<td>EECS 490</td>
<td>Digital Image Processing</td>
<td>3</td>
</tr>
<tr>
<td>OPRE 433</td>
<td>Foundations of Probability and Statistics</td>
<td>3</td>
</tr>
</tbody>
</table>

  **"Application" lists:**

**Business/Manufacturing Analytics:**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 350</td>
<td>Operations and Systems Design</td>
<td>3</td>
</tr>
<tr>
<td>EECS 360</td>
<td>Manufacturing and Automated Systems</td>
<td>3</td>
</tr>
<tr>
<td>BAFI 361</td>
<td>Empirical Analysis in Finance</td>
<td>3</td>
</tr>
<tr>
<td>MKMR 310</td>
<td>Marketing Analytics</td>
<td>3</td>
</tr>
<tr>
<td>OPMT 475</td>
<td>Supply Chain Logistics</td>
<td>3</td>
</tr>
<tr>
<td>OPMT 477</td>
<td>Enterprise Resource Planning in the Supply Chain</td>
<td>3</td>
</tr>
<tr>
<td>EECS 490</td>
<td>Digital Image Processing</td>
<td>3</td>
</tr>
</tbody>
</table>

**Healthcare Analytics**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 319</td>
<td>Applied Probability and Stochastic Processes for Biology</td>
<td>3</td>
</tr>
<tr>
<td>EECS 365</td>
<td>Complex Systems Biology</td>
<td>3</td>
</tr>
<tr>
<td>MATH 378</td>
<td>Computational Neuroscience</td>
<td>3</td>
</tr>
</tbody>
</table>
### Suggested Program of Study: Major in Systems and Control Engineering

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

#### First Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES First Year Seminar*</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Elementary Computer Programming (ENGR 131)**</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>SAGES University Seminar*</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>General Physics I - Mechanics (PHYS 121)**</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Calculus for Science and Engineering II (MATH 122)**</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Year Total:</td>
<td></td>
<td>18 15</td>
</tr>
</tbody>
</table>

#### Second Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Calculus for Science and Engineering III (MATH 223)**</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Statistics for Signal Processing (STAT 332)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>SAGES University Seminar*</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Fundamental System Concepts (EECS 216)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Elementary Differential Equations (MATH 224)**</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Statics and Strength of Materials (ENGR 200)**</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Introduction to Linear Algebra for Applications (MATH 201)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Year Total:</td>
<td></td>
<td>17 16</td>
</tr>
</tbody>
</table>

#### Third Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth elective**</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

#### Fourth Year

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth elective**</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGL 398)**</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)**</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Engineering Economics and Decision Analysis (EECS 352)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Engineering Projects I (EECS 398)b</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Approved technical electivec</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Breadth elective**</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Engineering Projects II (EECS 399)b</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Approved technical electivec</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Approved technical electivec</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Approved technical electivec</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Year Total:</td>
<td></td>
<td>16 15</td>
</tr>
</tbody>
</table>

Total Units in Sequence: 129

* University general education requirement
** Engineering general education requirement
a Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics and PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics I - Mechanics and PHYS 122 General Physics II - Electricity and Magnetism.
b Co-op students may obtain design credit for one semester of Senior Project Lab if their co-op assignment includes significant design responsibility. This credit can be obtained by submitting a suitable written report and making an oral presentation on the co-op work in coordination with the senior project instructor.
Technical electives from approved list of courses in the three tracks/program concentration areas (Energy systems, Control systems, and Data Analytics) listed under “Depth Requirement” above.

There are five technical elective courses available within the Bachelor of Science in Engineering degree program with a major in Systems and Control Engineering curriculum that represent a depth of the discipline. Students can satisfy these four technical elective requirements by choosing three courses from one of the three tracks (to meet the Depth Requirement) with the fourth and fifth courses chosen from any of the three tracks listed under the Depth Requirement section above.

Dual Major: Systems and Control Engineering & Electrical Engineering

From Systems and Control Engineering (S&CE) to Electrical Engineering (EE): S&CE students can earn a double major with EE by taking the following five courses as Technical Electives in the S&CE program:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>EECS 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>EECS 309</td>
<td>Electromagnetic Fields I</td>
<td>3</td>
</tr>
<tr>
<td>EECS 321</td>
<td>Semiconductor Electronic Devices</td>
<td>4</td>
</tr>
<tr>
<td>EECS 375</td>
<td>Applied Control</td>
<td>3</td>
</tr>
</tbody>
</table>

As the three courses EECS 281, EECS 245, and EECS 321 are 4 credit-hours instead of 3, the three credit-hour "Open Elective" course in the original S&CE program is not needed.

Cooperative Education Program (http://engineering.case.edu/coop) in Systems and Control Engineering

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop.

Alternatively or additionally, students may obtain employment as summer interns.

BS/MS Program in Systems and Control Engineering

The department encourages highly motivated and qualified students to apply for admission to the five-year BS/MS Program in the junior year. This integrated program, which permits up to 9 credit hours of graduate level coursework to be counted towards both BS and MS degree requirements (including an option to substitute MS thesis work for EECs 399 Engineering Projects II, the second senior project). It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatstudies/gradprofessional/#accelerationtowardgraduatedegreestext).

Minor Program in Systems and Control Engineering

A total of five courses (15 credit hours) are required to obtain a minor in systems and control engineering. This includes:

- EECS 246 Signals and Systems
- Three of the following four courses selected in consultation with the program minor advisor: EECS 304 Control Engineering I with Laboratory/EECS 305 Control Engineering I Laboratory; EECS 324 Modeling and Simulation of Continuous Dynamical Systems; EECS 346 Engineering Optimization; EECS 352 Engineering Economics and Decision Analysis;
- One of EECS 313 Signal Processing, EECS 351 Communications and Signal Analysis, or EECS 354 Digital Communications.

Bachelor of Science in Computer Engineering

The Bachelor of Science in Engineering degree program with a major in Computer Engineering is designed to give a student a strong background in the fundamentals of computer engineering through combined classroom and laboratory work. A graduate of this program will be able to use these fundamentals to analyze and evaluate computer systems, both hardware and software. A computer engineering graduate would also be able to design and implement a computer system for general purpose or embedded computing incorporating state-of-the-art solutions to a variety of computing problems. This includes systems which have both hardware and software component, whose design requires a well-defined interface between the two and the evaluation of the associated trade-offs.

The Bachelor of Science in Engineering degree program with a major in Computer Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Mission

The educational mission of the computer engineering program is to graduate students who have fundamental technical knowledge of their profession along with requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies which will advance the general field of computer engineering. Core courses provide our students with a strong background in digital systems design, computer organization, hardware architecture, and digital electronics.

Program Educational Objectives

1. Graduates will be successful professionals obtaining positions appropriate to their background, interests, and education.
2. Graduates will engage in life-long learning to improve and enhance their professional skills.
3. Graduates will demonstrate leadership in their profession by using their knowledge, communication skills, and engineering ability.

Student Outcomes

As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Computer Engineering is designed so that students attain:

- 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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
• 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 engineering solutions in a global, economic, environmental, 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

Major in Computer Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

### Major Requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 132</td>
<td>Introduction to Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>ENGR 210</td>
<td>Introduction to Circuits and Instrumentation</td>
<td>4</td>
</tr>
<tr>
<td>EECS 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>EECS 301</td>
<td>Digital Logic Laboratory</td>
<td>2</td>
</tr>
<tr>
<td>EECS 302</td>
<td>Discrete Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>EECS 314</td>
<td>Computer Architecture</td>
<td>3</td>
</tr>
<tr>
<td>EECS 315</td>
<td>Digital Systems Design</td>
<td>4</td>
</tr>
</tbody>
</table>

One of the following: 4

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 318</td>
<td>VLSI/CAD</td>
</tr>
<tr>
<td>EECS 338</td>
<td>Intro to Operating Systems and Concurrent Programming</td>
</tr>
</tbody>
</table>

### Statistics Requirement

One Statistics elective may be chosen from:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 312</td>
<td>Basic Statistics for Engineering and Science</td>
<td>3</td>
</tr>
<tr>
<td>STAT 313</td>
<td>Statistics for Experimenters</td>
<td>3</td>
</tr>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>STAT 333</td>
<td>Uncertainty in Engineering and Science</td>
<td>3</td>
</tr>
</tbody>
</table>

### Design Requirement

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 398</td>
<td>Engineering Projects I</td>
<td>4</td>
</tr>
</tbody>
</table>

In consultation with a faculty advisor, a student completes the program by selecting technical and open elective courses that provide in-depth training in the principles and practice of computer engineering. With the approval of the advisor, a student may emphasize a specialty of his/her choice by selecting elective courses from other programs or departments.

Many courses have integral or associated laboratories in which students gain “hands-on” experience with computer engineering principles and instrumentation. Students have ready access to the teaching laboratory facilities and are encouraged to use them during nonscheduled hours in addition to the regularly scheduled laboratory sessions. Opportunities also exist for undergraduate student participation in the wide spectrum of research projects being conducted in the department.

**Suggested Program of Study: Major in Computer Engineering**

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

### First Year

<table>
<thead>
<tr>
<th>Term</th>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>SAGES First Year Seminar*</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Introduction to Programming in Java (EECS 132)**</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>SAGES University Seminar*</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>General Physics I - Mechanics (PHYS 121)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Calculus for Science and Engineering II (MATH 122)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Chemistry of Materials (ENGR 145)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Year Total:</td>
<td>15</td>
</tr>
</tbody>
</table>

### Second Year

<table>
<thead>
<tr>
<th>Term</th>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>SAGES University Seminar*</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Calculus for Science and Engineering III (MATH 223)**</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Introduction to Data Structures (EECS 233)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Breadth elective**</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Elementary Differential Equations (MATH 224)**</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Statics and Strength of Materials (ENGR 200)**</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Logic Design and Computer Organization (EECS 281)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Technical elective*</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Year Total:</td>
<td>16</td>
</tr>
</tbody>
</table>

### Third Year

<table>
<thead>
<tr>
<th>Term</th>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>Breath elective**</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Discrete Mathematics (EECS 302)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Technical elective*</td>
<td>7</td>
</tr>
</tbody>
</table>
Professional Communication for Engineers (ENGL 398)**  2
Professional Communication for Engineers (ENGR 398)**  1
Digital Logic Laboratory (EECS 301)  2
Computer Architecture (EECS 314)  3
Digital Systems Design (EECS 315)  4
Intro to Operating Systems and Concurrent Programming (EECS 338) (or Technical elective,3)  4

Year Total:  17  16

Fourth Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Statistics electivec</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Technical electivea</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Technical elective (or EECS 318 VLSI/CAD) b</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Breadth elective**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Engineering Projects I (EECS 398)d</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Technical electivea</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Year Total:</td>
<td>15</td>
<td>14</td>
</tr>
</tbody>
</table>

Total Units in Sequence: 129

** Hours Required for Graduation: 129

1. University general education requirement
2. Engineering general education requirement
3. Technical electives are more generally defined as any course related to the principles and practice of computer engineering. This includes all EECS courses at the 200 level and above, and can include courses from other programs. All non-EECS technical electives must be approved by the student's advisor.
4. The student must take either EECS 318 VLSI/CAD (Fall Semester) EECS 338 Intro to Operating Systems and Concurrent Programming (Spring Semester), or a three credit hour technical elective.
6. May be taken in the Fall semester if the student would like to take EECS 399 Engineering Projects II.

Cooperative Education (http://engineering.case.edu/coop) Program in Computer Engineering

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop.

Alternatively or additionally, students may obtain employment as summer interns.

BS/MS Program in Computer Engineering

Highly motivated and qualified students are encouraged to apply to the BS/MS Program which will allow them to get both degrees in five years. The BS can be in Computer Engineering or a related discipline, such as mathematics or electrical engineering. Integrating graduate study in computer engineering with the undergraduate program allows a student to satisfy all requirements for both degrees in five years. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatestudies/gradprofessional/#accelerationtowardgraduatedegreestext).

Minor in Computer Engineering

The department also offers a minor in computer engineering. The minor has a required two-course sequence followed by a two-course sequence in either hardware or software aspects of computer engineering. The following two courses are required for any minor in computer engineering:

- EECS 281 Logic Design and Computer Organization 4
- EECS 233 Introduction to Data Structures 4

Students should note that EECS 132 Introduction to Programming in Java is a prerequisite for EECS 233 Introduction to Data Structures.

The two-course hardware sequence is:

- EECS 314 Computer Architecture 3
- EECS 315 Digital Systems Design 4

The corresponding two-course software sequence is:

- EECS 338 Intro to Operating Systems and Concurrent Programming 4
- EECS 3XX Approved by advisor 4

Computer Science Mission

The mission of the Bachelor of Science degree program in Computer Science and the Bachelor of Arts degree program in Computer Science is to graduate students who have fundamental technical knowledge of their profession and the requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies which will advance the field of computer science and its application to other disciplines.

Program Educational Objectives

1. To educate and train students in the fundamentals of computer science and mathematics
2. To educate students with an understanding of real-world computing needs
3. To train students to work effectively, professionally and ethically in computing-related professions
Student Outcomes
As preparation for achieving the above educational objectives, the BS and BA degree programs in Computer Science are designed so that Bachelor of Science students attain:

- An ability to apply knowledge of computing and mathematics appropriate to the program’s student outcomes and to the discipline
- An ability to analyze a problem, and identify and define the computing requirements appropriate to its solution
- An ability to design, implement, and evaluate a computer-based system, process, component, or program to meet desired needs
- An ability to function effectively on teams to accomplish a common goal
- An understanding of professional, ethical, legal, security and social issues and responsibilities
- An ability to communicate effectively with a range of audiences
- An ability to analyze the local and global impact of computing on individuals, organizations, and society
- Recognition of the need for and an ability to engage in continuing professional development
- An ability to use current techniques, skills, and tools necessary for computing practice
- An ability to apply mathematical foundations, algorithmic principles, and computer science theory in the modeling and design of computer-based systems in a way that demonstrates comprehension of the tradeoffs involved in design choices
- An ability to apply design and development principles in the construction of software systems of varying complexity

Core and breadth courses provide our students with the flexibility to work across many disciplines and prepare them for a variety of professions. Our curriculum is designed to teach fundamental skills and knowledge needed by all CS graduates while providing the greatest flexibility in selecting topics. Students are also required to develop depth in at least one of the following technical areas: software engineering; algorithms and theory; computer systems, networks, and security; databases and data mining; bioinformatics; or artificial intelligence.

Bachelor of Science in Computer Science
The Bachelor of Science degree program in Computer Science is designed to give a student a strong background in the fundamentals of mathematics and computer science. The curriculum is designed according to the latest ACM/IEEE computer science curriculum guidelines. A graduate of this program should be able to use these fundamentals to analyze and evaluate software systems and the underlying abstractions upon which they are based. A graduate should also be able to design and implement software systems which are state-of-the-art solutions to a variety of computing problems; this includes problems which are sufficiently complex to require the evaluation of design alternatives and engineering trade-offs. In addition to these program-specific objectives, all students in the Case School of Engineering are exposed to societal issues, professionalism, and are provided opportunities to develop leadership skills.

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

Bachelor of Arts in Computer Science
The Bachelor of Arts degree program in Computer Science is a combination of a liberal arts program and a computing major. It is a professional program in the sense that graduates can be employed as computer professionals, but it is less technical than the Bachelor of Science degree program in Computer Science. This degree is particularly suitable for students with a wide range of interests. For example, students can major in another discipline in addition to computer science and routinely complete all of the requirements for the double major in a 4 year period. This is possible because over a third of the courses in the program are open electives. Furthermore, if a student is majoring in computer science and a second technical field such as mathematics or physics many of the technical electives will be accepted for both majors. Another example of the utility of this program is that it routinely allows students to major in computer science and take all of the pre-med courses in a four-year period.

Major in Computer Science (BS and BA)
BS Degree. Each student is required to complete a total of 14 CS courses. CS courses consist of the courses listed in the core, technical breadth, and depth areas below. BS students must complete: all 6 core courses; 5 of 7 technical breadth courses; and at least 4 courses in one of the listed depth areas, including all starred courses in that area (many of these also count toward the technical breadth requirement). Each student is also required to complete 5 technical electives. These can be satisfied using courses from the list of approved technical electives, additional technical breadth or depth courses, or from other CS-related courses with prior permission from the student’s academic advisor.

BA Degree. Students are required to complete a total of 9 CS courses. BA students must complete all 6 core courses and 3 of 7 technical breadth courses. In addition, each student is also required to complete 4 technical electives. There is no depth requirement for the BA degree.

Major Requirements
In addition to engineering general education requirements (Computer Science-BS) (http://bulletin.case.edu/undergraduatetudies/csedegree/#bachelorofscienceincomputersciencetext), arts & sciences general education requirements (BA) (http://bulletin.case.edu/undergraduatetudies/casdegree) and university general education requirements (http://bulletin.case.edu/undergraduatetudies/degreeprograms), the major requires the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 132</td>
<td>Introduction to Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>EECS 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>EECS 302</td>
<td>Discrete Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>EECS 340</td>
<td>Algorithms</td>
<td>3</td>
</tr>
<tr>
<td>EECS 395</td>
<td>Senior Project in Computer Science</td>
<td>4</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHEM 111</td>
<td>Principles of Chemistry for Engineers</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 145</td>
<td>Chemistry of Materials</td>
<td>4</td>
</tr>
<tr>
<td>MATH 121</td>
<td>Calculus for Science and Engineering I</td>
<td>4</td>
</tr>
<tr>
<td>MATH 122</td>
<td>Calculus for Science and Engineering II</td>
<td>4</td>
</tr>
</tbody>
</table>

BA Degree:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 111</td>
<td>Principles of Chemistry for Engineers</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 145</td>
<td>Chemistry of Materials</td>
<td>4</td>
</tr>
<tr>
<td>MATH 121</td>
<td>Calculus for Science and Engineering I</td>
<td>4</td>
</tr>
<tr>
<td>MATH 122</td>
<td>Calculus for Science and Engineering II</td>
<td>4</td>
</tr>
</tbody>
</table>
are also technical breadth courses, one additional CS course is required of the depth area. For depth areas that have two starred courses that ensure that the total number of required courses is the same irrespective (courses listed in the core, technical breadth, and depth requirements) to CS BS students are required to complete a total of 14 CS courses to reach the required total of 14. Additional CS courses taken beyond the required 14 can count toward the technical elective requirement (see below).

### Area 1: Software Engineering
- Eecs 293 Software Craftsmanship 4
- Eecs 337 Compiler Design 4
- Eecs 345 Programming Language Concepts * 3
- Eecs 392 App Development for iOS 3
- Eecs 393 Software Engineering * 3
- Eecs 402 Internet Security and Privacy 3
- Eecs 441 Internet Applications 3
- Eecs 444 Computer Security 3

### Area 2: Algorithms and Theory
- Eecs 340 Algorithms * 3
- Eecs 343 Theoretical Computer Science * 3
- Eecs 440 Machine Learning 3
- Eecs 454 Analysis of Algorithms 3
- Eecs 477 Advanced Algorithms 3
- Math 408 Introduction to Cryptology 3

Recommended preparation: MATH 380 Introduction to Probability, Eecs 455 Applied Graph Theory, Phil 306 Mathematical Logic and Model Theory.

### Area 3: Computer Systems, Networks and Security
- Eecs 325 Computer Networks I * 3
- Eecs 337 Compiler Design 4
- Eecs 338 Intro to Operating Systems and Concurrent Programming * 4
- Eecs 402 Internet Security and Privacy 3
- Math 408 Introduction to Cryptology 3
- Eecs 441 Internet Applications 3
- Eecs 444 Computer Security 3

### Area 4: Databases and Data Mining
- Eecs 339 Web Data Mining 3
- Eecs 341 Introduction to Database Systems * 3
- Eecs 405 Data Structures and File Management 3
- Eecs 433 Database Systems 3
- Eecs 435 Data Mining 3
- Eecs 440 Machine Learning 3

### Area 5: Bioinformatics
- Eecs 341 Introduction to Database Systems 3
- Eecs 435 Data Mining 3
- Eecs 440 Machine Learning 3
- Eecs 454 Analysis of Algorithms 3
- Eecs 458 Introduction to Bioinformatics * 3
- Eecs 459 Bioinformatics for Systems Biology * 3

Recommended breadth and preparation: STAT 325 Data Analysis and Linear Models or PQHS 431 Statistical Methods I, SYBB 311A Survey of Bioinformatics: Technologies in Bioinformatics, SYBB 311B Survey of Bioinformatics: Data Integration in Bioinformatics, SYBB 311C Survey...

**Area 6: Artificial Intelligence**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 391</td>
<td>Introduction to Artificial Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>EECS 440</td>
<td>Machine Learning</td>
<td>3</td>
</tr>
<tr>
<td>EECS 442</td>
<td>Causal Learning from Data</td>
<td>3</td>
</tr>
<tr>
<td>EECS 484</td>
<td>Computational Intelligence I: Basic Principles</td>
<td>3</td>
</tr>
<tr>
<td>EECS 491</td>
<td>Artificial Intelligence: Probabilistic Graphical Models</td>
<td>3</td>
</tr>
<tr>
<td>EECS 496</td>
<td>Artificial Intelligence: Sequential Decision Making</td>
<td>3</td>
</tr>
<tr>
<td>EECS 497</td>
<td>Artificial Intelligence: Statistical Natural Language Processing</td>
<td>3</td>
</tr>
<tr>
<td>EECS 499</td>
<td>Algorithmic Robotics</td>
<td>3</td>
</tr>
<tr>
<td>EECS 531</td>
<td>Computer Vision</td>
<td>3</td>
</tr>
</tbody>
</table>

Recommended breadth and preparation: MATH 380 Introduction to Probability, and either EECS 416 Convex Optimization for Engineering or EECS 477 Advanced Algorithms.

**Technical Electives**

Computer Science BS students are required to complete a total of 5 technical electives, totaling at least 14 credit hours; CS BA students are required to complete 4, totaling at least 11 credit hours. Technical electives are divided into two groups according to how closely a course is related to the core knowledge areas as defined in the ACM/IEEE computer science curriculum guidelines. CS students may complete any (or all) of their technical electives from group 1 and have the option to satisfy up to two of their technical electives from group 2. Students may also satisfy any of their technical elective requirements by taking additional technical breadth or depth courses listed above. CS-related courses not listed below may count toward the technical elective requirement but require prior permission from the student's academic advisor.

**Group 1**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 275</td>
<td>Fundamentals of Robotics</td>
<td>4</td>
</tr>
<tr>
<td>EECS 290</td>
<td>Introduction to Computer Game Design and Implementation</td>
<td>3</td>
</tr>
<tr>
<td>EECS 301</td>
<td>Digital Logic Laboratory</td>
<td>2</td>
</tr>
<tr>
<td>EECS 315</td>
<td>Digital Systems Design</td>
<td>4</td>
</tr>
<tr>
<td>EECS 316</td>
<td>Computer Design</td>
<td>3</td>
</tr>
<tr>
<td>EECS 318</td>
<td>VLSI/CAD</td>
<td>4</td>
</tr>
<tr>
<td>EECS 366</td>
<td>Computer Graphics</td>
<td>3</td>
</tr>
<tr>
<td>EECS 373</td>
<td>Modern Robot Programming</td>
<td>3</td>
</tr>
<tr>
<td>EECS 376</td>
<td>Mobile Robotics</td>
<td>4</td>
</tr>
<tr>
<td>EECS 390</td>
<td>Advanced Game Development Project</td>
<td>3</td>
</tr>
<tr>
<td>EECS 419</td>
<td>Computer System Architecture</td>
<td>3</td>
</tr>
<tr>
<td>EECS 485</td>
<td>VLSI Systems</td>
<td>3</td>
</tr>
<tr>
<td>EECS 488</td>
<td>Embedded Systems Design</td>
<td>3</td>
</tr>
<tr>
<td>EECS 490</td>
<td>Digital Image Processing</td>
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</tr>
</tbody>
</table>

**Group 2**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>EECS 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
</tbody>
</table>

**Bachelor of Science**

**Suggested Program of Study: Major in Computer Science**

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

**First Year**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES First Year Seminar*</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering I (MATH 121)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Introduction to Programming in Java (EECS 132)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
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**Group 2**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES University Seminar*</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>General Physics I - Mechanics (PHYS 121)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering II (MATH 122)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Chemistry of Materials (ENGR 145)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
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</table>
### Second Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES University Seminar*</td>
<td>3</td>
</tr>
<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 122)</td>
<td>4</td>
</tr>
<tr>
<td>Calculus for Science and Engineering III (MATH 223)</td>
<td>3</td>
</tr>
<tr>
<td>Introduction to Data Structures (EECS 233)</td>
<td>4</td>
</tr>
<tr>
<td>Discrete Mathematics (EECS 302)</td>
<td>3</td>
</tr>
<tr>
<td>Logic Design and Computer Organization (EECS 281)</td>
<td>4</td>
</tr>
<tr>
<td>Introduction to Linear Algebra for Applications (MATH 201)</td>
<td>3</td>
</tr>
<tr>
<td>Statistics elective(^a)</td>
<td>3</td>
</tr>
<tr>
<td>Technical breadth elective(^c)</td>
<td>3</td>
</tr>
<tr>
<td>Breadth elective(^**)</td>
<td>3</td>
</tr>
<tr>
<td><strong>Year Total:</strong></td>
<td>17</td>
</tr>
<tr>
<td><strong>Fall</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Spring</strong></td>
<td></td>
</tr>
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</table>

### Third Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algorithms (EECS 340)</td>
<td>3</td>
</tr>
<tr>
<td>Technical breadth elective(^c)</td>
<td>3</td>
</tr>
<tr>
<td>Technical breadth elective(^c)</td>
<td>3</td>
</tr>
<tr>
<td>Technical elective(^b)</td>
<td>3</td>
</tr>
<tr>
<td>Breadth elective(^**)</td>
<td>3</td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGL 398)</td>
<td>2</td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)</td>
<td>1</td>
</tr>
<tr>
<td>Technical breadth elective(^c)</td>
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</tr>
<tr>
<td>Technical breadth elective(^c)</td>
<td>3</td>
</tr>
<tr>
<td>Depth elective(^d)</td>
<td>3</td>
</tr>
<tr>
<td>Breadth elective(^**)</td>
<td>3</td>
</tr>
<tr>
<td><strong>Year Total:</strong></td>
<td>15</td>
</tr>
<tr>
<td><strong>Fall</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Spring</strong></td>
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</table>

### Fourth Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth elective(^**)</td>
<td>3</td>
</tr>
<tr>
<td>Depth elective(^d)</td>
<td>3</td>
</tr>
<tr>
<td>Technical elective(^b)</td>
<td>3</td>
</tr>
<tr>
<td>Technical elective(^b)</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td>Senior Project in Computer Science (EECS 395)</td>
<td>4</td>
</tr>
<tr>
<td>CS course elective(^e)</td>
<td>3</td>
</tr>
<tr>
<td>Technical elective(^b)</td>
<td>3</td>
</tr>
<tr>
<td>Technical elective(^b)</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td><strong>Year Total:</strong></td>
<td>15</td>
</tr>
<tr>
<td><strong>Fall</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Spring</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Total Units in Sequence:** 127

**Hours Required for Graduation:** 127

\(^a\) Chosen from: MATH 380 Introduction to Probability, STAT 312 Basic Statistics for Engineering and Science, STAT 313 Statistics for Experimenters, STAT 332 Statistics for Signal Processing, STAT 333 Uncertainty in Engineering and Science

\(^b\) Chosen from the list of CS technical electives. All other technical electives must be approved by the student’s advisor.

\(^c\) Each student must complete 5 of the 7 following courses: EECS 314 Computer Architecture, EECS 325 Computer Networks I, EECS 338 Intro to Operating Systems and Concurrent Programming, EECS 341 Introduction to Database Systems, EECS 345 Programming Language Concepts, EECS 391 Introduction to Artificial Intelligence, and EECS 393 Software Engineering. EECS 338 Intro to Operating Systems and Concurrent Programming is a 4 unit course.

\(^d\) Each student must complete 4 courses in one of the technical depth areas listed above, including all starred courses.

\(^e\) Needed to complete the requirement of 14 CS courses. This can be an additional breadth or depth course, depending on what is needed to satisfy the depth requirement.

### Bachelor of Arts

#### Suggested Program of Study: Major in Computer Science

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

<table>
<thead>
<tr>
<th>First Year</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES First Year Seminar*</td>
<td>4</td>
</tr>
<tr>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci I (MATH 125)</td>
<td>4</td>
</tr>
<tr>
<td>Introduction to Programming in Java (EECS 132)</td>
<td>3</td>
</tr>
<tr>
<td>Breadth elective(^**)</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
</tr>
<tr>
<td>SAGES University Seminar*</td>
<td>3</td>
</tr>
<tr>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci II (MATH 126)</td>
<td>4</td>
</tr>
<tr>
<td>Breadth elective(^**)</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
</tr>
<tr>
<td><strong>Year Total:</strong></td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Second Year</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES University Seminar*</td>
<td>3</td>
</tr>
<tr>
<td>Logic Design and Computer Organization (EECS 281)</td>
<td>4</td>
</tr>
<tr>
<td>Breadth elective(^**)</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td>Discrete Mathematics (EECS 302)</td>
<td>3</td>
</tr>
<tr>
<td>Introduction to Data Structures (EECS 233)</td>
<td>4</td>
</tr>
<tr>
<td>Breadth elective(^**)</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
</tbody>
</table>
Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop. Alternatively or additionally, students may obtain employment as summer interns.

**BS/MS Program in Computer Science**

Students with a grade point average of 3.2 or higher are encouraged to apply to the BS/MS Program which will allow them to get both degrees in five years. The BS can be in Computer Science or a related discipline, such as mathematics or electrical engineering. Integrating graduate study in computer science with the undergraduate program allows a student to satisfy all requirements for both degrees in five years. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatestudies/gradprofessional/#accelerationtowardgraduatedegree).

**Minor in Computer Science (BS or BSE)**

For students pursuing a BS or BSE degree, the following four courses are required for a minor in computer science:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 132</td>
<td>Introduction to Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>EECS 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>EECS 302</td>
<td>Discrete Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>EECS 340</td>
<td>Algorithms</td>
<td>3</td>
</tr>
</tbody>
</table>

A student must take an additional 4 credit hours of CS Courses (see Major Requirements) with the exclusion of ENGR 131 Elementary Computer Programming.

**Minor in Computer Science (BA)**

For students pursuing BA degrees, the following courses are required for a minor in computer science:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 132</td>
<td>Introduction to Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>EECS 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>MATH 125</td>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci I</td>
<td>4</td>
</tr>
</tbody>
</table>

Two additional CS Courses (see Major Requirements) are required for this minor.

**Minor in Artificial Intelligence**

The minor consists of five courses. Every student who takes the minor in artificial intelligence must take the two courses, ENGR 131 Elementary Computer Programming and EECS 391 Introduction to Artificial Intelligence. Students who take the Artificial Intelligence minor must also take an additional three courses from one of two minor tracks.

**Technology Track (requires 3 of the following courses):**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 373</td>
<td>Introduction to Neurobiology</td>
<td>3</td>
</tr>
<tr>
<td>BIOL 374</td>
<td>Neurobiology of Behavior</td>
<td>3</td>
</tr>
<tr>
<td>EECS 477</td>
<td>Advanced Algorithms</td>
<td>3</td>
</tr>
<tr>
<td>EECS/BIOL 478</td>
<td>Computational Neuroscience</td>
<td>3</td>
</tr>
<tr>
<td>EECS 350</td>
<td>Operations and Systems Design</td>
<td>3</td>
</tr>
<tr>
<td>EECS 352</td>
<td>Engineering Economics and Decision Analysis</td>
<td>3</td>
</tr>
</tbody>
</table>
Graduate Programs

MS Degree Program (Electrical Engineering, Computer Engineering, Systems and Control Engineering)

Admission
Graduate students shall be admitted to one of two MS degree programs (Plan A or Plan B) upon recommendation of the faculty of the Department. Requirements for admission include a strong record of scholarship in a completed bachelor’s degree program in a field of engineering, mathematical or physical sciences, and fluency in written and spoken English. The University requires all foreign applicants to show English proficiency by achieving a TOEFL score of at least 577 on the paper-based exam or 90 on the internet-based exam. It is required that all students submit original copies of GRE scores, with the exception of CWRU students applying to the BS/MS program. Applications from students with a bachelor’s degree in fields other than those listed above may be granted admission on a provisional basis. Such provisional students may be advanced to full standing upon completion of prerequisite conditions stipulated in the letter of admission.

Registration
Course registration is performed through the SIS system. Each semester before registration, students should update any personal information that may have changed by logging onto the SIS and editing the appropriate information. All registration holds must be lifted in order to successfully complete the registration process.

Advising
Upon admission to the graduate program, each graduate student is assigned an academic advisor to assist in registration as well as planning a program of study. This is a temporary assignment made by the Department Chairperson based on the student’s academic and research interests as identified at the time of application. During the first semester in the program, it is strongly suggested that each student meet with various members of faculty to discuss academic objectives/goals and research opportunities. In order to complete the research component of their respective degree program, each student must identify a faculty member who is willing to serve as the student’s research advisor. The research advisor will also serve as the student’s permanent academic advisor if he/she is a member of the department faculty. If, however, the research advisor is not a member of the department faculty, the student is required to find a permanent academic advisor from the department faculty. For students enrolled in the MS Plan A degree program, the research advisor is commonly known as the “thesis advisor”.

Students may change advisors for a variety of reasons of which one of the most common is a change of the student’s field of interest. It should be noted that a change in research advisor may require that the student start a new research project, which could result in delaying graduation. It is the responsibility of the student to inform the EECS Office of Student Affairs in the event of a change in advisor. In addition, the student must file all appropriate forms with Graduate Studies.

The MS Plan A Degree Program
The MS Plan A degree program is composed of two components: (1) graduate-level coursework and (2) a research-oriented thesis. Progression through the program is monitored by a Program of Study. Each MS Plan A student is required to file a Program of Study through SIS. The Program of Study contains a comprehensive list of all courses to be applied to the degree (including transfer courses), and must be approved by his/her academic advisor, Department Chairperson, and Dean of Graduate Studies. The Program of Study must contain at least 30 semester credit hours of coursework at the 400 level or above, of which a minimum of 18 credits must be from non-thesis related courses. Each MS Plan A student must complete at least 9 credit hours of EECS 651 Thesis M.S., which is the course associated with MS thesis research. Each student must complete an approved Program of Study with a cumulative grade point average of 3.0 or greater. Full-time MS students are recommended to file a Program of Study before the beginning of the second semester.

Cognitive Science Track (requires 3 of the following courses):

- BIOL 373 Introduction to Neurobiology
- BIOL 374 Neurobiology of Behavior
- ENGL 301 Linguistic Analysis
- PHIL 201 Introduction to Logic
- PSCL 306 Mathematical Logic and Model Theory
- PSCL 101 General Psychology I
- PSCL 352 Physiological Psychology
- PSCL 353 Psychology of Learning
- PSCL 355 Sensation and Perception
- PSCL 357 Cognitive Psychology
- PSCL 370 Human Intelligence
- PSCL 402 Cognition and Information Processing

Minor in Computer Gaming (CGM)
The minor is 16 hours as follows:

- EECS 233 Introduction to Data Structures
- EECS 290 Introduction to Computer Game Design and Implementation
- EECS 366 Computer Graphics
- EECS 390 Advanced Game Development Project
- EECS 391 Introduction to Artificial Intelligence

It is recommended that one additional open elective be a "content creation" course taken from the following areas: Art, English, or Music. Students should note that EECS 132 Introduction to Programming in Java is a prerequisite for EECS 233 Introduction to Data Structures.
Completion of the MS Plan A degree requires that the student submit a written thesis and make an oral presentation of the findings (hereafter known as the defense) to a thesis guidance committee. The thesis guidance committee shall consist of the student’s research advisor and at least two additional faculty members recommended by the advisor. At least two members of the committee must be faculty members in the EECS department. The chairperson of the guidance committee is normally the candidate’s research advisor. The student is responsible for forming the thesis guidance committee. The student will work closely with his/her advisor to determine when the thesis is ready for review by the guidance committee. The student shall provide an announcement containing a title, abstract, date, time and location of the defense to the EECS Office of Student Affairs for general distribution at least 10 days in advance of the thesis defense.

The MS Plan B Degree Program
The MS Plan B degree program is composed of two components: (1) graduate-level coursework and (2) a research-oriented project. Progression through the program is monitored by a Program of Study. Each MS Plan B student is required to file a Program of Study through SIS. The Program of Study contains a comprehensive list of all courses to be applied to the degree (including transfer courses), and must be approved by his/her academic advisor, Department Chairperson, and Dean of Graduate Studies. The Program of Study must contain at least 30 semester credit hours of coursework at the 400 level or above, of which a minimum of 21 credits must be from courses other than EECS 695 Project M.S. (which is the course associated with the MS research project). A MS Plan B student must complete at least 3 credit hours of EECS 695 Project M.S. Each student must complete an approved Program of Study with a cumulative grade point average of 3.0 or greater. Full-time students are strongly recommended to file a Program of Study before the beginning of the second semester.

Each candidate for the master’s degree under Plan B must pass a comprehensive examination to be administered by a committee of department faculty. The examination committee should be composed of the student’s academic advisor and at least two additional members of the department faculty. In such cases, the chairperson of the committee is normally the candidate’s academic advisor. The examination may be written, oral or a combination as determined by the committee. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master’s Comprehensive Exam.

Appeals
Any decision by an academic advisor, thesis guidance committee, or department associate chairperson may be appealed, in writing, to the department associate chairperson who shall present the appeal, with his recommendations, to the faculty at its next regular faculty meeting. The faculty’s decision shall be final.

Other Regulations
All students pursuing graduate studies in the Department of Electrical Engineering and Computer Science must abide by the academic regulations of the School of Graduate Studies and the Case School of Engineering contained in the most recent issue of the Bulletin of Case Western Reserve University, and supplemented by the Department of Electrical Engineering and Computer Science regulations.

NOTE: The above regulations apply to graduate students who entered the degree programs in computer engineering, electrical engineering, and systems & control engineering after January 1, 2005.

MS Degree Program (Computing and Information Science)
Admission
Graduate students shall be admitted to the MS degree program upon recommendation of the faculty of the CS program. Requirements for admission include a strong record of scholarship in a completed bachelor’s degree program in computer science and related areas, and fluency in written and spoken English. The University requires all foreign applicants to show English proficiency by achieving a TOEFL score of at least 577 on the paper-based exam or 90 on the internet-based exam. It is required that all students submit original copies of GRE scores, with the exception of CWRU students applying to the BS/MS program.

The MS program requires students to have substantial knowledge of undergraduate computer science material. Applications from students with a bachelor’s degree in fields other than computer science may be granted admission on a provisional basis. In particular, students should have knowledge in data structures, algorithms and operating systems equivalent to that in the courses:

EECS 233 Introduction to Data Structures
EECS 340 Algorithms
EECS 338 Intro to Operating Systems and Concurrent Programming

Students deficient in one or more of these areas (admission with provision) may be required to satisfy this requirement by taking the corresponding courses listed above. A student taking and passing a more advanced course in an area automatically demonstrates knowledge of the material in the area; e.g. taking EECS 454 Analysis of Algorithms demonstrates knowledge of the material in EECS 340 Algorithms.

Registration
Course registration (including submission of the Planned Program of Study) can be performed through the SIS system. Each semester before registration, students should update any personal information that may have changed by logging onto the SIS and editing the appropriate information. All registration holds must be lifted in order to successfully complete the registration process.

Advising
Each MS student has a faculty advisor who assists the student in formulating a program of study. Initially, the advisor is the chair of the CS graduate committee. Students are expected to pick a research advisor by the end of their first semester in the program who will supervise their thesis or project. Each student, in consultation with their advisor, must submit a Planned Program of Study preferably before completing 9 credit hours of coursework. The Planned Program of Study should specify all courses and thesis work that will be counted toward the 30 credit hour requirement.

The MS Plan A and Plan B programs
As provided for by the School of Graduate Studies, there are two plans for the Master of Science degree, each requiring 30 semester hours of credit. Plan A requires at least 9 semester hours of thesis (EECS 651 Thesis M.S.) and at least 18 semester hours of courses. The additional 3 semester hours can be either thesis (EECS 651 Thesis M.S.) or a regular
course. Plan B requires 6 semester hours of project (EECS 695 Project M.S.) and 24 semester hours of coursework credit. Plan B is normally restricted to part-time students or students in the BS/MS program with the approval of their project advisor's. (A BS/MS student who follows plan B is required to do a two-semester 6 credit hours MS project.)

All coursework must be at the 400-level or higher. Students must achieve a grade point average of 3.0 or higher; it is computed for all of the courses, excluding project and thesis credits, on the student's program of study.

Both the thesis and the Plan B project require a formal written report, as well as a final oral examination by a committee of at least three faculty members, two of whom must be primarily affiliated with the CS program. A student whose thesis is supervised by a faculty member not in the EECS department must also have academic advisor in the CS program. For Plan B students, the oral examination fulfills the Comprehensive Examination requirement of the School of Graduate Studies.

**Course Requirements**

Students are required to have specialized knowledge in at least one of the following tracks, by taking at least three graduate level classes from that track. The list of acceptable classes is shown below. Generally, the chosen track should correspond to the student’s thesis research area or project. EECS 600 Special Topics classes relevant to the student’s research area or project will also qualify in this category with approval from the student’s advisor.

The remaining classes can be (i) any other class from the classes listed below, or (ii) any CS-related class offered by EECS, or (iii) graduate level classes in other departments necessary for the student’s research or project. At most two classes can be from the third category.

All coursework must be at the 400-level or higher. Students must achieve a grade point average of 3.0 or higher; it is computed for all of the courses, excluding project and thesis credits, on the student’s program of study.

**List of tracks and corresponding courses**

1. **Algorithms & Theory:**
   a. EECS 440 Machine Learning
   b. EECS 454 Analysis of Algorithms
   c. EECS 455 Applied Graph Theory
   d. EECS 456
   e. EECS 477 Advanced Algorithms
   f. MATH 408 Introduction to Cryptology

2. **Artificial Intelligence:**
   a. EECS 440 Machine Learning
   b. EECS 442 Causal Learning from Data
   c. EECS 455 Applied Graph Theory
   d. EECS 484 Computational Intelligence I: Basic Principles
   e. EECS 491 Artificial Intelligence: Probabilistic Graphical Models
   f. EECS 496 Artificial Intelligence: Sequential Decision Making
   g. EECS 497 Artificial Intelligence: Statistical Natural Language Processing
   h. EECS 499 Algorithmic Robotics
   i. EECS 531 Computer Vision

3. **Bioinformatics:**
   a. EECS 435 Data Mining
   b. EECS 440 Machine Learning
   c. EECS 454 Analysis of Algorithms
   d. EECS 456 Course EECS 456 Not Found
   e. EECS 458 Introduction to Bioinformatics
   f. EECS 459 Bioinformatics for Systems Biology
   g. SYBB 412 Survey of Bioinformatics: Programming for Bioinformatics

4. **Computer Networks and Systems:**
   a. EECS 402 Internet Security and Privacy
   b. EECS 414 Wireless Communications
   c. EECS 425 Computer Networks I
   d. EECS 428 Computer Communications Networks II
   e. EECS 438 High Performance Computing
   f. EECS 441 Internet Applications
   g. EECS 444 Computer Security
   h. EECS 448 Smartphone Security

5. **Databases and Data Mining:**
   a. EECS 405 Data Structures and File Management
   b. EECS 433 Database Systems
   c. EECS 435 Data Mining
   d. EECS 439 Web Data Mining
   e. EECS 440 Machine Learning
   f. STAT 426 Multivariate Analysis and Data Mining
   g. PQHS 471 Machine Learning & Data Mining

6. **Security and Privacy:**
   a. EECS 402 Internet Security and Privacy
   b. EECS 444 Computer Security
   c. EECS 448 Smartphone Security
   d. EECS 456
   e. EECS 493 Software Engineering
   f. MATH 408 Introduction to Cryptology

7. **Software Engineering:**
   a. EECS 425 Computer Networks I
   b. EECS 433 Database Systems
   c. EECS 438 High Performance Computing
   d. EECS 441 Internet Applications
   e. EECS 442 Causal Learning from Data
   f. EECS 444 Computer Security
   g. EECS 448 Smartphone Security
   h. EECS 493 Software Engineering

**Master of Science in Engineering with Specialization**

**Wearable Computing**

The MS degree in Electrical Engineering (EE) with a specialization in Wearable Computing may be completed as a "course-only" option program of study. Students who complete this 9-course, 30-credit course-only option will have the requisite knowledge to enter and advance the wearable computing industry.

**Wireless Health**

The MS degree in Electrical Engineering (EE) with a specialization in Wireless Health is a "course-only" option program of study. Students who complete this 10-course, 30-credit course-only option will have the requisite knowledge to enter and advance the wireless health industry, with a greater emphasis on the technology aspects.
For more details, please refer to the Master’s Degree (http://engineering.case.edu/sandiego/ms) information on the Case School of Engineering website.

PhD Graduate Student Requirements (Electrical Engineering, Computer Engineering, Systems and Control Engineering)

These regulations are in addition to the Academics Regulations of the School of Graduate Studies and the Specific Requirements for the PhD Degree of the Graduate Program in the Case School of Engineering as found in the General Catalog of Case Western Reserve University.

Admission
Requirements for admission include a strong record of scholarship in a completed bachelor’s degree program in a field of engineering, mathematical or physical sciences, and fluency in written and spoken English. The University requires all foreign applicants to show English proficiency by achieving a TOEFL score of at least 577 on the paper-based exam or 90 on the internet-based exam. It is required that all students submit original copies of GRE scores. Applications from students with a bachelor’s degree in fields other than those listed above may be granted admission on a provisional basis. Such provisional students may be advanced to full standing upon completion of prerequisite conditions stipulated in the letter of admission.

Registration
Course registration is performed through SIS. Each semester before registration, students should update any personal information that may have changed by logging onto the SIS and editing the appropriate information. All registration holds must be lifted in order to successfully complete the registration process.

Advising
Upon admission to the graduate program, each graduate student is assigned an academic advisor to assist in registration. This is a temporary assignment made by the Department Chairperson based on the student’s academic and research interests as identified at the time of application. During the first two semesters in the program, it is strongly suggested that each student meet with various members of faculty to discuss academic objectives/goals and research opportunities. In order to complete the research component of their respective degree program, each student must identify a faculty member who is willing to serve as the student’s research advisor. The research advisor will also serve as the student’s permanent academic advisor if he/she is a member of the department faculty. If, however, the research advisor is not a member of the department faculty, the student is required to find a permanent academic advisor from the department faculty. For students enrolled in the Ph.D program, the research advisor is commonly known as the “dissertation” advisor.

Students may change advisors for a variety of reasons of which one of the most common is a change of the student’s field of interest. It should be noted that a change in research advisor may require that the student start a new research project, which could result in delaying graduation. It is the responsibility of the student to inform the EECS Office of Student Affairs in the event of a change in advisor.

The student shall be responsible for forming a dissertation guidance committee which shall consist of the student’s academic advisor and additional faculty members recommended by the advisor. For the PhD program, the minimum number of additional faculty members on the dissertation guidance committee is three, and at least two of the committee must be within the ECSE program areas (Computer Engineering, Electrical Engineering, and Systems and Control Engineering). The chairperson of the guidance committee is normally the candidate’s research advisor. Each student is required to file a Program of Study, which must be approved by the student’s advisor and the Department Chairperson, and submitted to the Dean of Graduate Studies. Full-time PhD students should choose a research advisor and file a Program of Study before taking the qualifier but no later than the beginning of the third semester. Upon passing the qualifier, full time PhD students will be required to assemble the dissertation guidance committee, prepare a dissertation proposal, and present this proposal to the committee for their approval. This process should be completed within one semester of passing the PhD qualifier.

The PhD Degree Program
In order to successfully complete the PhD Degree Program, a student must satisfy the following requirements:

• Select a major dissertation subject area in Electrical Engineering, Computer Engineering, or Systems and Control Engineering
• Fulfill all PhD course requirements in the chosen major area
• Have an approved Program of Study and complete the CWRU courses in the approved Program of Study with a cumulative grade point average of 3.25 or greater
• Successfully complete the PhD Qualifying Examination
• Successfully complete the PhD Proposal Defense
• Successfully complete and defend the PhD Dissertation
• Fulfill the PhD residency requirement

PhD Course Requirements and Program of Study
Each PhD student is required to have a Program of Study, approved by the academic advisor, Department Chairperson, and Dean of Graduate Studies, that includes a minimum of 36 credit hours of coursework beyond the BS degree. At least 18 credit hours of coursework must be taken at CWRU. In addition, the student is also required to complete a minimum of 18 credit hours of EECS 701 Dissertation Ph.D. to fulfill the requirement for PhD-level research. Acceptable courses include suitable CWRU courses at the 400 level or higher and approved graduate-level courses taken at other institutions. Students holding a MS degree in an appropriate field of study from CWRU or another degree-granting institution may apply up to 18 credit hours of coursework completed for their MS degree towards the aforementioned 36 credit hour requirement.

Each PhD student is required to have a fully-approved Program of Study before taking the PhD Qualifying examination and before registering for the final 18 credit hours of the program. The Program of Study shall be prepared by the student and approved by the research advisor or the permanent academic advisor in the case where the research advisor is not in the Department.

A Program of Study must meet the following requirements:

• A minimum of two courses in mathematics, statistics, or basic science.
• At least six approved courses from the student’s major area of study. At least 4 of these courses must be from within the EECS department.
• Four additional courses that are not listed under the student’s major program area. These courses should satisfy the requirement for breadth in the student’s program of study.
• A minimum of 18 hours of PhD Dissertation research as noted by enrollment in and successful completion of EECS 701 Dissertation Ph.D.
• Successful completion of EECS 400T Graduate Teaching I, EECS 500T Graduate Teaching II and EECS 600T Graduate Teaching III.
• Successful completion of the EECS 500 EECS Colloquium requirement (see below)

The above represents the minimum course requirements beyond the BS degree. The total number of 3 credit hour courses in the Program of Study is at least 12 (twelve) beyond the BS level. The selection of these courses should be done with the guidance from the student’s permanent academic advisor. Any additional courses may be in any one of the above categories as approved by the student’s advisor.

The PhD program includes a colloquium and public presentation requirement. For those who matriculated during or after Fall 2012, the requirement involves passing 3 semesters of EECS 500 EECS Colloquium and a public presentation of their research. Public presentations include conference presentations, department seminars, workshop presentations or similar presentations in a public venue. MS thesis and PhD dissertation defenses cannot be used to fulfill the public presentation requirement. It is expected that the EECS 500 EECS Colloquium requirement will be completed before the student applied for Advancement to Candidacy. Alternatively, the student may complete this requirement by giving a presentation as part of the EECS department seminar series. Additional details and the associated forms can be acquired from the EECS Office of Student Affairs. For students who matriculated before Fall 2012, the requirement can be met in one of two ways: (1) completing the requirements detailed above, or (2) passing 5 semesters of EECS 500 EECS Colloquium. Students (such as part-time students working in industry) may propose an alternative arrangement for fulfilling this requirement by submitting a written petition to the EECS Graduate Studies Committee.

PhD Qualifying Examination

A student shall be admitted to PhD candidacy only after he or she has passed the PhD Qualifying Examination. The Qualifying Exam is intended to test the students’ knowledge in the student’s chosen major program area: Electrical Engineering, Computer Engineering, or Systems and Control Engineering. The objectives of the exam are:

1. To assess the PhD student’s understanding of the fundamental concepts in Electrical Engineering, Computer Engineering, or Systems and Control Engineering, as embodied in the respective graduate curriculum.

1. To ensure that the student have the ability to pursue PhD level research, and have mastered the graduate level coursework necessary to succeed as researchers

Full-time PhD students are recommended to take the PhD qualifier before the beginning of their third semester of full-time (or equivalent) enrollment, and must pass the exam within two years of being admitted to the program. For part-time students, the Qualifying Exam must be passed before more than 27 credit-hours of coursework have been completed. For students who must take remedial courses to make up for shortcomings in their engineering and mathematics knowledge base, the deadline can be extended to the fifth semester of full-time (or equivalent) enrollment, but this requires a petition to the ECSE Graduate Committee. Students have two opportunities to pass the PhD Qualifier. A student who fails to pass the Qualifier after two attempts will not be allowed to continue in the PhD program in the Department of Electrical Engineering and Computer Science.

To pass the PhD Qualifier, the student must demonstrate proficiency in two parts:

Part 1

The first part of the PhD Qualifier assesses the student’s fundamental knowledge and proficiency in the student’s major program area:

**Computer Engineering**

Part 1 of the PhD Qualifier will consist of a written examination with questions drawn from several course areas listed below. At least three (3) topic areas must be pursued by the student for a complete qualifier.

The exam style is a mini-project oriented, take home test that must be completed within a one week period.

1. EECS 419 Computer System Architecture
2. EECS 425 Computer Networks I
3. EECS 315 Digital Systems Design
4. EECS 488 Embedded Systems Design
5. EECS 485 VLSI Systems
6. EECS 401 Digital Signal Processing

Additional topic areas may be assigned depending on the student interests and their advisors recommendations.

If a student fails all three areas of the written examination, the entire exam must be taken again. If a student fails some areas, the faculty may elect to give another exam to the student in just the areas failed.

The written part of the Qualifying Exam for Computer Engineering will be offered at least once a year at the end of the spring semester.

**Electrical Engineering**

(For students matriculating after 8/1/2014)

Students must demonstrate competency in one of the following areas within electrical engineering in which the electrical engineering faculty have established research thrust areas:

1. Circuits and Instrumentation
2. Robotics
3. Micro- and Nano-systems

To demonstrate competency in one of these areas, the student must do one of the following: (1) take the course for that area and pass that course with a grade of A, or (2) pass a written exam for that specific area. The designated courses for each of the areas are:

1. EECS 426 MOS Integrated Circuit Design
2. EECS 489 Robotics I
3. EECS 422 Solid State Electronics II

In the event that a designated course is not offered within a reasonable period of time, the student may petition the faculty in electrical engineering to designate a suitable substitute.

A student failing to meet the requirements proscribed above may, with the support of his/her dissertation research advisor, petition the faculty for an oral exam. The oral exam will consist of a 30-minute presentation by the student to a 3-member examination committee made up of electrical engineering faculty. The topic will be drawn from the student’s area of interest as selected by his/her advisor and approved by the committee. The topic may not come directly from the student’s MS thesis conducted at CWRU or elsewhere.
A student has completed the PhD Qualifier in electrical engineering when: (1) he/she has successfully completed the aforementioned competency requirement, (2) a group of faculty within his/her selected research area has conducted a review of the student's academic record and determined that adequate progress has been made, and (3) the student has formally identified a dissertation advisor.

(For students matriculating prior to 8/1/2014)

The written portion of the PhD Qualifier in Electrical Engineering is designed to assess a student's knowledge and understanding of topics fundamental to all electrical engineering students pursuing a doctorate in the field. The written exam will consist of questions at the advanced undergraduate level covering material from the three topic areas listed below. Courses currently in the EE undergraduate curriculum corresponding to a particular topic area are listed in parentheses.

1. EECS 309 Electromagnetic Fields I
2. EECS 245 Electronic Circuits, EECS 281 Logic Design and Computer Organization
3. EECS 246 Signals and Systems

Exam problems will be limited to materials contained in the selected references as well as the aforementioned courses. Sample problems from previous exams as well as a list of relevant references are available upon request.

Students must show competency in all three tested areas. Upon recommendation of the faculty, a student showing marginal proficiency in one area may be required to correct this deficiency, for example, by taking an appropriate course (as determined by the faculty) and pass this course with at least a B grade or by serving as a teaching assistant of an appropriate course.

The written part of the Qualifying Exam for Electrical Engineering will be offered at least once a year during the month of January, prior to the beginning of the spring semester.

**Systems and Control Engineering**

Students must show competency in control systems engineering, signals and systems, and systems analysis (optimization, simulation, stochastic modeling, and decision and economic analysis). Students must demonstrate proficiency in at least three of the following areas:

1. Control Systems (EECS 408 Introduction to Linear Systems, EECS 304 Control Engineering I with Laboratory)
2. Optimization (EECS 416 Convex Optimization for Engineering, EECS 346 Engineering Optimization)
4. Simulation and Discrete Event Systems (EECS 324 Modeling and Simulation of Continuous Dynamical Systems)
5. Stochastic Models and Decisions (EECS 352 Engineering Economics and Decision Analysis, EECS 452 Random Signals)

To demonstrate proficiency in an area, the student can either take one of the courses listed for that area and obtain a course grade of A or take and pass an exam for that specific area. Upon recommendation by the faculty, the student showing marginal proficiency in any area may be required to improve proficiency by serving as a teaching assistant of an appropriate course.

**Part 2**

The second part of the PhD Qualifier shall be prepared and administered by the designated PhD Qualifying committee for students in the Electrical Engineering program and in the Computer Engineering program or by the student’s PhD dissertation guidance committee for each PhD student in the Systems and Control Engineering program. This exam will test the student on advanced topics in the student’s major area of study as well as specialized topics relevant to the student's research area.

**Computer Engineering**

Part 2 will consist of an oral exam based on the areas of the written examination. However, the oral maybe waived if the student has performed well in all three topic areas of the written exam.

**Electrical Engineering**

(For students matriculating after 8/1/2014)

Does not apply

(For students matriculating prior to 8/1/2014)

Only those students performing adequately on the written exam will advance to the oral portion of the qualifier. The exam will be administered by a three-member examination committee assembled from the ECSE faculty. The oral portion of the PhD Qualifier will consist of a two-part examination. The first part of the oral exam will consist of a 20-minute presentation by the student on a topic selected by the examination committee. The topic will be one that is well documented in the scientific/engineering literature. In selecting the topic, the examination committee will take into account the student’s research interests, academic background, and experience in the field. The student will be given the topic 15 working days prior to the examination. The topic will be presented to the student in the form of a published paper or collection of papers. The student will be required to demonstrate competency in the following areas: (1) the material directly covered by the paper(s), (2) the material covered in the important references in the paper(s), and (3) any relevant background material that is necessary for the fundamental understanding of the paper.

The second part of the oral exam will consist of a series of questions drawn from the topic areas covered by the written exam.

As with the written exam, a student showing marginal proficiency during the oral exam may be asked to perform some sort of remediation at the discretion of the oral examination committee.

**Systems and Control Engineering**

A typical exam begins with a selection by the student's dissertation guidance committee of 5-6 research articles relevant to the student’s research area. The students will be given 4 weeks to write a report answering questions formulated from those papers by the dissertation guidance committee. This will be followed within one week by an oral exam during which the student will give an oral presentation based on the report and answer questions from the dissertation guidance committee and other attending EECS faculty. Questions will be based on the report as well as miscellaneous questions on advanced topics in Systems and Control Engineering as deemed appropriate by committee members and/or other attending faculty.

**PhD Candidacy**

The final consideration of whether to admit the student to PhD candidacy will be taken by the PhD Qualifying Committee (for Electrical Engineering and Computer Engineering students) or the student’s dissertation guidance committee (for Systems and Control Engineering students).
after the student has passed the PhD Qualifier. A written report on the results of the qualifier and PhD candidacy will be prepared by the committee and submitted to the Department Chairperson, who, in turn, will notify the School of Graduate Studies of the results.

PhD Proposal
After passing the Qualifier and being admitted to PhD candidacy, the PhD candidate is required to pass a Dissertation Proposal Exam on a timely basis, generally within one semester after being admitted to candidacy. This exam shall be administered by the student’s dissertation guidance committee and consists of a written dissertation proposal and an oral presentation of the proposed dissertation research. As part of the oral presentation, the student will be expected to answer questions covering the proposed research as well as questions on related topics as deemed appropriate by the student’s dissertation guidance committee. The written dissertation proposal must be received by the committee members at least ten days before the date scheduled for the oral exam and presentation. The Dissertation Proposal Exam, the PhD research, the final oral dissertation defense, and all other requirements in the student’s PhD program of study must be completed within five years after the student is admitted to PhD candidacy.

The PhD Oral Defense
The student shall provide an announcement containing a title, abstract, date, time, and location of the defense to the EECS Office of Student Affairs for general distribution at least 10 days in advance of the thesis defense.

The PhD Residency Requirements
All PhD students shall fulfill the PhD residency requirements set forth by the Case School of Engineering and the School of Graduate Studies. Specifically, the PhD student is required either to register for at least 9 credit hours during each of two consecutive semesters or to engage in academic work (taking courses, assisting in course development and/or teaching, fully engaging in research, or some other scholarly activities) in at least six consecutive terms (fall, spring, or summer) between matriculation and a period not exceeding 5 years after the first credited hour of EECS 701. The period during a leave of absence cannot be counted to fulfill the residency requirement.

Appeals
Any decision by an academic advisor, dissertation guidance committee, or Department Associate Chairperson may be appealed, in writing, to the Department Associate Chairperson who shall present the appeal, with his recommendations, to the faculty at its next regular faculty meeting. The faculty’s decision shall be final.

Other Regulations
All students pursuing graduate studies in the Electrical Engineering and Computer Science department must abide by the academic regulations of the School of Graduate Studies and the Case School of Engineering contained in the most recent issue of the General Catalog of Case Western Reserve University, and supplemented by the Department of Electrical Engineering and Computer Science regulations.

NOTE: The above regulations apply to graduate students who entered the degree programs in computer engineering, electrical engineering, and systems & control engineering after January 1, 2005.

PhD Degree Program (Computing and Information Science)

Admission
Requirements for admission include a strong record of scholarship in a completed bachelor’s degree program in computer science and related areas, and fluency in written and spoken English. The University requires all foreign applicants to show English proficiency by achieving a TOEFL score of at least 577 on the paper-based exam or 90 on the internet-based exam. It is required that all students submit original copies of GRE scores. Applications from students with a bachelor’s degree in fields other than computer science may be granted admission on a provisional basis. Such provisional students may be advanced to full standing upon completion of prerequisite conditions stipulated in the letter of admission. When applying to this program, please select the CIS (Computing and Information Sciences) option in your application.

Registration
Course registration (including submission of the Planned Program of Study) can be performed through SIS. Each semester before registration, students should update any personal information that may have changed by logging onto the SIS and editing the appropriate information. All registration holds must be lifted in order to successfully complete the registration process.

PhD Requirements
Each student must satisfy requirements in the following categories:

- Course Work
- Mathematics and Science Requirement
- Research Proposal
- Qualifying Examination
- Dissertation

All programs of study must contain at least 36 hours of courses past the undergraduate degree. All courses must be at the 400-level or higher. Six hours must be in a basic science or mathematics. A minimum of 12 hours must be in courses outside the student’s thesis area. A student must have attained a minimum 3.25 grade point average (GPA) at the time of graduation. The minimum GPA is calculated based on all courses in the student’s Program of Study that carry quality points.

These regulations are in addition to the Academics Regulations of the School of Graduate Studies and the Specific Requirements for the PhD Degree of the Graduate Program in the Case School of Engineering as found in the General Bulletin of Case Western Reserve University.

Academic Advisor and Research Advisor
Upon arrival, each graduate student is assigned an academic advisor from the Computer Science (CS) program faculty, typically the CS graduate representative. By the end of the second semester of study, a PhD student should transfer to a research advisor who may or may not be the same as the academic advisor. Once a research advisor is selected, the research advisor will also serve as the academic advisor, with whom a student consults to ensure that the balance of the PhD course work constitutes a coherent program of study.

If the research advisor is not from the Computer Science program, the student must have an academic advisor from the CS program. The academic advisor may serve as a research co-advisor if so desired by the student and the research advisor.
Program of Study
Each PhD student must submit a Program of Study detailing his or her course work, Qualifying Examination and dissertation schedules. The Program of Study lists all courses taken beyond the undergraduate degree and shows how these courses satisfy the following course requirements for the PhD:

1. The minimum course requirement beyond the B. S. level is 36 credit hours of courses taken for credit, at least 18 hours of which must be taken at CWRU. The following courses taken for credit will be acceptable:
   - All 400, 500, 600 level courses.
   - Graduate level courses taken at other institutions approved by the student’s advisor.

The above courses must include the following:

1. 1 - A minimum of 12 credit hours in the student’s dissertation research area.
2. 1.2 - A minimum of 6 credit hours in mathematics or basic science.
3. 1.3 - A minimum of 12 credit hours of breadth courses that are not in the student’s dissertation research area.

Note: The courses for items 1.1, 1.2, and 1.3 must be disjoint.

1. 1.4 - A minimum of 18 credit hours of courses approved by the Computer Science program which can be courses used in item 1.1 and item 1.3. These approved Computer Science courses are listed below.

2. A minimum of 18 credit hours of EECS 701 Dissertation Ph.D.

3. The cumulative grade-point average of all CWRU courses on the program of study must be at least 3.25.

4. All PhD students are required to register for and pass EECS 400T Graduate Teaching I, EECS 500T Graduate Teaching II and EECS 600T Graduate Teaching III which are 0 credit hour courses that provide students with teaching experience.

5. All PhD students are required to register for and pass three semesters of "EECS 500 EECS Colloquium" (a 0 credit hour course) before advancement to candidacy and complete a public presentation of their work.

The Program of Study must be approved by the student’s academic advisor and the chair of the EECS Department, and it must be approved before the student advances to candidacy.

Qualifying Examination
The Computer Science PhD qualifying examination is in the form of an oral exam and a written report, assessing the student’s ability to survey a specific research topic, discuss the state-of-the-art in depth, provide a critical description of the literature, and propose creative ideas on improving the state-of-the-art. The written and oral parts of the exam are administered by a committee consisting of three faculty members. The exam is supplemented by the evaluation of the student’s course performance and the final decision is made in a meeting of faculty affiliated with the CS program.

Students who hold a MS degree are required to take the qualifying exam at the start of their 3rd semester, and pass the qualifying exam before the start of their 4th semester in the PhD program. Students who do not hold a MS degree are required to take the qualifying exam at the start of their 5th semester, and pass the qualifying exam before the start of their 6th semester in the PhD program.

Committee: The exam will be administered by a committee composed of 3 faculty members, at least 2 of them being faculty members whose primary affiliation is Computer Science. The student will provide 0 to 3 names as suggested committee members and the CS Graduate Committee will appoint the committee, taking into account the student’s suggestion and maintenance of the load balance of the faculty. If the student has a research advisor at the time of the exam, then the advisor must be a member of the committee, but cannot serve as the chair of the committee. The CS Graduate Committee will make every effort to include a faculty member outside the research area in the committee. The committee must be appointed at least 2 months prior to the exam.

Format: The student will select a research area from the following list:

1. Algorithms and Theory
2. Artificial Intelligence
3. Bioinformatics
4. Computer Networks and Systems
5. Databases and Data Mining
6. Security and Privacy
7. Software Engineering

The exam committee will ask the student to write a report that adequately demonstrates the student’s ability to perform research in their chosen area of research. Specific examples of this might be a survey of a broad area and/or approaches to a specific problem in the area. This will be followed by an oral examination.

Written Report: The student will submit a written report on the specific research problem. The report has to adequately describe the problem and justify its relevance, identify the challenges associated with the problem, provide a broad classification of existing approaches, point out their key differences and trade-offs, identify limitations, and propose solutions for these limitations. The report must be at most 10 pages in length (11 pt font, single-spaced, single column, 1” margins) and use illustrative figures, tables, and other visual material to communicate key ideas. In addition, the report must include a comprehensive list of references. The written report must be submitted to the exam committee three weeks before the date of the oral exam.

Oral Exam: In the oral exam, the student will answer questions by the committee members on a specific research problem chosen by the committee in the selected research area, assessing the knowledge, technical depth, and broader vision of the student on the problem. The committee may also ask questions on the fundamentals of computer science as they relate to the specific research problem. The student may prepare slides in advance that will help answer questions or use the chalk board (or both), but the exam will not be in the format of a presentation. The exam will be one hour in duration. All students who are taking the exam for the first time have to take their oral exam in the week prior to the beginning or in the first two weeks of the Fall semester.

Scoring: Each of the three committee members will prepare a report rating the student’s exam performance according to the following criteria:

- Fundamentals: Does the student have broad knowledge of fundamental concepts in computer science that will enable the student to understand and tackle the challenges in the specific research area?
• Knowledge of Chosen Area: Does the student have sufficient technical depth and command of the key challenges and the state-of-the-art in the chosen area of research?

• Vision: Does the student demonstrate a solid understanding of the relevance of the problem in the context of scientific progress and societal needs? Does the student show creativity in innovating their chosen area of research?

• Communication: Can the student explain the concepts in an accessible and comprehensible manner and handle questions effectively?

• Overall Score for the Written Report and the Oral Exam.

Possible ratings are 2 (Pass), 1 (Retake), or 0 (Fail).

Course Work: The student’s performance in all courses taken before the exam will also be considered by the CS program faculty in making a decision. At the time of the exam, the student must have completed at least two 400-level Computer Science courses with a “B” or above. One of these courses must be EECS 454 Analysis of Algorithms or EECS 477 Advanced Algorithms. The second course must be relevant to their chosen area of research. The relevance of the additional course to the research area is subject to approval by the CS Graduate Studies Committee. The following courses are pre-approved for each area:

1. Algorithms and Theory:
   a. EECS 454 Analysis of Algorithms
   b. EECS 477 Advanced Algorithms

2. Artificial Intelligence:
   a. EECS 440 Machine Learning
   b. EECS 491 Artificial Intelligence: Probabilistic Graphical Models

3. Bioinformatics:
   a. EECS 458 Introduction to Bioinformatics,
   b. EECS 459 Bioinformatics for Systems Biology

4. Computer Networks and Systems:
   a. EECS 425 Computer Networks I,
   b. EECS 428 Computer Communications Networks II,
   c. EECS 402 Internet Security and Privacy

5. Databases and Data Mining:
   a. EECS 433 Database Systems,
   b. EECS 435 Data Mining

6. Security and Privacy:
   a. EECS 402 Internet Security and Privacy
   b. EECS 444 Computer Security
   c. EECS 448 Smartphone Security
   d. EECS 456

7. Software Engineering:
   a. EECS 493 Software Engineering

Outcome: The final decision will be made by the CS program faculty based on the committee's reports and the student's coursework. The outcome of the exam will be one of Pass (the student advances to candidacy), Retake (the student has to retake the exam once more before the end of the following semester. The Retake decision can be partial, i.e. the student may be asked to retake the oral exam only, rewrite the report only, or take/retake a course), Fail (the student will be separated from the PhD program). The decision will be documented by the CS graduate chair and the student will be sent a notification letter.

Advancement to Candidacy
A student formally advances to candidacy after passing the Qualifying Examination and finding a faculty member who agrees to be the student’s research advisor. The student should advance to candidacy within one semester of passing the Qualifying Examination.

Students should submit documentation, approved by the academic and research advisor(s), to the Chairman of the Graduate Studies Committee of Computer Science to be admitted to candidacy.

Students who have failed to complete the conditions above within the time limit will be separated from the PhD program. Separation may also occur in the event of failure of the student to maintain a satisfactory GPA. A student who has been separated may not undertake further study for credit toward the PhD degree. With the approval of the Department and the Dean of Graduate Studies, such a student may complete a master's degree, may register as a non-degree student or seek admission to the graduate program of another department.

Dissertation Advisory Committee
Each PhD student must form a Dissertation Advisory Committee which consists of at least 4 members of University faculty. The student's academic advisor serves as the chair of this committee. Both the chair of the committee and at least one other member must be a regular faculty member whose primary affiliation is with the Computer Science program. The committee must also include one member whose primary appointment is not in the Computer Science program.

Dissertation Proposal
The PhD student must write a formal thesis proposal and defend it in an oral presentation to his or her Dissertation Advisory Committee. Normally this is done within a year of advancing to candidacy. A student who fails to defend his or her thesis proposal can attempt to defend it a second time after modifying the thesis proposal, but a second failure will cause the student to be separated from the program.

Dissertation
The student's dissertation must be original research in CS which represents a significant contribution to existing knowledge in the student’s research area, a portion of which must be suitable for publication in reputable research journals or selective peer-reviewed conferences. In addition to the written dissertation, the doctoral candidate must pass an oral examination in defense of the dissertation. The Dissertation Advisory Committee is responsible for certifying that the quality and suitability of the material presented in the dissertation meet acceptable scholarly standards. To satisfy requirement 5 of the Program of Study above, if the student has not publicly presented their work at a conference or similar external venue, they must also present the dissertation research in a departmental seminar.

Course List for Program of Study Requirement

EECS 402 Internet Security and Privacy
EECS 405 Data Structures and File Management
EECS 425 Computer Networks I
EECS 428 Computer Communications Networks II
EECS 433 Database Systems
EECS 435 Data Mining
EECS 438 High Performance Computing
EECS 439 Web Data Mining
EECS 440 Machine Learning
EECS 441 Internet Applications
EECS 442 Causal Learning from Data
EECS 444 Computer Security
EECS 448 Smartphone Security
EECS 454 Analysis of Algorithms
EECS 455 Applied Graph Theory
EECS 456
EECS 458 Introduction to Bioinformatics
EECS 459 Bioinformatics for Systems Biology
EECS 466 Computer Graphics
EECS 477 Advanced Algorithms
EECS 484 Computational Intelligence I: Basic Principles
EECS 491 Artificial Intelligence: Probabilistic Graphical Models
EECS 493 Software Engineering
EECS 496 Artificial Intelligence: Sequential Decision Making
EECS 497 Artificial Intelligence: Statistical Natural Language Processing
EECS 499 Algorithmic Robotics
EECS 531 Computer Vision

EECS Colloquium and Presentation Requirement

**PhD Students**

The requirement has two parts: (1) passing 3 semesters of EECS 500 EECS Colloquium, and (2) a public presentation.

(1) *All PhD students are required to register for and pass EECS 500 EECS Colloquium for a total of three semesters of the PhD Program, and this is expected before Advancement to Candidacy.* (This is a 0 credit hour required course.) *Students (such as students working in industry) may propose an alternative arrangement for fulfilling this requirement, by submitting a written petition to the Graduate Studies Committee.*

(2) *All PhD students must give a public presentation of their research, in addition to their PhD dissertation defense. This presentation must be given either at a research conference or in the EECS seminar series.*

**Graduate Certificates**

Graduate Certificates are discipline independent and intended to enable knowledgeable entry into the field of study. They are prescribed 3-course, 9-credit subsets of our MS degree offerings.

**Wearable Computing Required Courses**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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<tr>
<td>EECS 480T</td>
<td>Wearable Computing Design</td>
<td>3</td>
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<tr>
<td>EECS 480U</td>
<td>Wearable Computing Technology</td>
<td>3</td>
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<tr>
<td>EECS 480W</td>
<td>Wearable Computing Manufacturing</td>
<td>3</td>
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</tbody>
</table>

**Wireless Health Required Courses**

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<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>EBME/EECS 480A</td>
<td>Introduction to Wireless Health</td>
<td>3</td>
</tr>
<tr>
<td>EBME/EECS 480B</td>
<td>The Human Body</td>
<td>3</td>
</tr>
<tr>
<td>EBME/EECS 480C</td>
<td>Biomedical Sensing Instrumentation</td>
<td>3</td>
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For more details, please refer to the Graduate Certificate information on the Case School of Engineering - San Diego website.

**Facilities**

**Computer Facilities**

The department computer facilities incorporate both Unix (primarily Solaris) and Microsoft Windows-based operating systems on high-end computing workstations for education and research. A number of file, printing, database, and authentication servers support these workstations, as well as the administrative functions of the department. Labs are primarily located in the Olin and Glennan buildings, but include Nord Hall, and are networked via the Case network.

The Case network is a state-of-the-art, high-speed fiber optic campus-wide computer network that interconnects laboratories, faculty and student offices, classrooms, and student residence halls. It is one of the largest fiber-to-desktop networks anywhere in the world. Every desktop has a 1 Gbps (gigabit per second) connection to a fault-tolerant 10 Gbps backbone. To complement the wired network, over 1,200 wireless access points (WAPs) are also deployed allowing anyone with a laptop or wireless enabled PDA to access resources from practically anywhere on campus.

Off-campus users, through the use of virtual private network (VPN) servers, can use their broadband connections to access many on-campus resources, as well as software, as if they were physically connected to the Case network. The department and the university participate in the Internet2 and National Lambda Rail projects, which provides high-speed, inter-university network infrastructure allowing for enhanced collaboration between institutions. The Internet2 infrastructure allows students, faculty and staff alike the ability to enjoy extremely high-performance connections to other Internet2 member institutions.

Aside from services provided through a commodity Internet connection, Case network users can take advantage of numerous online databases such as EUCLIDplus, the University Libraries' circulation and public access catalog, as well as Lexus-Nexis™ and various CD-ROM based dictionaries, thesauri, encyclopedias, and research databases. Many regional and national institutional library catalogs are accessible over the network, as well.

EECS faculty are active users of the Microfabrication Laboratory and participants in the Advanced Platform Technology Center described under Interdisciplinary Research Centers.

**Additional Department Facilities**

**Sally & Larry Sears Undergraduate Design Laboratory**

This laboratory supports all departmental courses in circuits and includes a state-of-the-art lecture hall, a modernistic glass-walled lab, an electronics "store", and a student lounge and meeting area. Specialized lab space is available for senior projects and sponsored undergraduate programs. The lab is open to all undergraduates, and components are provided free of charge, so students can "play and tinker" with
electronics and foster innovation and creativity. The laboratory provides access to PCs, oscilloscopes, signal generators, logic analyzers, and specialized equipment such as RF analyzers and generators. In addition, the lab includes full-time staff dedicated to the education, guidance and mentoring of undergraduates in the “art and practice” of hands-on engineering.

This is the central educational resource for students taking analog, digital, and mixed-signal courses in electronics, and has been supported by various corporations in addition to alumnus Larry Sears, a successful engineer and entrepreneur. Basic workstations consist of Windows-based computers equipped with LabView software, as well as Agilent 546xx oscilloscopes, 33120A Waveform Generators, 34401A Digital Multimeters, and E3631A power supplies. Advanced workstations are similarly configured, but with a wider variety of high-performance test equipment.

**Jennings Computer Center Lab**

Supported by an endowment from the Jennings Foundation, this lab provides our students with the educational resources necessary for their classwork and exploration of the art of computing. This lab has both PCs and Sun Unix workstations and includes two high-speed laser printers.

**EECS Undergraduate Computer Lab**

This laboratory (recently renovated with major funding provided by Rockwell Automation) on the 8th floor of the Olin building is accompanied by a suite of instructor/TA offices and supports the freshman computing classes: ENGR 131 Elementary Computer Programming and EECS 132 Introduction to Programming in Java. Thirty student Macintosh workstations with underlying UNIX operating systems are available for hands-on instruction and support the study of introductory programming at the university.

**Nord Computer Laboratory**

This is a general-purpose computer facility that is open 24 hours a day, to all students. The lab contains 50 PCs running Windows and four Apple Macintosh computers. Facilities for color printing, faxing, copying and scanning are provided. Special software includes PRO/Engineer, ChemCAD and Visual Studio. Blank CDs, floppy disks, transparencies and other supplies are available for purchase. Visit the website (http://www.scl.cwru.edu) for more information.

**Virtual Worlds (Gaming and Simulation) Laboratory**

The Virtual Worlds Gaming and Simulation Laboratory provides software and hardware to support education and research in computer gaming and simulation activities within the Electrical Engineering and Computer Science Department and the University at large. The lab has been leveraged to provide students with extensive game play opportunities and offers, strongly experiential simulation and game development educational opportunities — primarily targeted to the EECS undergraduate population.

The lab also stimulates large amounts of cross-disciplinary collaboration in both education and research. Simulation and visualization techniques are of great value in all science and engineering fields, and the lab is capable of supporting advanced applications of these techniques in real-time applications. In addition, interactive technologies and video games require substantial artistic resources, that has resulted in excellent opportunities for educational and research collaboration with the Cleveland Institute of Art (CIA), the School of Nursing, the Medical School, and the Psychology Department. Of particular note has been the Advanced Game Project course (EECS 390 Advanced Game Development Project) taught jointly by CWRU and CIA for juniors and seniors. This course has been very popular and has provided truly excellent student game design and production experiences while receiving industrial and popular recognition and acclaim. In addition, an entry-level computer game programming course (EECS 290 Introduction to Computer Game Design and Implementation) is available for students who have taken both a Java-based programming course and a data structures course to provide an introduction to many of the technical aspects of computer game development. Many other courses in the department also use the lab as an important part of their curriculum including courses on computer graphics, artificial intelligence, simulation, digital signal processing, and control systems. The lab also supports research in the department requiring significant computational resources, e.g. GPU acceleration, VLSI simulation, etc.

A recent large donation for the lab has allowed for the update and renovation of the entire lab including the physical infrastructure (carpeting, furniture, etc.), the gaming PCs, and the gaming consoles. In addition, a new VR and AR room has been added to represent this new area connected strongly to computer gaming. The lab is now structured into a PC gaming area and an adjacent gaming console area, a VR/AR room, a portable gaming development room, and a team collaboration room.

The renovated lab includes the following primary equipment:

- 24 New Alienware PCs with Dell 27” 4K monitors
- 4 Sony Bravia Television monitors 75” 3DTV
- 2 Microsoft HoloLens AR Units
- 4 Oculus Rift VR units with Haptic Touch Input devices
- A 3D projector (and large wall screen) with 3D capability for common presentations
- 4 Xbox One Units with Xbox One controllers
- 4 PS4 Sony PlayStation units with controllers

**Database and Bioinformatics Research Laboratory**

Primarily funded by equipment grants from the National Science Foundation and Microsoft Research, this laboratory provides PCs running Windows and Linux supporting research in database systems and bioinformatics.

**Networks Laboratory**

Supported through donations from both Cisco Systems and Microsoft Research, the networks lab has 15 stations complete with a PC, a Cisco switch and router, IP telephony equipment, as well as network patches back to a central rack where devices at one workstation may be routed to other equipment in the lab. A “library” of related equipment is also available.

**Intelligent Networks & Systems Architecting (INSA) Research Laboratory**

The Intelligent Networks & Systems Architecting (INSA) Research Laboratory is a state-of-the-art research facility dedicated to intelligent computer networks, systems engineering, design, and architecting. It includes optimization, simulation, artificial intelligence, visualization, and emulation. This lab has been partially supported by NASA’s Space Exploration programs for Human and Robotic Technology (H&R). The INSA Lab is equipped with 10 high-performance workstations and 2 servers in a mixed Windows and Linux environment, with over 40 installed network interface cards providing connectivity to its wired and wireless research networks. It includes software packages such as GINO and LINDO, Arena simulation, ns2 and OPNET, as well as the STK satellite
toolkit, artificial neural network, systems architecting and modeling, and statistical analysis and data management packages such as SPSS. The INSA Lab is also used for research in heterogeneous, sensor web, and mobile ad-hoc networks with space and battlefield applications.

**VLSI Design Laboratory**

This lab has been supported by the Semiconductor Research Corporation, NSF, NASA, Synopsys and Sun Microsystems. This laboratory has a number of advanced UNIX workstations that run commercial CAD software tools for VLSI design and is currently used to develop design and testing techniques for embedded system-on-chip.

**Embedded Systems Laboratory**

The Embedded Systems Laboratory is equipped with several Sun Blade Workstations running Solaris and Intel PCs running Linux. This lab has been recently equipped with advanced FPGA Virtex II prototype boards from Xilinx, including about 100 Xilinx Virtex II FPGAs and Xilinx CAD tools for development work. A grant-in-aid from Synopsys has provided the Synopsys commercial CAD tools for software development and simulation. This Lab is also equipped with NIOS FPGA boards from Altera, including software tools.

**Mixed-Signal Integrated Circuit Laboratory**

This research laboratory includes a cluster of Windows workstations and a UNIX server with integrated circuit design software (Cadence Custom IC Bundle), as well as a variety of equipment used in the characterization of mixed-signal (analog and digital) integrated circuits, which are typically fabricated using the MOSIS foundry service. Test equipment includes an IC probe station, surface-mount soldering equipment, logic and network/spectrum analyzers, an assortment of digital oscilloscopes with sample rates up to 1 GHz, and a variety of function generators, multi-meters, and power supplies.

**Microelectromechanical Systems (MEMS) Research Laboratory**

The MEMS Research Laboratory is equipped for microfabrication processes that do not require a clean room environment. These include chemical-mechanical polishing (two systems), bulk silicon etching, aqueous chemical release of free-standing micromechanical components, and supercritical point drying. In addition to the fabrication capabilities, the lab is also well equipped for testing and evaluation of MEMS components as it houses wafer-scale probe stations, a vacuum probe station, a multipurpose vacuum chamber, and an interferometric load-deflection station. Two large (8 x 2 ft2) vibration isolated air tables are available for custom testing setups. The laboratory has a wide variety of electronic testing instruments, including a complete IV-CV testing setup.

**BioMicroSystems Laboratory**

This research laboratory focuses on developing wireless integrated circuits and microsystems for a variety of applications in biomedical and neural engineering. The laboratory contains several PC computers, software packages for design, simulation, and layout of high-performance, low-noise, analog/mixed-signal/RF circuits and systems, and testing/measurement equipment such as dc power supply, arbitrary function generator, multichannel mixed-signal oscilloscope, data acquisition hardware, spectrum analyzer, potentiostat, and current source meter. Visit the website (http://www.mohsenilab-cwru.org) for more information.

**Emerging Materials Development and Evaluation Laboratory**

The EMDE Laboratory is equipped with tooling useful in characterizing materials for MEMS applications. The laboratory contains a PC-based apparatus for load-deflection and burst testing of micromachined membranes, a custom-built test chamber for evaluation and reliability testing of MEMS-based pressure transducers and other membrane-based devices, a probe station for electrical characterization of micro-devices, a fume hood configured for wet chemical etching of Si, polymers, and a wide variety of metals, tooling for electroplating, an optical reflectometer, and a supercritical-point dryer for release of surface micromachined devices. The lab also has a PC with layout and finite element modeling software for device design, fabrication process design, and analysis of testing data.

**Laboratory for Nanoscale Devices and Integrated Systems**

This research lab explores new engineering and physics at the nanoscale, and by applying such knowledge, develops new devices and tools for emerging technological applications in the new frontiers of information, biomedical, and life sciences. A primary current theme of the research is on developing nanoscale electromechanical systems (NEMS), based on exploration and understandings of mesoscopic devices fundamentals and new characteristics of various nanoscale structures and functional systems. The lab has been developing NEMS with new functions and high performance, in combination with some of the latest advances in advanced materials, integrated circuits, and others, through cross-disciplinary explorations and collaboration. The lab is dedicated to the development of various NEMS transducers, biosensors, high-frequency nanodevices, and high-precision instruments. For more information, contact Dr. Philip Feng (philip.feng@case.edu).

Some of the recent research highlights include: the first very-high-frequency silicon nanowire resonators and sensors, the first ultra-high-frequency self-sustaining oscillators (aka NEMS clocks), the first low-voltage (~1V), high-speed nanowire NEMS switches, and the first NEMS mass sensors for weighing single-biomolecules and for probing the noise arising from adsorbed atoms walking on the surface of a vibrating NEMS.

**Control and Energy Systems Center (CESC)**

The Control and Energy Systems Center (CESC) looks for new transformational research and engineering breakthroughs to build a better world, improving our industry, economy, energy, environment, water resources and society, all with sustainability and within an international collaboration framework. With an interdisciplinary and concurrent engineering approach, the CESC focuses on bridging the gap between fundamental and applied research in advanced control and systems engineering, with special emphasis in energy innovation, wind energy, power systems, water treatment plants, sustainability, spacecraft, environmental and industrial applications. Fundamental research foci are to gain knowledge and understanding on multi-input-multi-output physical worlds, nonlinear plants, distributed parameter systems, plants with non-minimum phase, time delay and/or uncertainty, etc., and to develop new methodologies to design quantitative robust controllers to improve the efficiency and reliability of such systems. Applied research aims to develop advanced solutions with industrial partners, for practical control engineering problems in energy systems, multi-megawatt wind turbines, renewable energy plants, power system dynamics and control, grid integration, energy storage, power electronics, wastewater treatment plants, desalination systems, formation flying spacecraft, satellites with flexible appendages, heating systems, robotics, parallel kinematics,
telescope control, etc. The Center was established in 2009 with the support of the Milton and Tamar Maltz Family Foundation and the Cleveland Foundation.

Process Control Laboratory
This laboratory contains process control pilot plants and computerized hardware for data acquisition and process control that is used for demonstrations, teaching, and research. This laboratory also has access to steam and compressed air for use in the pilot processes that include systems for flow and temperature control, level and temperature control, 
ph control, and pressure control plants.

Dynamics and Control Laboratory
This laboratory contains data acquisition and control devices, PLCs, electromechanical systems, and mechanical, pneumatic, and electrical laboratory experiments for demonstrations, teaching, and research. Particular systems include: AC/DC servo systems, multi-degree-of-freedom robotic systems, rectilinear and torsional multi-degree-of-freedom vibration systems, inverted pendulum, magnetic levitation system, and a PLC-controlled low-voltage AC smart grid demonstration system that includes conventional and renewable (wind and solar) generation, battery and compressed air energy storage, residential, commercial and industry loads, a capacitor bank for real-time power factor correction, and advanced sensing and controls implemented through an interconnected system of intelligent software agents.

Courses
EECS 132. Introduction to Programming in Java. 3 Units.
Introduction to computer programming and problem solving with the Java language. Computers, operating systems, and Java applications; software development; conditional statements; loops; methods; arrays; classes and objects; object-oriented design; unit testing; strings and text I/O; inheritance and polymorphism; GUI components; application testing; abstract classes and interfaces; exception handling; files and streams; GUI event handling; generics; collections; threads; comparison of Java to C, C++, and C#. Counts for CAS Quantitative Reasoning Requirement.

EECS 216. Fundamental System Concepts. 3 Units.
Develops framework for addressing problems in science and engineering that require an integrated, interdisciplinary approach, including the effective management of complexity and uncertainty. Introduces fundamental system concepts in an integrated framework. Properties and behavior of phenomena regardless of the physical implementation through a focus on the structure and logic of information flow. Systematic problem solving methodology using systems concepts. Recommended preparation: MATH 224.

EECS 233. Introduction to Data Structures. 4 Units.
The programming language Java; pointers, files, and recursion. Representation and manipulation of data: one way and circular linked lists, doubly linked lists; the available space list. Different representations of stacks and queues. Representation of binary trees, trees and graphs. Hashing; searching and sorting. Prereq: EECS 132.

EECS 245. Electronic Circuits. 4 Units.

EECS 246. Signals and Systems. 4 Units.

EECS 275. Fundamentals of Robotics. 4 Units.
The Fundamentals of Robotics course will expose students to fundamental principles of robotics. Students will explore high level conceptual foundations of robotics beginning with Braitenberg vehicles and apply this knowledge to simulated and physical robot hardware in laboratory experiences and in a final project. Laboratory experiences will guide students through applying theory to practice increasingly complex tasks in a project oriented, group work environment. The course culminates in a robotics challenge project at the end of the semester. Topics covered are: sensors, actuators, kinematics, control, planning and programming. Programming languages and concepts (e.g., C++, object oriented programming) used in robotics will be introduced and used with modern robotics programming toolboxes and frameworks. Prior experience with these languages will not be necessary. Previous experience with robotics is not required for this course. Prereq: (ENGR 131 or EECS 132) and PHYS 121 and MATH 121.

EECS 281. Logic Design and Computer Organization. 4 Units.
Fundamentals of digital systems in terms of both computer organization and logic level design. Organization of digital computers; information representation; boolean algebra; analysis and synthesis of combinational and sequential circuits; datapaths and register transfers; instruction sets and assembly language; input/output and communication; memory. Prereq: ENGR 131 or EECS 132.

EECS 290. Introduction to Computer Game Design and Implementation. 3 Units.
This class begins with an examination of the history of video games and of game design. Games will be examined in a systems context to understand gaming and game design fundamentals. Various topics relating directly to the implementation of computer games will be introduced including graphics, animation, artificial intelligence, user interfaces, the simulation of motion, sound generation, and networking. Extensive study of past and current computer games will be used to illustrate course concepts. Individual and group projects will be used throughout the semester to motivate, illustrate and demonstrate the course concepts and ideas. Group game development and implementation projects will culminate in classroom presentation and evaluation. Prereq: EECS 132.
EECS 293. Software Craftsmanship. 4 Units.
A course to improve programming skills, software quality, and the software development process. Software design; Version control; Control issues and routines; Pseudo-code programming process and developer testing; Defensive programming; Classes; Debugging; Self-documenting code; Refactoring. Offered as EECS 293 and EECS 293N. Prereq: Computer Science Major and EECS 233 with a C or higher.

EECS 293N. Software Craftsmanship. 4 Units.
A course to improve programming skills, software quality, and the software development process. Software design; Version control; Control issues and routines; Pseudo-code programming process and developer testing; Defensive programming; Classes; Debugging; Self-documenting code; Refactoring. Offered as EECS 293 and EECS 293N. Prereq: EECS 233 with a C or higher.

EECS 296. Independent Projects. 1 - 3 Units.

EECS 297. Special Topics. 1 - 3 Units.
Special topics in Computer Engineering, Computer Science, Electrical Engineering, and Systems and Control Engineering. Prereq: Limited to freshmen and sophomores.

EECS 301. Digital Logic Laboratory. 2 Units.
This course is an introductory experimental laboratory for digital networks. The course introduces students to the process of design, analysis, synthesis and implementation of digital networks. The course covers the design of combinational circuits, sequential networks, registers, counters, synchronous/asynchronous Finite State Machines, register based design, and arithmetic computational blocks. Prereq: EECS 281.

EECS 302. Discrete Mathematics. 3 Units.
A general introduction to basic mathematical terminology and the techniques of abstract mathematics in the context of discrete mathematics. Topics introduced are mathematical reasoning, Boolean connectives, deduction, mathematical induction, sets, functions and relations, algorithms, graphs, combinatorial reasoning. Offered as EECS 302 and MATH 304. Prereq: MATH 122 or MATH 124 or MATH 126.

EECS 303. Embedded Systems Design and Laboratory. 3 Units.
The purpose of this Course and Laboratory is to expose and train the students in modern embedded systems software and hardware design techniques and practices including networking and mobile connectivity. The rationale for the Course and Lab is based on the explosive growth of embedded systems in the industry, specifically industrial automation, aviation, surveillance, medical devices, but also common consumer products. The course topics cover a wide range of material as follows. Microcontroller systems based on the ARM processor. Essential components, memories, busses interfaces. Devices, peripherals, GPIOs, device drivers. Sensors and Actuators, A/D, D/A, DSP. Embedded Linux, kernels, kernel modules, compilers and assemblers. Libraries, and debugging facilities. The Lab will be based on common platforms such as Raspberry pi, Arduino, ARM embed, supported by a network of Linux workstations.

EECS 304. Control Engineering I with Laboratory. 3 Units.
Analysis and design techniques for control applications. Linearization of nonlinear systems. Design specifications. Classical design methods: root locus, bode, nyquist. PID, lead, lag, lead-lag controller design. State space modeling, solution, controllability, observability and stability. Modeling and control demonstrations and experiments single-input/ single-output and multivariable systems. Control system analysis/ design/implementation software. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: EECS 246 or EMAE 350.

EECS 305. Control Engineering I Laboratory. 1 Unit.
A laboratory course based on the material in EECS 304. Modeling, simulation, and analysis using MATLAB. Physical experiments involving control of mechanical systems, process control systems, and design of PID controllers. Coreq: EECS 304.

EECS 309. Electromagnetic Fields I. 3 Units.
Maxwell's integral and differential equations, boundary conditions, constitutive relations, energy conservation and Pointing vector, wave equation, plane waves, propagating waves and transmission lines, characteristic impedance, reflection coefficient and standing wave ratio, in-depth analysis of coaxial and strip lines, electro- and magneto-quasistatics, simple boundary value problems, correspondence between fields and circuit concepts, energy and forces. Prereq: PHYS 122 or PHYS 124. Prereq or Coreq: MATH 224.

EECS 313. Signal Processing. 3 Units.
Fourier series and transforms. Analog and digital filters. Fast-Fourier transforms, sampling, and modulation for discrete time signals and systems. Consideration of stochastic signals and linear processing of stochastic signals using correlation functions and spectral analysis. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: EECS 246.

EECS 314. Computer Architecture. 3 Units.
This course provides students the opportunity to study and evaluate a modern computer architecture design. The course covers topics in fundamentals of computer design, performance, cost, instruction set design, processor implementation, control unit, pipelining, communication and network, memory hierarchy, computer arithmetic, input-output, and an introduction to RISC and super-scalar processors. Prereq: EECS 281.

EECS 315. Digital Systems Design. 4 Units.
This course gives students the ability to design modern digital circuits. The course covers topics in logic level analysis and synthesis, digital electronics: transistors, CMOS logic gates, CMOS lay-out, design metrics space, power, delay. Programmable logic (partitioning, routing), state machine analysis and synthesis, register transfer level block design, datapath, controllers, ASM charts, microsequencers, emulation and rapid prototyping, and switch/logic-level simulation. Prereq: EECS 281.
EECS 316. Computer Design. 3 Units.
Methodologies for systematic design of digital systems with emphasis on programmable logic implementations and prototyping. Laboratory which uses modern design techniques based on hardware description languages such as VHDL, CAD tools, and Field Programmable Gate Arrays (FPGAs). Prereq: EECS 281 and EECS 315.

EECS 318. VLSI/CAD. 4 Units.
With Very Large Scale Integration (VLSI) technology there is an increased need for Computer-Aided Design (CAD) techniques and tools to help in the design of large digital systems that deliver both performance and functionality. Such high performance tools are of great importance in the VLSI design process, both to perform functional, logical, and behavioral modeling and verification to aid the testing process. This course discusses the fundamentals in behavioral languages, both VHDL and Verilog, with hands-on experience. Prereq: EECS 281 and EECS 315.

EECS 319. Applied Probability and Stochastic Processes for Biology. 3 Units.
Applications of probability and stochastic processes to biological systems. Mathematical topics will include: introduction to discrete and continuous probability spaces (including numerical generation of pseudo random samples from specified probability distributions), Markov processes in discrete and continuous time with discrete and continuous sample spaces, point processes including homogeneous and inhomogeneous Poisson processes and Markov chains on graphs, and diffusion processes including Brownian motion and the Ornstein-Uhlenbeck process. Biological topics will be determined by the interests of the students and the instructor. Likely topics include: stochastic ion channels, molecular motors and stochastic ratchets, actin and tubulin polymerization, random walk models for neural spike trains, bacterial chemotaxis, signaling and genetic regulatory networks, and stochastic predator-prey dynamics. The emphasis will be on practical simulation and analysis of stochastic phenomena in biological systems. Numerical methods will be developed using a combination of MATLAB, the R statistical package, MCell, and/or URDME, at the discretion of the instructor. Student projects will comprise a major part of the course. Offered as BIOL 319, EECS 319, MATH 319, SYBB 319, BIOL 419, EBME 419, MATH 419, PHOL 419, and SYBB 419. Prereq: MATH 224 or MATH 223 and BIOL 300 or BIOL 306 and MATH 201 or MATH 307 or consent of instructor.

EECS 321. Semiconductor Electronic Devices. 4 Units.
Energy bands and charge carriers in semiconductors and their experimental verifications. Excess carriers in semiconductors. Principles of operation of semiconductor devices that rely on the electrical properties of semiconductor surfaces and junctions. Development of equivalent circuit models and performance limitations of these devices. Devices covered include: junctions, bipolar transistors, Schottky junctions, MOS capacitors, junction gate and MOS field effect transistors, optical devices such as photodetectors, light-emitting diodes, solar cells, and lasers. Prereq: PHYS 122. Prereq or Coreq: MATH 224.

EECS 322. Integrated Circuits and Electronic Devices. 3 Units.
Technology of monolithic integrated circuits and devices, including crystal growth and doping, photolithography, vacuum technology, metalization, wet etching, thin film basics, oxidation, diffusion, ion implantation, epitaxy, chemical vapor deposition, plasma processing, and micromachining. Basics of semiconductor devices including junction diodes, bipolar junction transistors, and field effect transistors. Prereq: PHYS 122. Prereq or Coreq: MATH 224.

EECS 324. Modeling and Simulation of Continuous Dynamical Systems. 3 Units.
This course examines the computer-based modeling and simulation of continuous dynamical system behavior in a variety of systems including electric power systems, industrial control systems, and signal processing that are represented by a set of differential equations need to be solved numerically in order to compute and represent their behavior for study. In addition to these applications, there are many other important applications of these tools in computer games, virtual worlds, weather forecasting, and population models, to name a few examples. Numerical integration techniques are developed to perform these computations. Multiple computational engines such as Matlab, Simulink, Unity, and physics engines etc. are also examined as examples of commonly used software to solve for and visualize continuous-time system behavior. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide motivation and a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: MATH 224.

EECS 325. Computer Networks I. 3 Units.
An introduction to computer networks and the Internet. Applications: http, ftp, e-mail, DNS, socket programming. Transport: UDP, TCP reliable data transfer, and congestion control. Network layer: IP, routing, and NAT. Link layer: taxonomy, Ethernet, 802.11. Offered as EECS 325 and EECS 325N. Prereq: Computer Science Major with minimum Junior Standing and EECS 233 with a C or higher.

EECS 325N. Computer Networks I. 3 Units.

EECS 326. Instrumentation Electronics. 3 Units.
A second course in instrumentation with emphasis on sensor interface electronics. General concepts in measurement systems, including accuracy, precision, sensitivity, linearity, and resolution. The physics and modeling of resistive, reactive, self-generating, and direct-digital sensors. Signal conditioning for same, including bridge circuits, coherent detectors, and a variety of amplifier topologies: differential, instrumentation, charge, and transimpedance. Noise and drift in amplifiers and resistors. Practical issues of interference, including grounding, shielding, supply/return, and isolation amplifiers. Prereq: ENGR 210 and (EECS 246, EBME 308 or EMAE 350).

EECS 329. Introduction to Nanomaterials: Material Synthesis, Properties and Device Applications. 3 Units.
The behavior of nanoscale materials is close, to atomic behavior rather than that of bulk materials. The growth of nanomaterials, such as quantum dots, has the tendency to be viewed as an art rather than science. These nanostructures have changed our view of Nature. This course is designed to provide an introduction to nanomaterials and devices to both senior undergraduate and graduate students in engineering. Topics covered include an introduction to growth issues, quantum mechanics, quantization of electronic energy levels in periodic potentials, tunneling, distribution functions and density of states, optical and electronic properties, and devices. Offered as EECS 329 and EECS 429. Coreq: EECS 309.
EECS 337. Compiler Design. 4 Units.
Design and implementation of compilers and other language processors. Scanners and lexical analysis; regular expressions and finite automata; scanner generators; parsers and syntax analysis; context free grammars; parser generators; semantic analysis; intermediate code generation; runtime environments; code generation; machine independent optimizations; data flow and dependence analysis. There will be a significant programming project involving the use of compiler tools and software development tools and techniques. Prereq: EECS 233 and EECS 281.

EECS 338. Intro to Operating Systems and Concurrent Programming. 4 Units.
Intro to OS; OS Structures, processes, threads, CPU scheduling, deadlocks, memory management, file system implementations, virtual machines, cloud computing. Concurrent programming: fork, join, concurrent statement, critical section problem, safety and liveness properties of concurrent programs, process synchronization algorithms, semaphores, monitors. UNIX systems programming: system calls, UNIX System V IPCs, threads, RPCs, shell programming. Offered as EECS 338 and EECS 338N. Prereq: Computer Science Major or Minor and EECS 233 with a C or higher.

EECS 338N. Intro to Operating Systems and Concurrent Programming. 4 Units.
Intro to OS: OS Structures, processes, threads, CPU scheduling, deadlocks, memory management, file system implementations, virtual machines, cloud computing. Concurrent programming: fork, join, concurrent statement, critical section problem, safety and liveness properties of concurrent programs, process synchronization algorithms, semaphores, monitors. UNIX systems programming: system calls, UNIX System V IPCs, threads, RPCs, shell programming. Offered as EECS 338 and EECS 338N. Prereq: EECS 233 with a C or higher.

EECS 339. Web Data Mining. 3 Units.
Web crawling technology, web search and information extraction, unsupervised and semi-supervised learning techniques and their application to web data extraction, social network analysis, various pagerank algorithms, link analysis, web resource discovery, web, resource description framework (RDF), XML, Web Ontology Language (OWL). Prereq: EECS 338, EECS 341, and (EECS 302 or MATH 304).

EECS 340. Algorithms. 3 Units.
Fundamentals in algorithm design and analysis. Loop invariants, asymptotic notation, recurrence relations, sorting algorithms, divide-and-conquer, dynamic programming, greedy algorithms, basic graph algorithms. Offered as EECS 340 and EECS 340N. Prereq: (Computer Science Major/Minor or Data Science Major) and (EECS 302 or MATH 304) and (EECS 233 or DSCI 234 with a C or higher).

EECS 340N. Algorithms. 3 Units.
Fundamentals in algorithm design and analysis. Loop invariants, asymptotic notation, recurrence relations, sorting algorithms, divide-and-conquer, dynamic programming, greedy algorithms, basic graph algorithms. Offered as EECS 340 and EECS 340N. Prereq: (EECS 302 or MATH 304) and EECS 233 with a C or higher.

EECS 341. Introduction to Database Systems. 3 Units.
Relational model, ER model, relational algebra and calculus, SQL, OBE, security, views, files and physical database structures, query processing and query optimization, normalization theory, concurrency control, object relational systems, multimedia databases, Oracle SQL server, Microsoft SQL server. Offered as EECS 341 and EECS 341N. Prereq: Computer Science Major and (EECS 302 or MATH 304) and EECS 233 with a C or higher.

EECS 341N. Introduction to Database Systems. 3 Units.
Relational model, ER model, relational algebra and calculus, SQL, OBE, security, views, files and physical database structures, query processing and query optimization, normalization theory, concurrency control, object relational systems, multimedia databases, Oracle SQL server, Microsoft SQL server. Offered as EECS 341 and EECS 341N. Prereq: (EECS 302 or MATH 304) and EECS 233 with a C or higher.

EECS 342. Introduction to Global Issues. 3 Units.
This course is based on the paradigm of the world as a complex system. Global issues such as population, world trade and financial markets, resources (energy, water, land), global climate change, and others are considered with particular emphasis put on their mutual interdependence. A reasoning support computer system which contains extensive data and a family of models is used for future assessment. Students are engaged in individual, custom-tailored, projects of creating conditions for a desirable or sustainable future based on data and scientific knowledge available. Students at CWRU will interact with students from fifteen universities that have been strategically selected in order to give global coverage to UNESCO’S Global-problematic Education Network Initiative (GENie) in joint, participatory scenario analysis via the internet.

EECS 342I. Global Issues, Health, & Sustainability in India. 3 Units.
Global Issues, Health, & Sustainability in India is an interdisciplinary social work and engineering collaboration that includes a short-term cross-cultural immersion. This course brings together social work (knowledge, values, and skills) and health care (promotion, education, and community) perspectives to the understanding of technical project assessment, selection, planning and implementation in India. The course is also designed to help students understand culturally relevant community engagement strategies to ensure project acceptance in underserved and developing communities. Many field sites will be visited in order to observe first-hand the community assessment and development of projects that engineers implement. An example of these projects could include infrastructure to support green energy and water (resource planning, development, conservation, and sanitation). This study abroad course will acquaint students with history and culture of India, its social, political and economic development and the impact it has on health and the delivery of social services. Participants will learn about factors affecting the abilities to reach, treat, educate, and equip communities to improve health outcomes. Engineering students will learn the quantitative aspects using a paradigm of hierarchical systems, mathematical modeling, and scenario analysis using a ‘reasoning support’ system. Together the engineering, social work, and health sciences students in disciplinary-balanced teams will jointly work on real and meaningful projects marrying the descriptive scenarios (that is the ‘subjective’ aspect) with the numerical scenario analysis based on mathematical modeling (or ‘objective’ aspect) to form a coherent view of the future. The course will be taught using both lecture and experiential modalities. Engineering students will conduct computer modeling work. Along with visiting a variety of governmental and non-governmental institutions, organizations and projects, students will visit historical sites and attend cultural events. Offered as EECS 342I and SASS 375I. Counts for CAS Global & Cultural Diversity Requirement.

EECS 343. Theoretical Computer Science. 3 Units.
Introduction to different classes of automata and their correspondence to different classes of formal languages and grammars, computability, complexity and various proof techniques. Offered as EECS 343 and MATH 343. Prereq: EECS 302 or MATH 304.
EECS 344. Electronic Analysis and Design. 3 Units.
The design and analysis of real-world circuits. Topics include: junction diodes, non-ideal op-amp models, characteristics and models for large and small signal operation of bipolar junction transistors (BJTs) and field effect transistors (FETs), selection of operating point and biasing for BJT and FET amplifiers. Hybrid-pi model and other advanced circuit models, cascaded amplifiers, negative feedback, differential amplifiers, oscillators, tuned circuits, and phase-locked loops. Computers will be extensively used to model circuits. Selected experiments and/or laboratory projects. Prereq: EECS 245.

EECS 345. Programming Language Concepts. 3 Units.
This course examines the four main programming paradigms: imperative, object-oriented, functional, and logical. It is assumed that students will come to the course with significant exposure to object-oriented programming and some exposure to imperative programming. The course will teach the functional paradigm in depth, enhance the students’ knowledge of the object-oriented and imperative paradigms, and introduce the logical paradigm. The course will explore language syntax, semantics, names/scopes, types, expressions, assignment, subprograms, abstraction and inheritance. This exploration will have several forms. Students will study the programming language concepts at a theoretical level, use the concepts in functional language programming, and implement the concepts by designing language interpreters. Offered as EECS 345 and EECS 345N. Prereq: Computer Science Major and (EECS 302 or MATH 304) and EECS 233 with a C or higher.

EECS 345N. Programming Language Concepts. 3 Units.
This course examines the four main programming paradigms: imperative, object-oriented, functional, and logical. It is assumed that students will come to the course with significant exposure to object-oriented programming and some exposure to imperative programming. The course will teach the functional paradigm in depth, enhance the students’ knowledge of the object-oriented and imperative paradigms, and introduce the logical paradigm. The course will explore language syntax, semantics, names/scopes, types, expressions, assignment, subprograms, abstraction and inheritance. This exploration will have several forms. Students will study the programming language concepts at a theoretical level, use the concepts in functional language programming, and implement the concepts by designing language interpreters. Offered as EECS 345 and EECS 345N. Prereq: (EECS 302 or MATH 304) and EECS 233 with a C or higher.

EECS 346. Engineering Optimization. 3 Units.
Optimization techniques including linear programming and extensions; transportation and assignment problems; network flow optimization; quadratic, integer, and separable programming; geometric programming; and dynamic programming. Nonlinear optimization topics: optimality criteria, gradient and other practical unconstrained and constrained methods. Computer applications using engineering and business case studies. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Recommended preparation: MATH 201.

EECS 350. Operations and Systems Design. 3 Units.
Introduction to design, modeling, and optimization of operations and scheduling systems with applications to computer science and engineering problems. Topics include, forecasting and time series, strategic, tactical, and operational planning, life cycle analysis, learning curves, resources allocation, materials requirement and capacity planning, sequencing, scheduling, inventory control, project management and planning. Tools for analysis include: multi-objective optimization, queueing models, simulation, and artificial intelligence.

EECS 351. Communications and Signal Analysis. 3 Units.
Fourier transform analysis and sampling of signals. AM, FM and SSB modulation and other modulation methods such as pulse code, delta, pulse position, PSK and FSK. Detection, multiplexing, performance evaluation in terms of signal-to-noise ratio and bandwidth requirements. Prereq: EECS 246 or requisites not met permission.

EECS 352. Engineering Economics and Decision Analysis. 3 Units.
Economic analysis of engineering projects, focusing on financial decisions concerning capital investments. Present worth, annual worth, internal rate of return, benefit/cost ratio. Replacement and abandonment policies, effects of taxes, and inflation. Decision making under risk and uncertainty. Decision trees. Value of information. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course.

EECS 354. Digital Communications. 3 Units.

EECS 360. Manufacturing and Automated Systems. 3 Units.
Formulation, modeling, planning, and control of manufacturing and automated systems with applications to computer science and engineering problems. Topics include, design of products and processes, location/spatial problems, transportation and assignment, product and process layout, group technology and clustering, cellular and network flow layouts, computer control systems, reliability and maintenance, and statistical quality control. Tools and analysis include: multi-objective optimization, artificial intelligence, and heuristics for combinatorial problems. Offered as EECS 360 and EECS 460.

EECS 365. Complex Systems Biology. 3 Units.
Complex Systems Biology is an interdisciplinary course based on systems science, engineering, biology, and medicine. The objective is to provide students with an understanding of the current state of systems biology and major challenges ahead. The biological phenomena across the level of complexity will be considered from molecular to organisms and ecology to provide universality of the systems concepts for understanding the functions and behavior of biological systems. Case studies are used and a course project is required to be completed. Prereq: Junior Standing.
EECS 366. Computer Graphics. 3 Units.

EECS 368. Power System Analysis I. 3 Units.
This course introduces the steady-state modeling and analysis of electric power systems. The course discusses the modeling of essential power system network components such as transformers and transmission lines. The course also discusses important steady-state analysis of three-phase power system network, such as the power flow and economic operation studies. Through the use of PowerWorld Simulator education software, further understanding and knowledge can be gained on the operational characteristics of AC power systems. Special topics concerning new grid technologies will be discussed towards the semester end. The prerequisite requirements of the course include the concepts and computational techniques of Alternative Current (AC) circuit and electromagnetic field. Offered as EECS 368 and EECS 468. Prereq: EECS 245.

EECS 369. Power System Analysis II. 3 Units.
This course extends upon the steady state analysis of power systems to cover study topics that are essential for power system planning and operation. Special system operating conditions are considered, such as unbalanced network operation and component faults. Among the most important analytical methods developed, are symmetrical components and sequence networks. Other study topics discussed include the electric machine modeling and power system transient stability. The latter half of the course presents computational methods and control algorithms that are essential for power system operation, such as generation control and state estimation. Offered as EECS 369 and EECS 469. Prereq: EECS 368.

EECS 370. Smart Grid. 3 Units.
This course starts with an introduction to the US electric power system infrastructure and national electricity policy. Then power system operations and reliability practices are described. In the context of currently existing infrastructure and operation strategies, the course discusses the new Smart Grid technologies such as renewable resources, distributed generation, demand response, energy storage and electric vehicles. Additional important topics of discussion include Advanced Meter Infrastructure, microgrids, the IEEE 1547 Interconnection Standard, and other interoperability standards. The course captures the evolving progress made in Smart Grid technologies and the impacts on power system economics and reliability. Offered as EECS 370 and EECS 470. Prereq: EECS 368.

EECS 371. Applied Circuit Design. 4 Units.
This course will consist of lectures and lab projects designed to provide students with an opportunity to consolidate their theoretical knowledge of electronics and to acquaint them with the art and practice of circuit and product design. The lectures will cover electrical and electronic circuits and many electronic and electrical devices and applications. Examples include mixed-signal circuits, power electronics, magnetic and piezo components, gas discharge devices, sensors, motors and generators, and power systems. In addition, there will be discussion of professional topics such as regulatory agencies, manufacturing, testing, reliability, and product cost. Weekly labs will be true "design" opportunities representing real-world applications. A specification or functional description will be provided, and the students will design the circuit, select all components, construct a breadboard, and test. The objective will be functional, pragmatic, cost-effective designs. Prereq: EECS 245.

EECS 373. Modern Robot Programming. 3 Units.
The goal of this course is to learn modern methods for building up robot capabilities using the Robot Operating System (ROS). Through a sequence of assignments, students learn how to write software to control both simulated and physical robots. Material includes: interfacing software to robot I/O; path and trajectory planning for robot arms; object identification and localization from 3-D sensing; manipulation planning; and development of graphical interfaces for supervisory robot control. Laboratory assignments are scheduled in small groups to explore implementations on specific robots. Graduate students will also perform an independent project. Offered as EECS 373 and EECS 473. Prereq: ENGR 131 or EECS 132. Coreq: EECS 373L.

EECS 373L. Modern Robot Programming Lab. 1 Unit.
Lab to accompany EECS 373, Modern Robot Programming. Coreq: EECS 373.

EECS 374. Advanced Control and Energy Systems. 3 Units.
This course introduces applied quantitative robust and nonlinear control engineering techniques to regulate automatically renewable energy systems in general and wind turbines in particular. The course also studies the fundamentals for dynamic multidisciplinary modeling and analysis of large multi-megawatt wind turbines (mechanics, aerodynamics, electrical systems, control concepts, etc.). The course combines lecture sessions and lab hours. The 400-level includes an experimental lab competition, where the object is to design, implement, and experimentally validate a control strategy to regulate a real system in the laboratory (helicopter control competition or similar); it will also include additional project design reports. Offered as EECS 374 and EECS 474. Prereq: EECS 304.

EECS 375. Applied Control. 3 Units.
This course provides a practical treatment of the study of control engineering systems. It emphasizes best practices in industry so that students learn what aspects of plant and control system design are critical. The course develops theory and practice for digital computer control systems; PID controller design (modes, forms and tuning methods); Control structure design (feed-forward, cascade control, predictive control, disturbance observers, multi-loop configurations, multivariable control); Actuators, sensors and common loops; Dynamic performance evaluation; and some advanced control techniques (quantitative robust control, gain-scheduling and adaptive control) to achieve a good performance over a range of operating conditions. Recommended preparation: EECS 374 or EECS 474. Offered as EECS 375 and EECS 475. Prereq: EECS 304 or Requisites Not Met permission.
EECS 376. Mobile Robotics. 4 Units.
Design of software systems for mobile robot control, including: motion control; sensory processing; localization and mapping; mobile-robot planning and navigation; and implementation of goal-directed behaviors. The course has a heavy lab component involving a sequence of design challenges and competitions performed in teams. Prereq: EECS 373 or EECS 473.

EECS 377. Introduction to Connected Devices. 3 Units.
Introduction to Connected Devices (e.g., Internet of Things). Undergraduates work in pairs to build a complete connected-device system, an embedded device with wireless networking, cloud and web, and mobile, and then develop hands-on experience with systems-level aspects of the connected-device system, including analytics, remote firmware update, load testing, and essential security. Students learn about current architectures, languages, and technologies, such as Pub/Sub (MQTT), Python, Objective-C, Python Django, JavaScript, HTML/CSS, and Bluetooth Low Energy.

EECS 390. Advanced Game Development Project. 3 Units.
This game development project course will bring together an interdisciplinary group of advanced undergraduate students in the fields of Electrical Engineering and Computer Science, Art, Music, and English to focus on the design and development of a complete, fully-functioning computer game (as an interdisciplinary team). The student teams are given complete liberty to design their own fully functional games from their original concept to a playable finished product, i.e., from the initial idea through to the wrapped box. The student teams will experience the entire game development cycle as they execute their projects. Responsibilities include creating a game idea, writing a story, developing the artwork, designing characters, implementing music and sound effects, programming and testing the game, and documenting the entire project. Recommended preparation: Junior or Senior standing and consent of instructor. Prereq: EECS 233 and EECS 290.

EECS 391. Introduction to Artificial Intelligence. 3 Units.
This course is an introduction to artificial intelligence. We will study the concepts that underlie intelligent systems. Topics covered include problem solving with search, constraint satisfaction, adversarial games, knowledge representation and reasoning using propositional and first order logic, reasoning under uncertainty, introduction to machine learning, automated planning, reinforcement learning and natural language processing. Recommended: basic knowledge of probability and statistics. Prereq: ENGR 131 or EECS 132.

EECS 392. App Development for iOS. 3 Units.
This course is an introduction to app development for iPhone and iPad using Cocoa Touch Framework and Xcode development environment. Topics include Objective-C programming language and iOS SDK foundations, object-oriented design and model-view-controller framework, user interface design using Xcode. Additional topics may include data management, map applications, animations and some recent developments in iOS. Recommended preparations: experiences in object-oriented programming and Mac OS; knowledge in software engineering and databases. Prereq: EECS 293 and Junior or Senior standing.

EECS 393. Software Engineering. 3 Units.
Topics: Introduction to software engineering; software lifecycle models; development team organization and project management; requirements analysis and specification techniques; software design techniques; programming practices; software validation techniques; software maintenance practices; software engineering ethics. Undergraduates work in teams to complete a significant software development project. Graduate students are required to complete a research project. Offered as EECS 393, EECS 393N, and EECS 493. Counts as SAGES Senior Capstone. Prereq: (Computer Science Major/Minor or Data Science Major) or (EECS 233 or DSCI 234 with a C or higher).

EECS 393N. Software Engineering. 3 Units.
Topics: Introduction to software engineering; software lifecycle models; development team organization and project management; requirements analysis and specification techniques; software design techniques; programming practices; software validation techniques; software maintenance practices; software engineering ethics. Undergraduates work in teams to complete a significant software development project. Graduate students are required to complete a research project. Offered as EECS 393, EECS 393N, and EECS 493. Counts as SAGES Senior Capstone. Prereq: EECS 233 with a C or higher.

EECS 394. Introduction to Information Theory. 3 Units.
This course is intended as an introduction to information and coding theory with emphasis on the mathematical aspects. It is suitable for advanced undergraduate and graduate students in mathematics, applied mathematics, statistics, physics, computer science and electrical engineering. Course content: Information measures-entropy, relative entropy, mutual information, and their properties. Typical sets and sequences, asymptotic equipartition property, data compression. Channel coding and capacity: channel coding theorem. Differential entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory inequalities (400 level). Additional topics, which may include compressed sensing and elements of quantum information theory. Recommended preparation: MATH 201 or MATH 307. Offered as MATH 394, EECS 394, MATH 494 and EECS 494. Prereq: MATH 223 and MATH 380 or requisites not met permission.

EECS 395. Senior Project in Computer Science. 4 Units.
Capstone course for computer science seniors. Material from previous and concurrent courses used to solve computer programming problems and to develop software systems. Professional engineering topics such as project management, engineering design, communications, and professional ethics. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Scheduled formal project presentations during last week of classes. Counts as SAGES Senior Capstone. Prereq: Senior standing.

EECS 396. Independent Projects. 1 - 6 Units.

EECS 397. Special Topics. 1 - 6 Units.
Special topics in Computer Engineering, Computer Science, Electrical Engineering, and Systems and Control Engineering. Prereq: Limited to juniors and seniors.
EECS 398. Engineering Projects I. 4 Units.
Capstone course for electrical, computer and systems and control engineering seniors. Material from previous and concurrent courses used to solve engineering design problems. Professional engineering topics such as project management, engineering design, communications, and professional ethics. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Scheduled formal project presentations during last week of classes. Counts as SAGES Senior Capstone. Prereq: Senior Standing. Prereq or Coreq: ENGR 398 and ENGL 398.

EECS 399. Engineering Projects II. 3 Units.
Continuation of EECS 398. Material from previous and concurrent courses applied to engineering design and research. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Prereq: Senior Standing.

EECS 400T. Graduate Teaching I. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities: grading homeworks, quizzes, and exams, having office hours for students, tutoring students. Recommended preparation: Ph.D. student in EECS department.

EECS 401. Digital Signal Processing. 3 Units.

EECS 402. Internet Security and Privacy. 3 Units.
This course introduces students to research on Internet security and privacy. Covered topics include denial of service attacks, attacks enabled by man-in-the-middle surveillance, communication hijacking, botnet and fast-flux networks, email and Web spam, threats to privacy on the Internet, and Internet censorship. The course will be based on a collection of research papers. Students will be required to attend lectures, read the materials, prepare written summaries of discussed papers, present a paper in class, complete a course project and take the final exam (in the form of the course project presentation). Prereq: EECS 325 or EECS 425 or graduate standing in Computer Science or Computer Engineering.

EECS 404. Digital Control Systems. 3 Units.
Analysis and design techniques for computer based control systems. Sampling, hybrid continuous-time/discrete-time system modeling; sampled data and state space representations, controllability, observability and stability, transformation of analog controllers, design of deadbeat and state feedback controllers; pole placement controllers based on input/output models, introduction to model identification, optimal control and adaptive control. Recommended Preparation: EECS 304 or equivalent.

EECS 405. Data Structures and File Management. 3 Units.
Fundamental concepts: sequential allocation, linked allocation, lists, trees, graphs, internal sorting, external sorting, sequential, binary, interpolation search, hashing file, indexed files, multiple level index structures, btrees, hashed files. Multiple attribute retrieval; inverted files, multi lists, multiple-key hashing, hd trees. Introduction to data bases. Data models. Recommended preparation: EECS 233 and MATH 304. Prereq: EECS 341 or Graduate standing.

In this course, money and profit as measures of "goodness" in engineering design are studied. Methods for economic analysis of capital investments are developed and the financial evaluation of machinery, manufacturing processes, buildings, R&D personnel development, and other long-lived investments is emphasized. Optimization methods and decision analysis techniques are examined to identify economically attractive alternatives. Basic concepts of cost accounting are also covered. Topics include: economics criteria for comparing projects: present worth, annual worth analysis; depreciation and taxation; retirement and replacement; effect of inflation and escalation on economic evaluations; case studies; use of optimization methods to evaluate many alternatives; decision analysis; accounting fundamentals: income and balance sheets; cost accounting. Offered as EECS 407 and EPOM 407.

EECS 408. Introduction to Linear Systems. 3 Units.

EECS 410. Mobile Health (mHealth) Technology. 3 Units.
Advances in communications, computer, and medical technology have facilitated the practice of personalized health, which utilizes sensory computational communication systems to support improved and more personalized healthcare and healthy lifestyle choices. The current proliferation of broadband wireless services, along with more powerful and convenient handheld devices, is helping to introduce real-time monitoring and guidance for a wide array of patients. Indeed, a large research community and a nascent industry is beginning to connect medical care with technology developers, vendors of wireless and sensing hardware systems, network service providers, and enterprise data management communities. Students in the course and labs will explore cutting-edge technologies in 1) information technologies and 2) healthcare/medical applications, through lectures, lab assignments, exams, presentations, and final projects. The overall course objectives are to introduce electrical engineering, computer engineering, and computer science students the fundamentals of wearable sensors, mobile health informatics, big data analysis, telehealthcare security & privacy, and human computer interaction considerations. Prereq: MS and PhD student only.
EECS 411. Applied Engineering Statistics. 3 Units.
In this course a combination of lectures, demonstrations, case studies, and individual and group computer problems provides an intensive introduction to fundamental concepts, applications and the practice of contemporary engineering statistics. Each topic is introduced through realistic sample problems to be solved first by using standard spreadsheet programs and then using more sophisticated software packages. Primary attention is given to teaching the fundamental concepts underlying standard analysis methods. Offered as EPOM 405 and EECS 411.

EECS 413. Nonlinear Systems I. 3 Units.
This course will provide an introduction to techniques used for the analysis of nonlinear dynamic systems. Topics will include existence and uniqueness of solutions, phase plane analysis of two dimensional systems including Poincare-Bendixson, describing functions for single-input single-output systems, averaging methods, bifurcation theory, stability, and an introduction to the study of complicated dynamics and chaos. Recommended preparation: Concurrent enrollment in EECS 408.

EECS 414. Wireless Communications. 3 Units.
This course introduces the fundamentals of wireless communications, including background, important concepts, and cutting-edge technologies. In particular, the course focuses on interesting and important topics in wireless communications, such as (but not limited to): Overview of wireless communication networks and protocols, the cellular concept, system design fundamentals, brief introduction to wireless physical layer fundamentals, multiple access control protocols for wireless systems, wireless networking (routing/rerouting, wireless TCP/IP), mobility management, call admission control and resource allocation, revolution/evolution towards future generation wireless networks, overview of wireless mesh networks, mobile ad hoc networks and wireless sensor networks, and wireless security (optional). Prereq: Undergraduate student with a C or better in EECS 351, or Graduate student.

EECS 415. Integrated Circuit Technology I. 3 Units.

EECS 416. Convex Optimization for Engineering. 3 Units.
This course will focus on the development of a working knowledge and skills to recognize, formulate, and solve convex optimization problems that are so prevalent in engineering. Applications in control systems; parameter and state estimation; signal processing; communications and networks; circuit design; data modeling and analysis; data mining including clustering and classification; and combinatorial and global optimization will be highlighted. New reliable and efficient methods, particular those based on interior-point methods and other special methods to solve convex optimization problems will be emphasized. Implementation issues will also be underscored. Recommended preparation: MATH 201 or equivalent.

EECS 417. System Identification and Adaptive Control. 3 Units.

EECS 419. Computer System Architecture. 3 Units.
Interaction between computer systems hardware and software. Pipeline techniques - instruction pipelines - arithmetic pipelines. Instruction level parallelism. Cache mechanism. I/O structures. Examples taken from existing computer systems.

EECS 421. Optimization of Dynamic Systems. 3 Units.

EECS 422. Solid State Electronics II. 3 Units.

EECS 424. Introduction to Nanotechnology. 3 Units.
An exploration of emerging nanotechnology research. Lectures and class discussion on 1) nanostructures: superlattices, nanowires, nanotubes, quantum dots, nanoparticles, nanocomposites, proteins, bacteria, DNA; 2) nanoscale physical phenomena: mechanical, electrical, chemical, thermal, biological, optical, magnetic; 3) nanofabrication: bottom up and top-down methods; 4) characterization: microscopy, property measurement techniques; 5) devices/applications: electronics, sensors, actuators, biomedical, energy conversion. Topics will cover interdisciplinary aspects of the field. Offered as EECS 424 and EMAE 424.

EECS 425. Computer Networks I. 3 Units.

EECS 426. MOS Integrated Circuit Design. 3 Units.

EECS 427. Optoelectronic and Photonic Devices. 3 Units.
In this course, we will study the optical transitions, absorptions, and gains in semiconductors. We will discuss the optical processes in semiconductor bulk as well as low dimensional structures such as quantum well and quantum dot. The fundamentals, technologies and applications of important optoelectronic devices (e.g., light-emitting diodes, semiconductor lasers, solar cells and photo-detectors) will be introduced. We will learn the current state-of-the-art of these devices. Recommended Preparation: EECS 321.

EECS 428. Computer Communications Networks II. 3 Units.
Introduction to topics and methodology in computer networks and middleware research. Traffic characterization, stochastic models, and self-similarity. Congestion control (Tahoe, Reno, Sack). Active Queue Management (RED, FQ) and explicit QoS. The Web: overview and components, HTTP, its interaction with TCP, caching. Overlay networks and CDN. Expected work includes a course-long project on network simulation, a final project, a paper presentation, midterm, and final test. Recommended preparation: EECS 425 or permission of instructor.
EECS 429. Introduction to Nanomaterials: Material Synthesis, Properties and Device Applications. 3 Units.
The behavior of nanoscale materials is close, to atomic behavior rather than that of bulk materials. The growth of nanomaterials, such as quantum dots, has the tendency to be viewed as an art rather than science. These nanostructures have changed our view of Nature. This course is designed to provide an introduction to nanomaterials and devices to both senior undergraduate and graduate students in engineering. Topics covered include an introduction to growth issues, quantum mechanics, quantization of electronic energy levels in periodic potentials, tunneling, distribution functions and density of states, optical and electronic properties, and devices. Offered as EECS 329 and EECS 429.

EECS 433. Database Systems. 3 Units.

EECS 434. Microsystems Technology. 3 Units.
This course provides an overarching coverage of microsystems technology, which is rooted in micro-electromechanical systems (MEMS). It covers the convergence of sensors and actuators, with wireless communications, computing and (social) networks. Microsystems incorporate sensors and actuators to interface computing with its physical environment-enabling perception and control. Microsystems are key enablers of smartphones, wearables, drones, robots, cars, aircrafts, weapons, etc. Recommended preparation: EECS 322.

EECS 435. Data Mining. 3 Units.
Data Mining is the process of discovering interesting knowledge from large amounts of data stored either in databases, data warehouses, or other information repositories. Topics to be covered includes: Data Warehouse and OLAP technology for data mining, Data Preprocessing, Data Mining Primitives, Languages, and System Architectures, Mining Association Rules from Large Databases, Classification and Prediction, Cluster Analysis, Mining Complex Types of Data, and Applications and Trends in Data Mining. Recommended preparation: EECS 341 or equivalent.

EECS 438. High Performance Computing. 3 Units.
High performance computing (HPC) leverages parallel processing in order to maximize speed and throughput. This hands-on course will cover theoretical and practical aspects of HPC. Theoretical concepts covered include computer architecture, parallel programming, and performance optimization. Practical applications will be discussed from various information and scientific fields. Practical considerations will include HPC job management and Unix scripting. Weekly assessments and a course project will be required. Prereq: EECS 233 or graduate standing.

EECS 439. Web Data Mining. 3 Units.
Web crawling technology, web search and information extraction, unsupervised and semi-supervised learning techniques and their application to web data extraction, social network analysis, various pagerank algorithms, link analysis, web resource discovery, web resource description framework (RDF), XML, Web Ontology Language (OWL). Recommended preparation: EECS 338, EECS 341.

EECS 440. Machine Learning. 3 Units.
Machine learning is a subfield of Artificial Intelligence that is concerned with the design and analysis of algorithms that "learn" and improve with experience. While the broad aim behind research in this area is to build systems that can simulate or even improve on certain aspects of human intelligence, algorithms developed in this area have become very useful in analyzing and predicting the behavior of complex systems. Machine learning algorithms have been used to guide diagnostic systems in medicine, recommend interesting products to customers in e-commerce, play games at human championship levels, and solve many other very complex problems. This course is focused on algorithms for machine learning: their design, analysis and implementation. We will study different learning settings, including supervised, semi-supervised and unsupervised learning. We will study different ways of representing the learning problem, using propositional, multiple-instance and relational representations. We will study the different algorithms that have been developed for these settings, such as decision trees, neural networks, support vector machines, k-means, harmonic functions and Bayesian methods. We will learn about the theoretical tradeoffs in the design of these algorithms, and how to evaluate their behavior in practice. At the end of the course, you should be able to: --Recognize situations where machine learning algorithms are applicable; --Understand, represent and formulate the learning problem; --Apply the appropriate algorithm(s), or if necessary, design your own, with an understanding of the tradeoffs involved; --Correctly evaluate the behavior of the algorithm when solving the problem. Prereq: EECS 391 or EECS 491 or consent of instructor.

EECS 441. Internet Applications. 3 Units.
This course exposes students to research in building and scaling internet applications. Covered topics include Web services, scalable content delivery, applications of peer-to-peer networks, and performance analysis and measurements of internet application platforms. The course is based on a collection of research papers and protocol specifications. Students are required to read the materials, present a paper in class, prepare short summaries of discussed papers, and do a course project (team projects are encouraged). Prereq: EECS 325 or EECS 425.
EECS 442. Causal Learning from Data. 3 Units.
This course introduces key concepts and techniques for characterizing, from observational or experimental study data and from background information, the causal effect of a specific treatment, exposure, or intervention (e.g., a medical treatment) upon an outcome of interest (e.g., disease status). The fundamental problem of causal inference is the impossibility of observing the effects of different and incompatible treatments on the same individual or unit. This problem is overcome by estimating an average causal effect over a study population. Making valid causal inferences with observational data is especially challenging, because of the greater potential for biases (confounding bias, selection bias, and measurement bias) that can badly distort causal effect estimates. Consequently, this topic has been the focus of intense cross-disciplinary research in recent years. Causal inference techniques will be illustrated by applications in several fields such as computer science, engineering, medicine, public health, biology, genomics, neuroscience, economics, and social science. Course grading will be based on quizzes, homeworks, a class presentation, and a causal data analysis project. Specific topics: treatments, exposures, and interventions; causal effects and causal effect measures; confounding bias; potential outcomes and counterfactuals; randomized experiments; observational studies; causal directed acyclic graphs (DAGs); exchangeability and conditional exchangeability; effect modification; causal interactions; nonparametric structural equations; Pearl’s Back-Door Criterion, Front-Door Criterion, and related results; covariate adjustment; matching on covariates; selection bias; measurement bias; instrumental variables; causal modeling; inverse probability weighting; marginal structural models; standardization; structural nested models; outcome regression; propensity scores; sensitivity analysis. Prereq: EECS 440 or MATH 380 or STAT 312 or STAT 313 or STAT 332 or STAT 333 or Requisites Not Met permission.

EECS 443. Flexible Electronics. 3 Units.
Learning about flexible and stretchable electronics from materials to applications. Covering organic and inorganic semiconductors, vacuum and solution-based metal-oxide semiconductors, nanomembranes and nanocrystals, conductors and insulators, flexible and ultra-high-resolution displays, lightemitting transistors, organic and inorganic photovoltaics, large-area imagers and sensors, non-volatile memories and radio-frequency identification tags. Discussing applications of flexible, stretchable and large-area electronics as part of the foregoing topics. Recommended Preparation: EECS 322.

EECS 444. Computer Security. 3 Units.
General types of security attacks; approaches to prevention; secret key and public key cryptography; message authentication and hash functions; digital signatures and authentication protocols; information gathering; password cracking; spoofing; session hijacking; denial of service attacks; buffer overruns; viruses, worms, etc., principles of secure software design, threat modeling; access control; least privilege; storing secrets; socket security; RPC security; security testing; secure software installation; operating system security; database security; web security; email security; firewalls; intrusions. Recommended preparation: EECS 337.

EECS 448. Smartphone Security. 3 Units.
This course is designed to better prepare undergraduate and graduate students for researching and developing in the neighborhood of mobile and software security. Lectures, paper readings and presentations, in-class discussions, and projects are the main components. The course covers the basics of Android programming and a wide range of security issues and solutions concerning mobile platforms, including permission analysis, textual artifacts analysis, malware analysis, program analysis, and UI analysis. Students should expect one literature survey paper and one system-building or empirical study project on one selected security solution in mobile app security. Prereq: EECS 132 and a Graduate or Undergraduate Computer Science major.

EECS 450. Operations and Systems Design. 3 Units.
Introduction to design, modeling, and optimization of operations and scheduling systems with applications to computer science and engineering problems. Topics include, forecasting and times series, strategic, tactical, and operational planning, life cycle analysis, learning curves, resources allocation, materials requirement and capacity planning, sequencing, scheduling, inventory control, project management and planning. Tools for analysis include: multi-objective optimization, queuing models, simulation, and artificial intelligence.

EECS 452. Random Signals. 3 Units.

EECS 454. Analysis of Algorithms. 3 Units.
This course covers fundamental topics in algorithm design and analysis in depth. Amortized analysis, NP-completeness and reductions, dynamic programming, advanced graph algorithms, string algorithms, geometric algorithms, local search heuristics. Offered as EECS 454 and OPRE 454. Prereq: EECS 340.

EECS 455. Applied Graph Theory. 3 Units.
This course serves as an introduction to many of the important aspects of graph theory. Topics include connectivity, flows, matchings, planar graphs, and graph coloring with additional topics selected from extremal graphs, random graphs, bounded treewidth graphs, social networks and small world graphs. The class will explore the underlying mathematical theory with a specific focus on the development and analysis of graph algorithms. Prereq: Graduate Student or (EECS 302 or MATH 304 or MATH 305 or MATH 307).

EECS 458. Introduction to Bioinformatics. 3 Units.
EECS 459. Bioinformatics for Systems Biology. 3 Units.

EECS 460. Manufacturing and Automated Systems. 3 Units.
Formulation, modeling, planning, and control of manufacturing and automated systems with applications to computer science and engineering problems. Topics include, design of products and processes, location/spatial problems, transportation and assignment, product and process layout, group technology and clustering, cellular and network flow layouts, computer control systems, reliability and maintenance, and statistical quality control. Tools and analysis include: multi-objective optimization, artificial intelligence, and heuristics for combinatorial problems. Offered as EECS 360 and EECS 460.

EECS 466. Computer Graphics. 3 Units.
Theory and practice of computer graphics: object and environment representation including coordinate transformations image extraction including perspective, hidden surface, and shading algorithms; and interaction. Covers a wide range of graphic display devices and systems with emphasis in interactive shaded graphics. Laboratory. Recommended preparation: EECS 233.

EECS 467. Commercialization and Intellectual Property Management. 3 Units.
This interdisciplinary course covers a variety of topics, including principles of intellectual property and intellectual property management, business strategies and modeling relevant to the creation of start-up companies and exploitation of IP rights as they relate to biomedical-related inventions. The goal of this course is to address issues relating to the commercialization of biomedical-related inventions by exposing law students, MBA students, and Ph.D. candidates (in genetics and proteomics) to the challenges and opportunities encountered when attempting to develop biomedical intellectual property from the point of early discovery to the clinic and market. Specifically, this course seeks to provide students with the ability to value a given technological advance or invention holistically, focusing on issues that extend beyond scientific efficacy and include patient and practitioner value propositions, legal and intellectual property protection, business modeling, potential market impacts, market competition, and ethical, social, and healthcare practitioner acceptance. During this course, law students, MBA students, and Ph.D. candidates in genomics and proteomics will work in teams of five (two laws students, two MBA students and one Ph.D. candidate), focusing on issues of commercialization and IP management of biomedical-related inventions. The instructors will be drawn from the law school, business school, and technology-transfer office. Please visit the following website for more information: fusioninnovate.com. Offered as LAWS 5341, MGMT 467, GENE 367, GENE 467, EBME 467 and EECS 467.

EECS 468. Power System Analysis I. 3 Units.
This course introduces the steady-state modeling and analysis of electric power systems. The course discusses the modeling of essential power system network components such as transformers and transmission lines. The course also discusses important steady-state analysis of three-phase power system network, such as the power flow and economic operation studies. Through the use of PowerWorld Simulator education software, further understanding and knowledge can be gained on the operational characteristics of AC power systems. Special topics concerning new grid technologies will be discussed towards the semester end. The prerequisite requirements of the course include the concepts and computational techniques of Alternative Current (AC) circuit and electromagnetic field. Offered as EECS 368 and EECS 468. Prereq: EECS 245.

EECS 469. Power System Analysis II. 3 Units.
This course extends upon the steady state analysis of power systems to cover study topics that are essential for power system planning and operation. Special system operating conditions are considered, such as unbalanced network operation and component faults. Among the most important analytical methods developed, are symmetrical components and sequence networks. Other study topics discussed include the electric machine modeling and power system transient stability. The latter half of the course presents computational methods and control algorithms that are essential for power system operation, such as generation control and state estimation. Offered as EECS 369 and EECS 469. Prereq: EECS 368.

EECS 470. Smart Grid. 3 Units.
This course starts with an introduction to the US electric power system infrastructure and national electricity policy. Then power system operations and reliability practices are described. In the context of currently existing infrastructure and operation strategies, the course discusses the new Smart Grid technologies such as renewable resources, distributed generation, demand response, energy storage and electric vehicles. Additional important topics of discussion include Advanced Meter Infrastructure, microgrids, the IEEE 1547 Interconnection Standard, and other interoperability standards. The course captures the evolving progress made in Smart Grid technologies and the impacts on power system economics and reliability. Offered as EECS 370 and EECS 470. Prereq: EECS 368.

EECS 473. Modern Robot Programming. 3 Units.
The goal of this course is to learn modern methods for building up robot capabilities using the Robot Operating System (ROS). Through a sequence of assignments, students learn how to write software to control both simulated and physical robots. Material includes: interfacing software to robot I/O; path and trajectory planning for robot arms; object identification and localization from 3-D sensing, manipulation planning, and development of graphical interfaces for supervisory robot control. Laboratory assignments are scheduled in small groups to explore implementations on specific robots. Graduate students will also perform an independent project. Offered as EECS 373 and EECS 473. Prereq: ENGR 131 or EECS 132.
EECS 474. Advanced Control and Energy Systems. 3 Units.
This course introduces applied quantitative robust and nonlinear control engineering techniques to regulate automatically renewable energy systems in general and wind turbines in particular. The course also studies the fundamentals for dynamic multidisciplinary modeling and analysis of large multi-megawatt wind turbines (mechanics, aerodynamics, electrical systems, control concepts, etc.). The course combines lecture sessions and lab hours. The 400-level includes an experimental lab competition, where the object is to design, implement, and experimentally validate a control strategy to regulate a real system in the laboratory (helicopter control competition or similar); it will also include additional project design reports. Offered as EECS 374 and EECS 474. Prereq: EECS 304.

EECS 475. Applied Control. 3 Units.
This course provides a practical treatment of the study of control engineering systems. It emphasizes best practices in industry so that students learn what aspects of plant and control system design are critical. The course develops theory and practice for digital computer control systems; PID controller design (modes, forms and tuning methods); Control structure design (feed-forward, cascade control, predictive control, disturbance observers, multi-loop configurations, multivariable control); Actuators, sensors and common loops; Dynamic performance evaluation; and some advanced control techniques (quantitative robust control, gain-scheduling and adaptive control) to achieve a good performance over a range of operating conditions. Recommended preparation: EECS 374 or EECS 474. Offered as EECS 375 and EECS 475. Prereq: EECS 304 or Requisites Not Met permission.

EECS 476. Mobile Robotics. 3 Units.
Design of software systems for mobile robot control, including: motion control; sensory processing; localization and mapping; mobile-robot planning and navigation; and implementation of goal-directed behaviors. The course has a heavy lab component involving a sequence of design challenges and competitions performed in teams. Prereq: EECS 373 or EECS 473.

EECS 477. Advanced Algorithms. 3 Units.

EECS 478. Computational Neuroscience. 3 Units.
Computer simulations and mathematical analysis of neurons and neural circuits, and the computational properties of nervous systems. Students are taught a range of models for neurons and neural circuits, and are asked to implement and explore the computational and dynamic properties of these models. The course introduces students to dynamical systems theory for the analysis of neurons and neural learning, models of brain systems, and their relationship to artificial and neural networks. Term project required. Students enrolled in MATH 478 will make arrangements with the instructor to attend additional lectures and complete additional assignments addressing mathematical topics related to the course. Recommended preparation: MATH 223 and MATH 224 or BIOL 300 and BIOL 306. Offered as BIOL 378, COGS 378, MATH 378, BIOL 478, EBME 478, EECS 478, MATH 478 and NEUR 478.

EECS 480A. Introduction to Wireless Health. 3 Units.
Study of convergence of wireless communications, microsystems, information technology, persuasive psychology, and health care. Discussion of health care delivery system, medical decision-making, persuasive psychology, and wireless health value chain and business models. Understanding of health information technology, processing of monitoring data, wireless communication, biomedical sensing techniques, and health monitoring technical approaches and solutions. Offered as EECS 480A and EBME 480A.

EECS 480B. The Human Body. 3 Units.
Study of structural organization of the body. Introduction to anatomy, physiology, and pathology, covering the various systems of the body. Comparison of elegant and efficient operation of the body and the related consequences of when things go wrong, presented in the context of each system of the body. Introduction to medical diagnosis and terminology in the course of covering the foregoing. Offered as EECS 480B and EBME 480B.

EECS 480C. Biomedical Sensing Instrumentation. 3 Units.
Study of principles, applications, and design of biomedical instruments with special emphasis on transducers. Understanding of basic sensors, amplifiers, and signal processing. Discussion of the origin of biopotential, and biopotential electrodes and amplifiers (including biotelemetry). Understanding of chemical sensors and clinical laboratory instrumentation, including microfluidics. Offered as EECS 480C and EBME 480C. Prereq: EECS/EBME 480A, EECS/EBME 480B

EECS 480D. The Health Care Delivery Ecosystem. 3 Units.
Health care delivery across the continuum of care in the United States, including health policy and reform, financing of care, comparative health systems, population health, public health, access to care, care models, cost and value, comparative effectiveness, governance, management, accountability, workforce, and the future. Discussions of opportunities and challenges for wireless health, integrated into the foregoing topics. Perspective on health care delivery in other countries. Offered as EECS 480D and EBME 480D.

EECS 480E. Wireless Communications and Networking. 3 Units.
Essentials of wireless communications and networking, including teletraffic engineering, radio propagation, digital and cellular communications, wireless wide-area network architecture, speech and channel coding, modulation schemes, antennas, security, networking and transport layers, and 4G systems. Hands-on learning of the anatomy of a cell phone, and a paired wireless health device and its gateway. Offered as EECS 480E and EBME 480E.

EECS 480F. Physicians, Hospitals and Clinics. 3 Units.
Rotation through one or more health care provider facilities for a first-hand understanding of care delivery practice, coordination, and management issues. First-hand exposure to clinical personnel, patients, medical devices and instruments, and organizational workflow. Familiarity with provider protocols, physician referral practices, electronic records, clinical decision support systems, acute and chronic care, and inpatient and ambulatory care. Offered as EECS 480F and EBME 480F.
EECS 480G. Applied Cryptography. 3 Units.
This course begins with a discussion of how mobility-driven computing and communication systems use cryptography to protect data and protocols. The foundation for critical cryptographic concepts, techniques, and algorithms are covered. The fundamental cryptographic concepts are studied, including: symmetric encryption, public key encryption, digital signatures, cryptographic hash function, and message authentication codes; cryptographic protocols, such as key exchange, remote user authentication, and interactive proofs; cryptanalysis of cryptographic primitives and protocols, such as by side-channel attacks, differential cryptanalysis, or replay attacks; and cryptanalytic techniques on deployed systems, such as memory remanence, timing attacks, fault attacks, and differential power analysis. Techniques used for code making (cryptographic) and break codes (cryptanalytic) are covered, as well as how these techniques are used within larger security systems.

EECS 480H. Software Security. 3 Units.
This course begins with discussions of good software engineering practices to ensure security in modern software systems and additional challenges to security due to code mobility in software for mobility-driven computing. The basics of software security and threat models, methods to protect software (operating systems, databases, distributed software) - including risk analysis, authentication and authorization, access control, and software architecture for security - are studied. Principles of secure coding, validation and verification of secure software, software and data watermarking, code obfuscation, tamper resistant software are studied, as well as the benefits of open source and closed source software. Use of software as an attack mechanism and emerging attack models (including joint hardware-software attacks) are studied.

EECS 480K. Hardware Security. 3 Units.
This course begins with the keys to enabling secure, trustworthy operation of computer hardware - understanding security issues and how appropriate security measures are included during design, verification, test, and deployment. Increasingly the security primitives such as the Trusted Computing Module are being introduced at the hardware level to prevent the compromise of security in systems being deployed today. A comprehensive coverage of security issues in computer hardware is provided. Topics of embedded systems security, hardware Trojans, security in implantable medical devices, security in RFID/NFC, protection from side channel attacks, tamper resisterance and crypto processor design, trusted FPGA design/JTAG, hardware-based cryptanalysis, and hardware IP protection against piracy and reverse-engineering are covered. A course project (Can you Hack It?) that challenges students to hack a hardware is included.

EECS 480M. Introduction to Medical Informatics. 3 Units.
Current state and emerging trends in Medical Informatics (MI) and associated health information systems. Principles, data, data management, system interoperability, patient privacy, information security, electronic records, telehealth, regulatory issues, clinical decision support, mobile documentation, devices and wireless communications in healthcare. Impact of wireless technology on emerging health information systems and processes. Offered as EECS 480M and EBME 480M.

EECS 480O. Introduction to Health Information Technology Implementation. 3 Units.
Current state and emerging trends in the implementation and adoption of health information technology (HIT). Macroergonomics; Technology transfer and adoption; Systems adoption life cycle; Impact of regulation; Decision and work transformation; HIT specification and acquisition; Contracting issues; Implementation, use, and evaluation; Impact of wireless technology on emerging processes. Offered as EECS 480O and EBME 480O. Prereq: EECS 480M.

EECS 480P. Advanced Biomedical Instrumentation. 3 Units.
Analysis and design of biosensors in the context of biomedical measurements. Base sensors using electrochemical, optical, piezoelectric, and other principles. Binding equilibria, enzyme kinetics, and mass transport modalities. Adding the "bio" element to base sensors and mathematical aspects of data evaluation. Applications to clinical problems and biomedical research. Offered as EECS 480P and EBME 480P.

EECS 480Q. Regulatory Policy and Regulations. 3 Units.
Introduction of wireless health technologies: spectrum, licensed versus unlicensed; personal area networks; body area networks; ultra-wideband low energy level short-range radios; wireless local area networks; wide area networks. The Federal system: separation of powers; the executive branch and its departments; the House of Representatives and its committees; the Senate and its committees; the FCC; policy versus regulatory versus legislative. What is a medical device: FDA; classification system; radiation-emitting products; software; RF in medical devices; converged medical devices; international aspects. Regulation of health information technology and wireless health: American Recovery and Reinvestment Act; Patient Protection and Affordable Care Act; FCC/ FDA MoU; CMS and Reimbursement; privacy and security. Offered as EECS 480Q and EBME 480Q.

EECS 480R. User Experience Engineering. 3 Units.
Social, cognitive, behavioral, and contextual elements in the design of healthcare technology and systems. User-centered design paradigm from a broad perspective, exploring dimensions of product user experience and learning to assess and modify the design of healthcare technology. Practical utilization of user centered design method and assessment techniques for approaching a design problem. Offered as EECS 480R and EBME 480R.

EECS 480S. Wireless Health Product Development. 3 Units.
Integrating application requirements, market data, concept formulation, design innovation, and manufacturing resources for creating differentiated wireless health products that delight the user. Learning user-centric product development best practices, safety, security and privacy considerations, and risk management planning. Understanding the regulatory process. Identifying and managing product development tradeoffs. Offered as EECS 480S and EBME 480S. Prereq: EECS 480R.
EECS 480T. Wearable Computing Design. 3 Units.
Learning about wearable devices using flexible/conformal electronics designed for convenience and uninterrupted wear-ability. Examining related design challenges from the technology, human and business points of view. Understanding wearable product design for general and special-purpose tasks in information processing, media operations, and information extraction from sensed data. Learning about the technological challenges for design, including miniaturization, power delivery and management, data storage, and wireless networking.
Learning about hardware choices (processor, field programmable gate array or custom ASIC based design) for wearable computers and software architectures for smart data processing. Learning about wearable designs centered on the human experience, including sensing and interfacing with the human body, as well as user interaction, convenience, and support for non-intrusive social appearance. Case studies tying the business requirements with the technology and design issues.

EECS 480U. Wearable Computing Technology. 3 Units.
Learning about a broad range of cutting-edge technologies suitable for wearable computing. Understanding printed and flexible electronics technologies required for creating wearable computing, in particular organics for active components due to their flexibility or conformity. Examine the tradeoffs between flexible/conformal versus rigid electronics in the context of wearable computing. Reviewing the history of printed electronics used as conductors for membrane keypads, car windscreens, and RFID tag antennas-to name a few application examples. Reviewing the latest technology advances in functional components such as displays, lighting, transistors (p-type & n-type), memory, batteries, photovoltaics (PV), sensors, and conductors as well as integration/packaging steps. Understanding the market potential of these technologies by reviewing emerging products.

EECS 480W. Wearable Computing Manufacturing. 3 Units.
Learning about the supply chain and manufacturing processes for flexible electronics, sensors, and other technologies contributing to the development of wearable products. Understanding supply chain issues in low mobility materials, multilevel substrates, nanocomposites, materials for low power sensors, and inks suitable for direct printing. Identifying the tradeoffs involved in various manufacturing methods such as roll-to-roll manufacturing a mature coating technology yet to be proven for full device integration. Studying other manufacturing techniques such as plate-to-plate, direct printing, 3D printing, and screening techniques for their applicability to the manufacturing and integration of flexible electronics. Understanding the use of lithography and vapor deposition techniques in the context of flexible electronics. Examining the issues of systems integration and packaging of the manufactured products.

EECS 480X. Mobility-Driven Computing. 3 Units.
Fundamental concepts in computing and architecture for mobile devices, mobile operating systems, mobility and mobile data management. Application of technologies for location awareness, context awareness, integrated sensors, mobile Internet, displays, pattern recognition and natural language processing, and touch/gesture based user interaction. Understanding the tradeoffs in design (smartphones, tablets) due to resource constraints such as wireless connectivity, application processing, power management, and graphics. Integration of near- and wide-area wireless communication technologies (Bluetooth, Wireless WAN). Exploration of emerging technologies and services for the mobile platform. Integration of the foregoing concepts in a specific mobile context application (home/office, pedestrian, vehicular).

EECS 480Y. Mobility-Driven Embedded Systems. 3 Units.
Foundations of reliable, energy-efficient and secure design of embedded systems. Fundamentals of mobility in embedded systems including wireless technology, location awareness, sensors, and actuators. Design consideration for processors, DSP, memory, and interfaces under mobility constraints (connectivity, power, and data management). Systems software for embedded computing, device management, and real-time I/O. Software design under constraints of size, performance, availability, and reliability. Software development techniques and practices (compilers, OS, and runtime systems). Case studies of mobility driven real-time embedded systems and software. Applications of mobility driven embedded systems, for example in in biomedical implant systems.

EECS 480Z. Mobile Applications Development. 3 Units.
Understanding of the mobile application architecture, operating systems, and platforms. Challenges and opportunities in mobile application development. Evaluation of the leading mobile platform frameworks with respect to their features, functions, libraries, support, and ease of development. Software design for mobile applications in gaming, multimedia, entertainment, and enterprise applications. Development of enhanced user experience in a multi-touch, multi-sensor (accelerometer, gyroscopes, camera, geo-location) environment. Understanding of software development environments and testing tools, and use of wireless connectivity and data in mobile applications. Development of or extension of a modest application based on a major mobile platforms (iOS, Windows Phone 7, or Android).

EECS 484. Computational Intelligence I: Basic Principles. 3 Units.
This course is concerned with learning the fundamentals of a number of computational methodologies which are used in adaptive parallel distributed information processing. Such methodologies include neural net computing, evolutionary programming, genetic algorithms, fuzzy set theory, and "artificial life." These computational paradigms complement and supplement the traditional practices of pattern recognition and artificial intelligence. Functionalities covered include self-organization, learning a model or supervised learning, optimization, and memorization.

EECS 485. VLSI Systems. 3 Units.
Basic MOSFET models, inverters, steering logic, the silicon gate, nMOS process, design rules, basic design structures (e.g., NAND and NOR gates, PLA, ROM, RAM), design methodology and tools (spice, N.mpc, Caesar, mkpla), VLSI technology and system architecture. Requires project and student presentation, laboratory.

EECS 488. Embedded Systems Design. 3 Units.
Objective: to introduce and expose the student to methodologies for systematic design of embedded system. The topics include, but are not limited to, system specification, architecture modeling, component partitioning, estimation metrics, hardware software codesign, diagnostics.

EECS 489. Robotics I. 3 Units.
EECS 490. Digital Image Processing. 3 Units.
Digital images are introduced as two-dimensional sampled arrays of data. The course begins with one-to-one operations such as image addition and subtraction and image descriptors such as the histogram. Basic filters such as the gradient and Laplacian in the spatial domain are used to enhance images. The 2-D Fourier transform is introduced and frequency domain operations such as high and low-pass filtering are developed. It is shown how filtering techniques can be used to remove noise and other image degradation. The different methods of representing color images are described and fundamental concepts of color image transformations and color image processing are developed. One or more advanced topics such as wavelets, image compression, and pattern recognition will be covered as time permits. Programming assignments using software such as MATLAB will illustrate the application and implementation of digital image processing.

EECS 491. Artificial Intelligence: Probabilistic Graphical Models. 3 Units.
This course is a graduate-level introduction to Artificial Intelligence (AI), the discipline of designing intelligent systems, and focuses on probabilistic graphical models. These models can be applied to a wide variety of settings from data analysis to machine learning to robotics. The models allow intelligent systems to represent uncertainties in an environment or problem space in a compact way and reason intelligently in a way that makes optimal use of available information and time. The course covers directed and undirected probabilistic graphical models, latent variable models, associated exact and approximate inference algorithms, and learning in both discrete and continuous problem spaces. Practical applications are covered throughout the course. Prereq: EECS 391 or requisites not met permission.

EECS 493. Software Engineering. 3 Units.
Topics: Introduction to software engineering; software lifecycle models; development team organization and project management; requirements analysis and specification techniques; software design techniques; programming practices; software validation techniques; software maintenance practices; software engineering ethics. Undergraduates work in teams to complete a significant software development project. Graduate students are required to complete a research project. Offered as EECS 393, EECS 393N, and EECS 493. Counts as SAGES Senior Capstone.

EECS 494. Introduction to Information Theory. 3 Units.
This course is intended as an introduction to information and coding theory with emphasis on the mathematical aspects. It is suitable for advanced undergraduate and graduate students in mathematics, applied mathematics, statistics, physics, computer science and electrical engineering. Course content: Information measures-entropy, relative entropy, mutual information, and their properties. Typical sets and sequences, asymptotic equipartition property, data compression. Channel coding and capacity, channel coding theorem. Differential entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory inequalities (400 level). Additional topics, which may include compressed sensing and elements of quantum information theory. Recommended preparation: MATH 201 or MATH 307. Offered as MATH 394, EECS 394, MATH 494 and EECS 494.

EECS 495. Nanometer VLSI Design. 3 Units.
Semiconductor industry has evolved rapidly over the past four decades to meet the increasing demand on computing power by continuous miniaturization of devices. Now we are in the nanometer technology regime with the device dimensions scaled below 100nm. VLSI design using nanometer technologies involves some major challenges. This course will explain all the major challenges associated with nanoscale VLSI design such as dynamic and leakage power, parameter variations, reliability and robustness. The course will present modeling and analysis techniques for timing, power and noise in nanometer era. Finally, the course will cover the circuit/architecture level design solutions for low power, high-performance, testable and robust VLSI system. The techniques will be applicable to design of microprocessor, digital signal processor (DSP) as well as application specific integrated circuits (ASIC). The course includes a project which requires the student to work on a nanometer design issue. Recommended preparation: EECS 426 or EECS 485.

EECS 496. Artificial Intelligence: Sequential Decision Making. 3 Units.
This course will study the formulation and solution of decision making problems by automated agents. Topics covered include one-shot decision making (decision trees and influence diagrams), Markov decision processes (MDPs), automated classical and probabilistic planning, reinforcement learning (RL), hierarchical planning and RL, partially observable MDPs, Bayesian RL, collaborative multi-agent systems. Recommended preparation: EECS 491 (Probabilistic Graphical Models). Prereq: EECS 391.

EECS 497. Artificial Intelligence: Statistical Natural Language Processing. 3 Units.
This course gives students an overview of the state of the art in natural language processing. We will discuss computational aspects of language modeling through probabilistic models, computational approaches to syntax (parsing) and semantic representations, discourse and dialog. We will study the applications of these techniques to a variety of problems including information extraction, translation and summarization. At the end of the course a student should be able to (i) understand the various statistical models and algorithms for NLP (ii) modify them as needed or design novel approaches for specific NLP tasks and (iii) understand how to evaluate the performance of these models and compare them to alternatives. Prereq: EECS 440.

EECS 499. Algorithmic Robotics. 3 Units.
This course introduces basic algorithmic techniques in robotic perception and planning. Course is divided into two parts. The first part introduces probabilistic modeling of robotic motion and sensing, Gaussian and nonparametric filters, and algorithms for mobile robot localization. The second part introduces fundamental deterministic and randomized algorithms for motion planning. Prereq: Graduate Standing or Requisites Not Met permission.

EECS 500. EECS Colloquium. 0 Unit.
Seminars on current topics in Electrical Engineering and Computer Science.
EECS 500T. Graduate Teaching II. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities: grading homeworks, quizzes, and exams, having office hours for students, running recitation sessions, providing laboratory assistance. Recommended preparation: Ph.D. student in EECS department.

EECS 516. Large Scale Optimization. 3 Units.
Concepts and techniques for dealing with large optimization problems encountered in designing large engineering structure, control of interconnected systems, pattern recognition, and planning and operations of complex systems; partitioning, relaxation, restriction, decomposition, approximation, and other problem simplification devices; specific algorithms; potential use of parallel and symbolic computation; student seminars and projects. Recommended preparation: EECS 416.

EECS 526. Integrated Mixed-Signal Systems. 3 Units.
Mixed-signal (analog/digital) integrated circuit design. D-to-A and A-to-D conversion, applications in mixed-signal VLSI, low-noise and low-power techniques, and communication sub-circuits. System simulation at the transistor and behavioral levels using SPICE. Class will design a mixed-signal CMOS IC for fabrication by MOSIS. Recommended preparation: EECS 426.

EECS 527. Advanced Sensors: Theory and Techniques. 3 Units.
Sensor technology with a primary focus on semiconductor-based devices. Physical principles of energy conversion devices (sensors) with a review of relevant fundamentals: elasticity theory, fluid mechanics, silicon fabrication and micromachining technology, semiconductor device physics. Classification and terminology of sensors, defining and measuring sensor characteristics and performance, effect of the environment on sensors, predicting and controlling sensor error. Mechanical, acoustic, magnetic, thermal, radiation, chemical and biological sensors will be examined. Sensor packaging and sensor interface circuitry.

EECS 531. Computer Vision. 3 Units.
The goal of computer vision is to create visual systems that recognize objects and recover structures in complex 3D scenes. This course emphasizes both the science behind our understanding of the fundamental problems in vision and the engineering that develops mathematical models and inference algorithms to solve these problems. Specific topics include feature detection, matching, and classification; visual representations and dimensionality reduction; motion detection and optical flow; image segmentation; depth perception, multi-view geometry, and 3D reconstruction; shape and surface perception; visual scene analysis and object recognition.

EECS 589. Robotics II. 3 Units.
Survey of research issues in robotics. Force control, visual servoing, robot autonomy, on-line planning, high-speed control, man/machine interfaces, robot learning, sensory processing for real-time control. Primarily a project-based lab course in which students design real-time software executing on multi-processors to control an industrial robot. Recommended preparation: EECS 489.

EECS 600. Special Topics. 1 - 18 Units.
Offered as EECS 600 and SYBB 600.

EECS 600T. Graduate Teaching III. 0 Unit.
This course will provide Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities running recitation sessions, providing laboratory assistance, developing teaching or lecture materials presenting lectures. Recommended preparation: Ph.D. student in EECS department.

EECS 601. Independent Study. 1 - 18 Units.

EECS 620. Special Topics. 1 - 18 Units.

EECS 621. Special Projects. 1 - 18 Units.

EECS 649. Project M.S.. 1 - 9 Units.

EECS 651. Thesis M.S.. 1 - 18 Units.

EECS 695. Project M.S.. 1 - 99 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in the EECS Plan B MS Program.

EECS 701. Dissertation Ph.D.. 1 - 9 Units.
Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Engineering Physics

Rockefeller Building (7079)
http://physics.case.edu/undergraduate-programs/undergrad-degree-programs/bsdegree-engrphys/
Phone: 216.368.4017; Fax: 216.368.4671
Michael Martens, Professor of Physics and Program Director
michael.martens@case.edu

The Engineering Physics major allows students with strong interests in both physics and engineering to concentrate their studies in the common areas of these disciplines. The Engineering Physics major prepares students to pursue careers in industry, either directly after undergraduate studies, or following graduate study in engineering or physics. Many employers value the unique problem-solving approach of physics, especially in industrial research and development. Its engineering science and design components prepare students to work as professional engineers.

Students majoring in engineering physics complete the Engineering Core as well as a rigorous course of study in physics. Students select a concentration area from an engineering discipline and must complete a sequence of at least four courses in this discipline. In addition, a senior research project under the guidance of a faculty member is required. The project includes a written report and participation in the senior seminar and symposium.

The Bachelor of Science in Engineering degree program with a major in Engineering Physics is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Mission

The mission of the Engineering Physics program is to prepare students for careers in engineering where physics principles can be applied to the advancement of technology. This education at the intersection
of engineering and physics will enable students to seek employment in engineering upon graduation while providing a firm foundation for the pursuit of graduate studies in either engineering or physics. The Engineering Physics program will develop sufficient depth in both engineering and physics skills to produce engineers who can relate fundamental physics to practical engineering problems and will possess the versatility to address new problems in our rapidly changing technological base. The program will provide a curriculum and environment to develop interdisciplinary collaboration, ethical and professional outlooks, communication skills, and the tools and desire for life-long learning.

Program Educational Objectives
1. Graduates of the Engineering Physics program will apply their strong problem-solving skills as physicists along with an understanding of the approach, methods, and requirements of engineering and engineering design for a successful career in advancing technology.
2. Graduates of the Engineering Physics program will use their strong skills in problem-solving, research experience and knowledge in physics and engineering as successful graduate students and researchers in highly ranked graduate programs.

Student Outcomes
As preparation for achieving the above program educational objectives, the Bachelor of Science in Engineering degree program with a major in Engineering Physics is designed so that students attain:

- 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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- 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 engineering solutions in a global, economic, environmental, 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.

Bachelor of Science in Engineering
Required Courses: Major in Engineering Physics
In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

**Major Required Courses**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 208</td>
<td>Instrumentation and Signal Analysis Laboratory</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 221</td>
<td>Introduction to Modern Physics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 250</td>
<td>Computational Methods in Physics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 310</td>
<td>Classical Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 313</td>
<td>Thermodynamics and Statistical Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 317</td>
<td>Engineering Physics Laboratory I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 318</td>
<td>Engineering Physics Laboratory II</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 324</td>
<td>Electricity and Magnetism I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 325</td>
<td>Electricity and Magnetism II</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 331</td>
<td>Introduction to Quantum Mechanics I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 352</td>
<td>Senior Physics Project Seminar a</td>
<td>1</td>
</tr>
<tr>
<td>PHYS 353</td>
<td>Senior Engineering Physics Project a</td>
<td>2</td>
</tr>
</tbody>
</table>

and one of the following courses (Applications of Quantum Mechanics): 3-4

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 321</td>
<td>Semiconductor Electronic Devices</td>
<td></td>
</tr>
<tr>
<td>PHYS 315</td>
<td>Introduction to Solid State Physics</td>
<td></td>
</tr>
<tr>
<td>PHYS 327</td>
<td>Laser Physics</td>
<td></td>
</tr>
<tr>
<td>PHYS 332</td>
<td>Introduction to Quantum Mechanics II</td>
<td></td>
</tr>
</tbody>
</table>

Breadth Elective Sequence 38-39

a  Two semester course.

Engineering Physics Concentration
Engineering Physics majors must complete a sequence of at least four upper-level courses in an engineering concentration. Students should seek advice from those engineering representatives listed below to select the courses consistent with scheduling, student preparation, and student interest. Both the program representative and the student’s adviser must approve the sequence. Following approval, students must submit the paperwork to undergraduate studies to insure credit for the sequence toward graduation.

Biomedical Engineering (Contact: Prof. Dustin Tyler)
Civil Engineering (Contact: Prof. Xiangwu Zeng)
Electrical Engineering and Computer Science (Contact: Prof. Michael Lewicki)
Macromolecular Science and Engineering (Contact: Prof. David Schiraldi)
Mechanical and Aerospace Engineering (Contact: Prof. Paul Barnhart)
Materials Science and Engineering (Contact: Prof. Frank Ernst)

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Bachelor of Science in Engineering
Suggested Program of Study: Major in Engineering Physics
The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://case.edu/sis).

**First Year**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td>4</td>
</tr>
<tr>
<td>Calculus for Science and Engineering I (MATH 121)**a</td>
<td>4</td>
</tr>
</tbody>
</table>
General Physics I - Mechanics (PHYS 121)**b 4
SAGES First Seminar* 4
PHED Physical Education Activities* 4
Calculus for Science and Engineering II (MATH 122)**a 4
General Physics II - Electricity and Magnetism (PHYS 122)**a 4
Elementary Computer Programming (ENGR 131)**c 3
Chemistry of Materials (ENGR 145)** 4
SAGES University Seminar* 3
PHED Physical Education Activities* 3
Year Total: 16 18

Second Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculus for Science and Engineering III (MATH 223)** 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to Modern Physics (PHYS 221) 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statics and Strength of Materials (ENGR 200)** 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210) 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAGES University Seminar* 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elementary Differential Equations (MATH 224)** 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrumentation and Signal Analysis Laboratory (PHYS 208) 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computational Methods in Physics (PHYS 250) 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classical Mechanics (PHYS 310) 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)** 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year Total: 16 17</td>
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<td></td>
</tr>
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</table>

Third Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermodynamics and Statistical Mechanics (PHYS 313) 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Physics Laboratory I (PHYS 317) 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Laboratory Physics Seminar (PHYS 303) 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to Quantum Mechanics I (PHYS 331) 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Concentrationd 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breadth elective ** 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Physics Laboratory II (PHYS 318) 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity and Magnetism I (PHYS 324) 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGL 398) 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&amp; Professional Communication for Engineers (ENGR 398)** 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breadth elective ** 3</td>
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<tr>
<td>Engineering Concentrationd 3</td>
<td></td>
<td></td>
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<tr>
<td>Year Total: 16 16</td>
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</tbody>
</table>

Fourth Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity and Magnetism II (PHYS 325) 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senior Physics Project Seminar (PHYS 352) 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senior Engineering Physics Project (PHYS 353) 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Engineering Concentrationd 3 |  |
| Breadth elective** 3 |  |
| Elective 3 |  |
| Senior Physics Project Seminar (PHYS 352) 1 |  |
| Senior Engineering Physics Project (PHYS 353) 2 |  |
| Applied Quantum Mechanics** 3 |  |
| Engineering Concentrationd 3 |  |
| Breadth elective** 3 |  |
| Elective 3 |  |
| Year Total: 15 15 |  |

Total Units in Sequence: 129

Hours required for graduation: 129

** University general education requirement
**a Engineering general education requirement

a Selected students may be invited to take MATH 124 Calculus II, MATH 227 Calculus III or MATH 228 Differential Equations in place of MATH 121 Calculus for Science and Engineering I, MATH 122 Calculus for Science and Engineering II, MATH 223 Calculus for Science and Engineering III or MATH 224 Calculus for Science and Engineering IV.

b Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics or PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics I - Mechanics or PHYS 122 General Physics II - Electricity and Magnetism.

c Students may also choose to fulfill this requirement with EECS 132 Introduction to Programming in Java.
d Engineering Physics Concentration courses are flexible, but must be in a specific engineering discipline or study area and be approved by an advisor. Possible concentration areas include: Biomedical Engineering (Biomedical Systems and Analysis, Devices and Instrumentation, Biomaterials); Chemical Engineering; Civil Engineering (Solid Mechanics, Structural Engineering, Geotechnical Engineering, Environmental Engineering); Electrical Engineering and Computer Science (Solid State, Computer Science, Computer Engineering-Software, Computer Engineering-Hardware, Systems and Control); Macromolecular Science and Engineering; Materials Science and Engineering; Mechanical and Aerospace Engineering (Aerospace, Mechanics).

e Students may choose to fulfill this requirement in their third year:

- PHYS 315 Introduction to Solid State Physics
- PHYS 332 Introduction to Quantum Mechanics II
- PHYS 327 Laser Physics/PHY 427 Laser Physics
- EECS 321 Semiconductor Electronic Devices

Department of Macromolecular Science and Engineering

314 Kent Smith Building (7202)
http://polymers.case.edu
Phone: 216.368.4172; Fax: 216.368.4202
David Schiraldi, Professor and Chair
david.schiraldi@case.edu
Macromolecular science and engineering is the study of the synthesis, structure, processing, and properties of polymers. These giant molecules are the basis of synthetic materials including plastics, fibers, rubber, films, paints, membranes, and adhesives. Research is constantly expanding these applications through the development of new high performance polymers, e.g. for engineering composites, electronic, optical, and biomedical uses. In addition, most biological systems are composed of macromolecules—proteins (e.g. silk, wool, tendon), carbohydrates (e.g. cellulose) and nucleic acids (RNA and DNA) are polymers and are studied by the same methods that are applied to synthetic polymers.

Production of polymers and their components is central to the chemical industry, and statistics show that over 75 percent of all chemists and chemical engineers in industry are involved with some aspect of polymers. Despite this, formal education in this area is offered by only a few universities in this country, resulting in a continued strong demand for our graduates upon completion of their BS, MS, or PhD degrees.

**Mission**
To educate students who will excel and lead in the development of polymeric materials and the application of structure-property relationships. The department seeks to prepare students for either professional employment or advanced education, primarily in this or related science or engineering disciplines, but also in professional schools of business, law or medicine. Undergraduate students are offered opportunities for significant research experience, capitalizing on the strength of our graduate program.

**Research**
The research activities of the department span the entire scope of macromolecular science and polymer technology.

**Synthesis**
New types of macromolecules are being made in the department’s synthesis laboratories. The emphasis is on creating polymers with novel functional properties such as photoconductivity, selective permeation, and biocompatibility, and in producing new materials which behave like classical polymers without being linked together by covalent bonds.

**Physical Characterization**
This is the broad area of polymer analysis, which seeks to relate the structure of the polymer at the molecular level to the bulk properties that determine its actual or potential applications. This includes characterization of polymers by infrared, Raman, and NMR and mass spectroscopy, thermal and rheological analysis, determination of structure and morphology by x-ray diffraction, electron microscopy, and atomic force microscopy, permeability and free volume, and investigation of molecular weights and conformation by light scattering.

**Mechanical Behavior and Analysis**
PolymERIC materials are known for their unusual mechanical capabilities, usually exploited as components of structural systems. Analysis includes the study of viscoelastic behavior, yielding and fracture phenomena and a variety of novel irreversible deformation processes.

**Processing**
A major concern of industry is the efficient and large scale production of polymer materials for commercial applications. Research in this area is focusing on reactive processing, multi-layer processing and polymer mixing, i.e., compounding and blends. The integration of sensors and processing equipment, and methods for examining changes in structure and composition during processing steps are growing areas of inquiry. Both laboratory and simulation research are brought to bear on these critical issues.

**Materials Development and Design**
Often, newly conceived products require the development of polymeric materials with certain specific properties or design characteristics. Materials can be tailor-made by designing synthesis and processing conditions to yield the best performance under specified conditions. Examples might be the design of photoluminescent and semi-conducting polymers for use in optoelectronic devices, polymers that are stable at high temperatures for fire-retardant construction materials, high temperature polymer electrolytes for use in advanced fuel cells, low density thermal insulating polymer composite materials, advanced polymeric optical devices, and biocompatible polymers for use in prosthetic implants, reconstructive medicine and drug-delivery vehicles.

**Biopolymers**
Living systems are composed primarily of macromolecules, and research is in progress on several projects of medical relevance. The department has a long-standing interest in the hierarchical structure and properties of the components of connective tissues (e.g., skin, cartilage, and bone). The department is also engaged in the development of new biocompatible polymers for applications in human health.

**Faculty**

*David Schiraldi, PhD (University of Oregon)*
*Peter A. Asseff Professor and Chair*
Advanced composites based on aerogels and nanofillers, monomer and polymer synthesis, structure-property relationships, polymer degradation, polymerization catalysis, synthetic fibers, barrier packaging materials.

*Rigoberto C. Advincula, PhD (University of Florida)*
*Professor*
Design and synthesis of nanostructured materials, dendrimers, polymer brushes, thin films, and the use of innovative surface characterization techniques. Applications in electro-optical devices, sensors, biomaterials, and smart coatings.

*Eric Baer, DEng (Johns Hopkins University)*
*Director, Centered for Layered Polymeric Systems (CLiPS) and Herbert Henry Dow Professor of Science and Engineering*
Multilayered and ultrathin polymer films and devices. Irreversible microdeformation mechanisms; pressure effects on morphology and mechanical properties; relationships between hierarchical structure and mechanical function; mechanical properties of soft connective tissue; polymer composites and blends; polymerization and crystallization on crystalline surfaces; viscoelastic properties of polymer melts; damage and fracture analysis of polymers and their composites. Structure-property relationships in biological systems.

*Liming Dai, PhD (Australian National University)*
*Kent Hale Smith Professor*
Multifunctional nanomaterials; optoelectronic macromolecules; and biomaterials and bioinspiration.
Michael Hore, PhD  
(University of Pennsylvania)  
Assistant Professor  
Polymer physics; neutron scattering; polymer nanocomposites; grafted polymers and brushes; theory and modeling; self-consistent field theory; structure-property relationships; reconfigurable materials.

Hatsuo Ishida, PhD  
(Case Western Reserve University)  
Professor  
Processing of polymers and composite materials; structural analysis of surfaces and interfaces; molecular spectroscopy of synthetic polymers

João Maia, PhD  
(University of Wales Aberystwyth, U.K.)  
Associate Professor  
Polymer rheology: extensional rheology and rheometry; micro- and nano-rheology; bio-rheology: food rheology and processing; rheology for macromolecular technology: development and optimization of polymer blends and composites; viscoelasticity of micro- and nano-layered polymer films; on- and in-line monitoring of extrusion-based processes; micro-processing; environmental rheology and processing

Ica Manas-Zloczower, DSc  
(Israel Institute of Technology)  
Professor  
Structure and micromechanics of fine particle clusters; interfacial engineering strategies for advanced materials processing; dispersive mixing mechanisms and modeling; design and mixing optimization studies for polymer processing equipment through flow simulations

Valentin Rodionov, PhD  
(Scripps Res. Institute)  
Assistant Professor  
Organic polymer chemistry; synthesis of novel macromolecular structures and architectures; catalysis

Gary Wnek, PhD  
(University of Massachusetts, Amherst)  
Associate Chair and The Joseph F. Toot, Jr.  
Polymeric biomaterials for drug delivery and regenerative medicine; nano- and micro-fiber fabrication; bio-mimicking approaches for polymer flammability mitigation; polymer packaging systems design; polyelectrolyte gels and elastomers; physiologically-mimicking macromolecular constructs with attention to primitive motile and irritable systems

Lei Zhu, PhD  
(University of Akron)  
Professor  
Nanoscale structure and morphology of crystalline/liquid crystalline polymers and block copolymers; ferroelectric and dielectric polymers for electric energy storage; polymer/inorganic hybrid nanocomposites; biodegradable polymers for diagnostic and drug delivery

James M. Anderson, PhD  
(Oregon State University, M.D.)  
Professor of Macromolecular Science, Pathology, and Biomedical Engineering  
Biocompatibility, inflammation, foreign body reaction to medical devices, prostheses, and biomaterials

Donald Feke, PhD  
(Princeton University)  
Professor of Chemical Engineering and Macromolecular Science  
Fine-particle processing, colloidal phenomena, dispersive mixing, and acoustic separation methods

Roger French, PhD  
(Massachusetts Institute of Technology)  
F. Alex Nason Professor of Materials Science  
Optical materials and elements, optical properties and electronic structure of materials, and electrodynamic van der Waals-London dispersion interactions

John Protasiewicz, PhD  
(Cornell University)  
Professor of Chemistry  
Inorganic, organic, main group, materials, polymer, catalysis, organometallic chemistry, and X-ray crystallography

Charles Rosenblatt, PhD  
(Harvard University)  
Professor of Physics  
Experimental condensed matter physics and liquid crystal physics

Kenneth Singer, PhD  
(University of Pennsylvania)  
Professor of Physics  
Modern optics and condensed matter experiment and nonlinear optics

Philip Taylor, PhD  
(Cambridge University, England)  
Perkins Professor of Physics  
Phase transitions and equations of state for crystalline polymers; piezoelectricity and pyroelectricity

Horst von Recum, PhD  
(University of Utah, Salt Lake City)  
Assistant Professor of Biomedical Engineering  
Novel platforms for the delivery of molecules and cells and the use of novel stimuli-responsive polymers for use in gene and drug delivery

Adjunct Faculty

Thomas Chapin, PhD  
(University of Connecticut)  
Vice President, UL Laboratories  
Polymer Flammability

Lashanda Korley, PhD  
(Massachusetts Institute of Technology)  
Associate Professor, Chemical Engineering and Materials Science and Engineering University of Delaware  
Hierarchical peptide polymer hybrids; new fiber manufacturing strategies for functional material development; responsive composites; interplay of covalent and non-covalent interactions

Secondary Faculty

Emily Pentzer, PhD  
(Northwestern University)  
Assistant Professor  
Polymer Synthesis, Advanced Materials
Jon Pokorski, PhD  
(Northwestern University)  
Associate Professor  
Biomaterials for delivery of therapeutic proteins; protein-polymer conjugates; drug-delivery; biopolymer catalysts; self-assembling peptides; affinity-based delivery of therapeutics; layered polymeric delivery systems

Alan Riga, PhD  
(Case Western Reserve University)  
Adjunct Full Professor  
Extensive industrial and forensic science experience in laboratory testing and characterization of materials, pharmaceuticals, excipients, proteins, metals, alloys, polymers, biopolymers, elastomers, organic chemicals, monomers, resins, thermosets, and thermoplastics

Stuart Rowan, PhD  
(University of Glasgow)  
Professor, The Institute for Molecular Engineering, University of Chicago  
Supramolecular chemistry; synthesis of metallosupramolecular and stimuli-responsive polymers; isolation and utilization of cellulose nanocrystals in biomimetic and porous systems; reversible covalent chemistry

Christoph Weder, DrScNat  
(ETH Zurich Switzerland)  
Professor of Polymer Chemistry and Materials and Director, Adolphe Merkle Institute of the University of Fribourg, Switzerland  
Design, synthesis and investigation of structure-property relationships of novel functional polymers: polymers with unusual optic and/or electronic properties; (semi)conducting conjugated polymers; stimuli-responsive polymers; biomimetic materials, polymer nanocomposites, supramolecular chemistry

CWRU/Brazil Dual PhD Degree Adjunct Professors

Rosario Elida Suman Bretas, PhD  
(Federal University of Sao Carlos)  
Professor  
Department of Materials Engineering

Veronica Maria de Araujo Calado, PhD  
(Federal University of Rio de Janeiro)  
Professor

Sebastiao Vicente Canavarolo Junior, PhD  
(Federal University of Sao Carlos)  
Professor  
Center for Exact and Technology, Dept of Materials Engineering

Leonardo Bresciani Canto, PhD  
(Federal University of Sao Carlos)  
Professor  
Department of Materials Engineering

Marcio da Silveira Carvalho, PhD  
(Pontifical Catholic University of Rio de Janeiro)  
Professor  
Department of Mechanical Engineering

Osvaldo de Lazaro Casagrande Junior, PhD  
(Federal University of Rio Grande do Sul)  
Professor  
Department of Organic Chemistry

Jose Roberto Moraes d’Almeida, PhD  
(Federal University of Rio de Janeiro)  
Professor  
Department of Chemical Engineering

Griselda Barrera Galland, PhD  
(Federal University of Rio Grande do Sul)  
Professor  
Institute of Chemistry

Aurora Perez Gramatges, PhD  
(Pontificical Catholic University of Rio de Janeiro)  
Professor  
Department of Chemistry

Elizabete Fernandes Lucas, PhD  
(Federal University of Rio de Janeiro)  
Professor  
Institute of Macromolecules

Raquel Santos Mauler, PhD  
(Federal University of Rio Grande do Sul)  
Professor  
Department of Organic Chemistry

Paulo de Souza Mendes, PhD  
(Pontificical Catholic University of Rio de Janeiro)  
Professor  
Department of Mechanical Engineering

Monica Feijo Naccache, PhD  
(Pontificical Catholic University of Rio de Janeiro)  
Professor  
Department of Mechanical Engineering

Sidnei Paciornik, PhD  
(Pontificical Catholic University of Rio de Janeiro)  
Professor  
Department of Materials Engineering

Luiz Antonio Pessan, PhD  
(Federal University of Sao Carlos)  
Professor  
Department of Materials Engineering

Cesar Liberato Petzhold, PhD  
(Federal University of Rio Grande do Sul)  
Professor  
Institute of Chemistry

Joao Henrique Zimnoc Dos Santos, PhD  
(Federal University of Rio Grande do Sul)  
Professor  
Institute of Chemistry

Paulo Henrique Schneider, PhD  
(Federal University of Rio Grande do Sul)  
Professor  
Institute of Chemistry
Emeriti Faculty

John Blackwell, PhD
(University of Leeds, England)
Professor

Leonard Case Jr. Professor

Determination of the solid state structure and morphology of polymers. X-ray analysis of the structure of thermotropic copolyesters, copolyimides, polyurethanes, polysaccharides; supramolecular assemblies, fluoropolymers; molecular modeling of semi-crystalline and liquid crystalline polymers; rheological properties of polysaccharides and glycoproteins

Alexandre M. Jamieson, DPhil
(Oxford University, England)
Professor

Quasielastic laser light scattering; relaxation and transport of macromolecules in solution and bulk; structure-function relationships of biological macromolecules

Jack L. Koenig, PhD
(University of Nebraska, Lincoln)
The Donnell Institute Professor Emeritus

Polymer structure-property relationships using infrared, Raman, NMR spectroscopy and spectroscopic imaging techniques

Jerome B. Lando, PhD
(Polytechnic Institute of Brooklyn)
Professor Emeritus

Solid state polymerization; X-ray crystallography of polymers; electrical properties of polymers; ultra-thin polymer films

Morton H. Litt, PhD
(Polytechnic Institute of Brooklyn)
Professor Emeritus

Kinetics and mechanisms of free radical and ionic polymerization; mechanical properties of polymers; fluorocarbon chemistry; synthesis of novel monomers and polymers; polymer electrical properties; cross-linked liquid crystal polymers

Undergraduate Programs

In 1970, the department introduced a program leading to the Bachelor of Science in Engineering degree with a major in Polymer Science and Engineering, which is designed to prepare the student both for employment in polymer-based industry and for graduate education in polymer science.

The Case School of Engineering is proud that the polymer science and engineering program was the first such undergraduate program in the country to receive accreditation from the Engineering Council for Professional Development. The curriculum combines courses dealing with all aspects of polymer science and engineering with basic courses in chemistry, physics, mathematics, and biology, depending on the needs and interests of the student. The student chooses a sequence of technical electives, in consultation with a faculty advisor, allowing a degree of specialization in one particular area of interest, e.g., biomaterials, chemical engineering, biochemistry, or physics. In addition to required formal laboratory courses, students are encouraged to participate in the research activities of the department, both through part-time employment as student laboratory technicians and through the senior project requirement: a one or two semester project that involves the planning and performance of a research project.

Polymer science undergraduates are also strongly encouraged to seek summer employment in industrial laboratories during at least one of their three years with the department. In addition to the general undergraduate curriculum in Polymer Science and Engineering, the department offers two specialized programs which lead to the Bachelor of Science in Engineering with a major in Polymer Science and Engineering. The cooperative program contains all the course work required for full-time resident students plus one or two six-month cooperative sessions in polymer-based industry. The company is selected by the student in consultation with his or her advisor, depending on the available opportunities. The dual-degree program allows students to work simultaneously on two baccalaureate level degrees within the university. It generally takes five years to complete the course requirements for each department for the degree. The BS/MS program leads to the simultaneous completion of requirements for both the master’s and bachelor’s degrees. Students with a minimum GPA of 3.0 may apply for admission to this program in their junior year.

The Bachelor of Science in Engineering degree program with a major in Polymer Science and Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Program Educational Objectives

This program will produce graduates who:

1. Are competent, creative, and highly valued professionals in industry, academia, or government.
2. Are flexible and adaptable in the workplace, possess the capacity to embrace new opportunities of emerging technologies, and embrace leadership and teamwork opportunities, all affording sustainable engineering careers.
3. Continue their professional development by obtaining advanced degrees in Polymer Science and Engineering or other professional fields, as well as medicine, law, management, finance or public policy.

4. Act with global, ethical, societal, ecological, and commercial awareness expected of practicing engineering professionals.

Student Outcomes
As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Polymer Science and Engineering is designed so that students attain:

- 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 in 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 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

Bachelor of Science in Engineering
Required Courses: Major in Polymer Science and Engineering
In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

Traditional track
EMAC 270 Introduction to Polymer Science and Engineering 3
EMAC 276 Polymer Properties and Design 3
EMAC 351 Physical Chemistry for Engineering 3
EMAC 352 Polymer Physics and Engineering 3
EMAC 355 Polymer Analysis Laboratory 3
EMAC 370 Polymer Chemistry 3
EMAC 372 Polymer Processing and Testing Laboratory 3
EMAC 375 Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology 3
EMAC 376 Polymer Engineering 3
EMAC 377 Polymer Processing 3
EMAC 378 Polymer Engineer Design Product 3
EMAC 398 Polymer Science and Engineering Project I 3

3 Technical Electives which can include a 3 or 6 credit sequence of
EMAC 125/EMAC 325 Undergraduate Research 9
1 Natural Science Elective, chosen in consultation with the student’s academic adviser.

Total Units 45

Biomaterials track
EMAC 270 Introduction to Polymer Science and Engineering 3
EMAC 276 Polymer Properties and Design 3
EMAC 351 Physical Chemistry for Engineering 3
EMAC 352 Polymer Physics and Engineering 3
EMAC 355 Polymer Analysis Laboratory 3
EMAC 370 Polymer Chemistry 3
EMAC 376 Polymer Engineering 3
EMAC 377 Polymer Processing 3
EMAC 378 Polymer Engineer Design Product 3
EMAC 398 Polymer Science and Engineering Project I 3
EBME 201 Physiology-Biophysics I 3
EBME 202 Physiology-Biophysics II 3
EBME 306 Introduction to Biomedical Materials 3

1 Natural Science Elective, chosen in consultation with the student’s academic adviser.

3 Technical Electives have to be taken from:
EBME 305 Materials for Prosthetics and Orthotics
EBME 316 Biomaterials for Drug Delivery
EBME 325 Introduction to Tissue Engineering
EBME 350 Quantitative Molecular, Cellular and Tissue Bioengineering
EBME 425 Tissue Engineering and Regenerative Medicine
EBME 426 Nanomedicine
EBME 406 Polymers in Medicine or EMAC 471 Polymers in Medicine

A three-credit research sequence may be substituted for one of the technical electives
EMAC 125 Freshman Research on Polymers (and/or)
EMAC 325 Undergraduate Research in Polymer Science

Total Units 51

Bachelor of Science in Engineering
Suggested Program of Study: Major in Polymer Science and Engineering (standard track)
The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).
### Bachelor of Science in Engineering

#### Suggested Program of Study: Major in Polymer Science and Engineering (biomaterials track)

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

**First Year**

<table>
<thead>
<tr>
<th>Units</th>
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<tr>
<td>Breadth elective**</td>
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<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
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<tr>
<td>Elementary Computer Programming (ENGR 131)**</td>
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<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
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<td>FSCC 100 Sages First Seminar</td>
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<tr>
<td>PHED Physical Education Activities*</td>
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<td>SAGES University Seminar I</td>
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<td>Chemistry of Materials (ENGR 145)**</td>
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**Second Year**

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<td>Introduction to Polymer Science and Engineering (EMAC 270)</td>
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<td>Calculus for Science and Engineering III (MATH 223)**</td>
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<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
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<td>Breadth elective**</td>
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<tr>
<td>Introductory Organic Chemistry II (CHEM 224)</td>
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<td>Polymer Properties and Design (EMAC 276) (SAGES Departmental Seminar)</td>
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<td>Statics and Strength of Materials (ENGR 200)**</td>
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<tr>
<td>Elementary Differential Equations (MATH 224)**</td>
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**Third Year**

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<tr>
<td>Chemical Laboratory Methods for Engineers (CHEM 290)</td>
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<tr>
<td>Physical Chemistry for Engineering (EMAC 351)</td>
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<tr>
<td>Breadth elective**</td>
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<td>Polymer Engineering (EMAC 376)</td>
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<td>Polymer Analysis Laboratory (EMAC 355)</td>
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**Fourth Year**

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<th>Units</th>
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<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
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<td>Polymer Chemistry (EMAC 370)</td>
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<tr>
<td>Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology (EMAC 375)</td>
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<tr>
<td>Polymer Processing (EMAC 377)</td>
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<tr>
<td>Polymer Science and Engineering Project I (EMAC 398) (SAGES Capstone Course)</td>
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<td>Polymer Processing and Testing Laboratory (EMAC 372)</td>
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<td>Open elective</td>
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</table>

**Total Units in Sequence:** 128

**Hours required for graduation:** 128

- University general education requirement
- **Engineering general education requirement
- c Approved Natural Science electives:
  - PHYS 221 Introduction to Modern Physics
  - STAT 312 Basic Statistics for Engineering and Science
  - PHYS 349 Methods of Mathematical Physics I
  - BIOC 307 Introduction to Biochemistry: From Molecules To Medical Science
- d EMAC 325 may be taken as a technical elective. Students choosing the polymer major in the freshman year are encouraged to register for EMAC 125 (https://sis.case.edu/psp/p90scwr/?cmd=login&languageCd=ENG&) (1 credit), which may be used as a technical elective provided the student also completes EMAC 325 (https://sis.case.edu/psp/p90scwr/?cmd=login&languageCd=ENG&) for at least 2 credits.
- e Technical sequence must be approved by department advisor.
- f Preparation for the polymer science project should commence in the previous semester.

---

Bachelor of Science in Engineering

Suggested Program of Study: Major in Polymer Science and Engineering (biomaterials track)

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

**First Year**

<table>
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<tr>
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<tr>
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<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
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<tr>
<td>Elementary Computer Programming (ENGR 131)**</td>
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<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
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PHED Physical Education Activities
SAGES University Seminar I
Chemistry of Materials (ENGR 145)**
Calculus for Science and Engineering II (MATH 122)**
General Physics I - Mechanics (PHYS 121)**
PHED Physical Education Activities

Year Total: 18 15

Second Year

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<tr>
<td>SAGES University Seminar II</td>
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<td>Physiology-Biophysics II (EBME 202)d</td>
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Third Year

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<td>Introduction to Biomedical Materials (EBME 306)</td>
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<td>Physical Chemistry for Engineering (EMAC 351)</td>
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<td>Polymer Engineering (EMAC 376)</td>
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<td>Structure of Biological Materials (EMAC 303)</td>
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Fourth Year

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<tr>
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<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)***</td>
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<tr>
<td>Polymer Chemistry (EMAC 370)</td>
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<tr>
<td>Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology (EMAC 375)</td>
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<td>Polymer Processing (EMAC 377)</td>
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<td>Polymer Engineer Design Product (EMAC 378)</td>
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<tr>
<td>Polymer Science and Engineering Project I (EMAC 398) (SAGES Capstone Course)g</td>
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Year Total: 19 15

Total Units in Sequence: 128

Hours required for graduation: 128

* University general education requirement
** Engineering general education requirement
c Approved Natural Science electives:
  • BIOL 214 Genes, Evolution and Ecology (d);
  • BIOL 215 Cells and Proteins (d);
  • BIOC 307 Introduction to Biochemistry: From Molecules To Medical Science (d);
  • BIOL 362 Principles of Developmental Biology
d Suggested for pre-med students
e EMAC 355 Polymer Analysis Laboratory is strongly recommended.
f At least 3 of the 4 Technical Electives have to be taken from:
  • EBME 316 Biomaterials for Drug Delivery;
  • EBME 325 Introduction to Tissue Engineering;
  • EBME 350 Quantitative Molecular, Cellular and Tissue Bioengineering;
  • EBME 426 Nanomedicine;
  • EMAC 471 Polymers in Medicine / EBME 406 Polymers in Medicine;
  • a three-credit research sequence of EMAC 125 Freshman Research on Polymers and EMAC 325 Undergraduate Research in Polymer Science
  • EMAC 372 Polymer Processing and Testing Laboratory (offered in the spring semester of the fourth year)
  • Other technical electives, as approved by the student’s academic advisor
g Preparation for the polymer science project should commence in the previous semester.

Electives for Polymer Science Majors:

Biomedical Engineering

<table>
<thead>
<tr>
<th>Units</th>
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<tbody>
<tr>
<td>EBME 201</td>
<td>Physiology-Biophysics I and Physiology-Biophysics II</td>
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<td>EMAC 303</td>
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Chemical Engineering

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<td>ECHE 260</td>
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<td>ECHE 361</td>
<td>Separation Processes</td>
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<td>ECHE 364</td>
<td>Chemical Reaction Processes</td>
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Co-op and Internship Programs ([http://engineering.case.edu/coop](http://engineering.case.edu/coop))

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering
project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop. Alternatively or additionally, students may obtain employment as summer interns.

**Five-Year Combined BS/MS Program**

This program offers outstanding undergraduate students the opportunity to obtain an MS degree, with a thesis, in one additional year of study beyond the BS degree (normally, it takes 2 years beyond the BS to earn an MS degree). In this program, an undergraduate student can take up to 9 credit hours that simultaneously satisfy undergraduate and graduate requirements. If the BS part of the BS/MS is in Polymer Science & Engineering, then participating students generally will not take the standard EMAC 401-405 sequence; the additional course work will be taken as electives in this case. Students in this program typically produce a senior thesis during the fall of their fourth year. They then start their research leading to the MS thesis in the spring semester of that year, culminating in a thesis defense spring semester of year five.

Application for admission to the five year BS /MS program is made after completion of five semesters of course work. Minimum requirements are a 3.2 grade point average and the recommendation of a faculty member of the department. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatestudies/gradprofessional/#accelerationtowardgraduatedegreetext).

**Year five plan**

<table>
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<td>Technical Elective 2 (3)</td>
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<tr>
<td>EMAC 651 Thesis M.S. (6)</td>
<td>EMAC 651 Thesis M.S. (3)</td>
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Thesis defense (typically by mid-March)

*Note: A number of 2 credit hour electives are offered each year by the Macro Department, so students may elect to take a sequence of four electives, totaling at least 9 credit hours, in addition to the required 9 hours of EMAC 651 Thesis M.S. EMAC 651 Thesis M.S.*

**Minor in Polymer Science and Engineering**

The minor in Polymer Science and Engineering consists of five courses from the list below (special arrangements can be made to include appropriate EMAC graduate courses as well).

EMAC 270 and EMAC 276 are required; choose any three of the remaining courses listed below

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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<tbody>
<tr>
<td>EMAC 270</td>
<td>Introduction to Polymer Science and Engineering</td>
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<td>Polymer Properties and Design</td>
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<tr>
<td>EMAC 370</td>
<td>Polymer Chemistry</td>
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<tr>
<td>EMAC 372</td>
<td>Polymer Processing and Testing Laboratory</td>
</tr>
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</table>

**Graduate Programs**

Courses leading to the Master of Science (MS) and Doctor of Philosophy (PhD) degrees in macromolecular science are offered within the Case School of Engineering. They are designed to increase the student's knowledge of macromolecular science and of his or her own basic area of scientific interest, with application to specific polymer research problems. Research programs derive particular benefit from close cooperation with graduate programs in chemistry, physics, materials science, chemical engineering, biological sciences, and other engineering areas. The interdisciplinary academic structure allows the faculty to fit the individual program to the student's background and career plans. Basic and advanced courses are offered in polymer synthesis, physical chemistry, physics, biopolymers, and applied polymer science and engineering. A laboratory course in polymer characterization instructs students in the use of modern experimental techniques and equipment. Graduate students are also encouraged to take advanced course work in polymer solid state physics, physical chemistry, synthesis, rheology, and polymer processing.

**Master of Science**

**Master’s Thesis (Plan A)**

The minimum requirement to complete a master’s degree under Plan A is 30 hours. Of the 30 hours, at least 18 hours must be coursework, and 9 hours must be EMAC 651 Thesis M.S. At least 18 semester hours of coursework, including thesis, must be at the 400 level or higher.

All Plan A MS students must take 6 credits of departmental fundamentals courses including the lab component. Please note: Once a student begins registration of EMAC 651 Thesis M.S., the student must register for at least one credit hour of this course every semester until graduation. The normal residency period for an MS degree is 2 years.

For completion of master’s degree Plan A, an oral examination (defense) of the master’s thesis is required. The examination is conducted by a committee of three university faculty members. The candidate's thesis advisor usually serves as the chair of the examining committee. The chair of the department or the curricular program faculty appoints members of the committee. The examining committee must agree unanimously that the candidate has passed the thesis examination.

**Master’s Comprehensive (Plan B)**

The master's Plan B program is available for individuals who live out-of-state or are working full-time. A research report and oral examination are required before graduation. This option requires 30 total credit hours; categorized by the following:

1. 3-6 cr. hrs. need to be project credit (independent study) which needs to be approved by advisor
2. 21-24 course credits (of which 9 must be based in Macromolecular Science); and
3. 6 core course credits.
Each candidate for the master's degree under Plan B must satisfactorily pass a comprehensive examination, which is administered by the department or curricular program committee. The examination may be written or oral or both. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master's Comprehensive Exam, before taking the examination.

Elective and core courses can be taken via Distance Learning (ITN) or by transfer (transfers need to be approved by chair of department and dean of graduate studies; core courses also need instructors’ approval).

MS Students will generally be required to take the core courses:

**EMAC 401 Polymer Foundation Course I: Organic Chemistry**
**EMAC 402 Polymer Foundation Course II: Physical Chemistry**
**EMAC 403 Polymer Foundation Course III: Physics**
**EMAC 404 Polymer Foundation Course IV: Engineering**

Plus an additional 6 credit hours of coursework for Plan A/15 additional credit hours for Plan B, courses to be approved by his/her adviser.

**Master of Science in Engineering with Specialization**

**Advanced Films and Packaging Systems**
The Department of Macromolecular Science and Engineering at Case Western Reserve University offers a Master's Degree track in Advanced Films and Packaging Systems. This program is designed to be completed over 12 months, but can be spread out over multiple years. Options for either a thesis-based or a course-based Master's are available.

Through a 30 credit hour curriculum, students explore and learn how to apply the fundamental principles of macromolecular science and engineering toward emerging challenges and opportunities in the utilization of plastics in films and packaging. The department offers a unique intersection of deep expertise polymer synthesis, structure-property relationships, and processing which can be applied to benefit an industry with a global economic impact of at least $1 trillion annually.

**Core Course Requirements (9 credits):**
- EMAC 436 Polymers in Advanced Packaging Systems
- EMAC 437 Advanced Polymeric Films
- EMAC 438 Packaging Design and Innovation
- EMAC 450 The Business of Polymers

**Elective and Core Courses:**

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<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>EMAC 401</td>
<td>Polymer Foundation Course I: Organic Chemistry</td>
<td>3</td>
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<tr>
<td>EMAC 402</td>
<td>Polymer Foundation Course II: Physical Chemistry</td>
<td>3</td>
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<tr>
<td>EMAC 403</td>
<td>Polymer Foundation Course III: Physics</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 404</td>
<td>Polymer Foundation Course IV: Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 461</td>
<td>Chemistry of Fire Safe Polymers and Composites</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 457</td>
<td>Combustion</td>
<td>3</td>
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<tr>
<td>EMAE 458</td>
<td>Fire Dynamics</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 463</td>
<td>Fire Protection Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 464</td>
<td>Fire Protection Engineering</td>
<td>3</td>
</tr>
</tbody>
</table>

**Elective tracks:**

Choose one of the following two elective tracks:

**Elective Track I: Macromolecular Science and Engineering (9 credits)**
- EMAC 401 Polymer Foundation Course I: Organic Chemistry
- EMAC 402 Polymer Foundation Course II: Physical Chemistry
- EMAC 403 Polymer Foundation Course III: Physics
- EMAC 405 Polymer Characterization Laboratory

**Elective Track II: Mechanical Engineering (9 credits)**
- EMAE 453 Advanced Fluid Dynamics I
- EMAE 459 Advanced Heat Transfer
- EMAE 558 Conduction and Radiation
- ECIV 424 Structural Dynamics

**Degree Options**
The Fire Science and Engineering master’s degree track comprises 30 credit hours, which may be all coursework or include an MS thesis (9 credit hours) or a project (3 to 6 credit hours). Students can choose to receive a Master of Science in Macromolecular Science and Engineering with a specialization in Fire Science and Engineering, or a Master of
Science in Mechanical Engineering with a specialization in Fire Science and Engineering.

All students will take six core fire protection engineering courses. Other courses can be chosen from the elective track for macromolecular science and engineering or mechanical engineering. The materials track focuses on polymer chemistry and materials, and the chemistry of flammability and fire suppression. The mechanical track follows a traditional mechanical engineering/combustion approach to fire protection and suppression, but with specialization classes in polymers.

The track can be finished in one year or in multiple years. Students have the option of completing a thesis or research project at their employers' laboratories with Case Western Reserve faculty members as co-advisors.

For additional information, please contact:

David Schiraldi, Chair of the Department of Macromolecular Science and Engineering

Ya-Ting Liao, Assistant Professor in the Department of Mechanical and Aerospace Engineering

**Academic Calendar**

This fire protection engineering degree is offered over three semesters: 12 credits in the fall semester; 12 credits in the spring semester; and 6 credits in the summer. See the university's academic calendar [here](http://www.case.edu/registrar/calendar.html).

**How to Apply**

Application to the Fire Science and Engineering program is handled through the university's School of Graduate Studies. Students will need to know whether they wish to apply for the MS in Macromolecular Science and Engineering or the MS in Mechanical Engineering.

Students interested in applying to the Fire Science and Engineering program should already have a bachelor's degree in Chemistry, Chemical Engineering, Mechanical Engineering or Materials Science & Engineering and have taken the GRE. Additional application requirements include a statement of objectives, academic transcripts, and three letters of recommendation. International students will also need to take the Test of English as a Foreign Language (TOEFL). Read more about the university's full application procedure requirements [here](http://gradstudies.case.edu/prospect/admissions/apply.html).

When you are ready to apply, electronic applications can be submitted here [here](https://app.applyyourself.com/AYApplicantLogin/ApplicantConnectLogin.asp?id=casegrad).

**PhD Programs**

The PhD program consists of 36 hours of coursework, including the departmental core courses and 18 credit hours of PhD thesis (EMAC 701 Dissertation Ph.D.) are required for the PhD degree, in addition to passing the research qualifying exam (oral proposal) and the written qualifying exam.

Of the coursework credit requirements, the core courses are designated as "depth" courses (12 credits). In addition, all students will take a minimum of two breadth courses in basic science and/or other departments in the School of Engineering (for a total of six credits). The remaining breadth requirements (up to 18 credits) are satisfied by course modules taken in Macromolecular Science and Engineering.

Each doctoral student is responsible for becoming sufficiently familiar with the research interests of the department or program faculty to choose in a timely manner a faculty member who will serve as the student's research advisor. The research advisor is expected to provide mentorship in research conception, methods, performance and ethics, as well as focus on development of the student's professional communication skills, building professional contacts in the field, and fostering the professional behavior standard of the field and research in general.

The research advisor also assists with the selection of three other faculty to serve as the required additional members of the dissertation advisory committee. This committee must be formed within the second semester following admission. Throughout the development and completion of the dissertation, these members are expected to provide constructive criticism and helpful ideas generated by the research problem from the viewpoint of their particular expertise. Each member will make an assessment of the originality of the dissertation, its value, the contribution it makes and the clarity with which concepts are communicated, especially to a person outside the field.

The doctoral student is expected to arrange meetings and maintain periodic contact with each committee member. A meeting of the full committee for the purpose of assessing the student's progress should occur at least once a year until the completion of the dissertation.

For students entering the PhD program with an MS degree, 18, instead of 36 credit hours, of coursework is required. Other requirements for a PhD remain the same as described above. Normally students should orient their training around their main area of interest/expertise and in relation to their research program. For those enrolled in the MD/PhD degree program, all 18 course credits for breadth and depth courses must be taken within the Medical School Program.

The core courses designated as depth courses are:

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<tr>
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<td>Polymer Foundation Course III: Physics</td>
<td>3</td>
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<tr>
<td>EMAC 404</td>
<td>Polymer Foundation Course IV: Engineering</td>
<td>3</td>
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</table>

Students are required to take all four depth courses (12 credits), but on the approval of the instructor, can be excused from one or more of the courses if the relevant course content is not satisfied by a course taken in prior undergraduate or graduate degrees. However, the excused credits must be fulfilled by taking additional breadth courses. **NOTE:** While EMAC 401 Polymer Foundation Course I: Organic Chemistry and EMAC 402 Polymer Foundation Course II: Physical Chemistry, and EMAC 404 Polymer Foundation Course IV: Engineering are offered at the same time in the Fall and Spring semesters, respectively, students can still sign up for both courses, since one is offered in the first half and the other in the second half of the semester.

Two courses in basic science and/or engineering are required. These courses can be taken in other departments of the School of Engineering, or in the departments of Mathematics, Biology, Biochemistry, Chemistry, or Physics as approved by the advisor.
As part of the course requirements, all students are required to register for EMAC 677 Colloquium in Macromolecular Science and Engineering (the Friday departmental seminars) which will be graded with either “Pass” or “No Pass.”

Students who have taken EMAC 370 Polymer Chemistry and EMAC 376 Polymer Engineering as undergraduates can use these courses to fulfill one or more of the depth requirements in the Department of Macromolecular Science and Engineering for the MS and PhD degree. However, the credits for this course cannot be applied towards the course credit requirements for the graduate degree. Exceptions are possible for the combined BS/MS program.

**Brazil CAPES Program**

**Scope**
The Brazilian Federal Agency for Support and Evaluation of Graduate Education, CAPES, and Case Western Reserve University, Case School of Engineering, entered into a Cooperation Agreement to implement the PhD Program in Polymer and Colloids Science and Engineering.

As the leading Polymer Department in the United States, the Department of Macromolecular Science and Engineering has partnered with four of the leading Brazilian sister Departments and Graduate Programs to offer this particular Program.

They are:

1. Pontificia Universidade Catolica-Rio; PUC-Rio; Graduate Program in Mechanical Engineering
2. Universidade Federal do Rio de Janeiro, UFRJ; Graduate Program in Chemical and Biochemical Processes
3. Universidade Federal de S. Carlos, UFSCar; Graduate Program in Materials Science and Engineering
4. Universidade Federal do Rio Grande do Sul, UFRGS; Graduate Program in Chemistry.

The Program will involve a Dual Degree PhD with two degrees issued, one by CWRU and one by each student’s Brazilian HEU. The PhD degrees to be issued by each partner institution are:

- CWRU - Macromolecular Science and Engineering
- PUC-Rio - Mechanical Engineering
- UFRJ - Chemical and Biochemical Processes
- UFSCar - Materials Science and Engineering
- UFRGS - Chemistry

**Admission Policy**
The Admission policy for students is as follows:

a. All the application documents will be in English. *The application packages will be sent to the Graduate Program Coordinator of the Macromolecular Science and Engineering Department at tac77@case.edu, with a copy to the Program Director, Professor Joao Maia, joao.maia@case.edu, and will include the following:*  
   1. A fully filled application form, including the order of preference of BPU.
   2. A CV in Lattes format.

b. Preference for admission into the PhD program will be given to students who hold a MSc degree or equivalent, in the areas of Engineering, Physics, Chemistry, Mathematics or Materials Science.

c. Students entering the Program with a Bachelor’s degree must take one extra year of courses in Master’s programs currently offered by the Partner Institutions, including the various Master’s Degrees at CWRU. In the latter case, the student may benefit from a Master’s Fellowship from CAPES, separately from those of the Program.

d. Once an offer has been made, a student has two weeks to accept. If he/she does not reply or does not accept, his/her place will be assigned to the next candidate on the list.

**Curricular Structure**
The curricular structure of the Program is as follows:

a. **Core Compulsory Courses (3 credits each; students choose a minimum of 12 credits and a maximum of 18 credits).** The core compulsory courses are as follows:
   
   i. EMAC 401 Polymer Foundation Course I: Organic Chemistry (3 cr)
   
   ii. EMAC 402 Polymer Foundation Course II: Physical Chemistry (3 cr)
   
   iii. EMAC 403 Polymer Foundation Course III: Physics (3 cr)
   
   iv. EMAC 404 Polymer Foundation Course IV: Engineering (3 cr)
   
   v. EMAC 690 Special Topics in Macromolecular Science (3 cr)
   
   vi. EMAC 405 Polymer Characterization Laboratory (3 cr)

b. **Elective Courses (students choose a minimum of 6 credits and a maximum of 12 credits).** These are to be chosen from the current graduate elective offering, which already includes classes offered by the Brazilian partner faculty.

c. In total, students must take 24 credits of classes, of which a minimum of 12 must be taken in core courses. Students may apply to be exempt from taking up to two core courses, if their prior education has covered such subjects. Any such request will be evaluated on a case-by-case basis and must have the approval of both advisors.

d. At the end of the first year, the students will take a Written Qualifier Exam ("WQE"). To continue in the program as a PhD student, his/her score must be 75 or higher, out of a maximum of 100. If the student receives a score between 60 and 75 on the WQE, he/she will be eligible to transfer to the Master’s program. If the student receives a score below 60, he/she will not be permitted to continue in the Program.

e. If a student fails to have a score that will keep him/her in the PhD program, he/she will be given the opportunity to qualify by taking and passing an oral examination.
f. In order to receive a PhD degree, students will complete the coursework above, followed by three years of research that meets the quality standards described below.

g. At the end of their second year, students will undergo a Research Qualifier Exam (RQE) consisting of a research proposal based on their Thesis theme. Students can take only a maximum of 6 research credits before defending the RQE.

h. The research phase will take place between Years 2 and 4, with Years 2 and 3 at CWRU and Year 4 at the host Brazilian HEU, respectively.

i. All research theses will be co-advised by a faculty member from CWRU and a faculty member from one of the partner Brazilian Universities.

j. The following are the minimum qualifications under which a student will be permitted to submit a thesis:

- Successfully complete a minimum of 24 credits of coursework, with a minimum GPA of 3.0.
- Pass both the WQE and the RQE.
- Demonstrate the ability to conduct independent research, as measured by the submission/publication of papers to ISI-indexed international journals or the provisional filing of patents. Typically, this would mean a minimum of two of such publications, although exceptions may be made to account for the quality of the journals.
- The thesis will be written in English and the final defense will, also, be in English. The Thesis format must conform to the criteria as determined by CWRU and the relevant BPU. If necessary, the student will deliver two copies with the same content but in agreement with the local formats.

k. The program will offer the possibility of short internships at Brazilian and U.S. companies in relevant areas.

Scholarships
Students enrolled in the Program will benefit from a PhD Scholarship from CAPES for all four years of study, including during their stay in the USA.

Application Deadline
Applications deadlines will be defined each Academic Year.

Information
For more information, please contact:

Program Director: Professor Joao Maia, joao.maia@case.edu,
+1-216-368-6372

Graduate Program Rules
Graduates entering the Department of Macromolecular Science and Engineering are subject to the academic rules of the University, of the School of Engineering, and of the Department. Consult the Graduate Student Handbook (http://gradstudies.case.edu).

A short abstract of important points include:

1. GPA requirements are described below in the Departmental Rules.
2. A student receiving a "U" in a course is automatically placed on probation and must remove him/herself from probation within one year (usually by repeating the course). If a course is repeated, both original and revised grades will count in the grade point average.
3. Some students are admitted on a probationary basis and must achieve a 3.0 GPA after two semesters to remain in good standing (this is a rule of the Engineering School).
4. Students entering the graduate program for a PhD will need to fill out the "Planned Program of Study" by the end of their second semester.
5. All students are required to serve as teaching assistants. Responsibilities as a TA include serving as an instructor, lab assistant, recitation leader, grader, or tutor in an undergraduate course. After fulfilling the required teaching assistant program, UNIV 400, students will make sure that three teaching courses (400T, 500T, and 600T) are listed on their Planned Program of Study. Completion of this teaching requirement will be monitored by Graduate Studies and is required in order to graduate.

Engineering School Rules
Most of these rules are incorporated in the number and type of courses required by the Department. However, Case School of Engineering PhD students are required to 1) maintain full-time status as a PhD bound student; 2) maintain a grade point average of 3.2 or above; and 3) continue making satisfactory academic progress as certified by their advisor.

Departmental Rules
1. Students in the PhD program receiving a GPA below 2.50 in any two consecutive semesters will be asked to terminate their graduate study program.
2. The GPA requirement established by the university at various stages of the graduate program shall exclude MS or PhD thesis credits which will be graded “S” or “U” until a final grade is given at the end of the program. Hence a student must maintain a minimum GPA of 3.0 (for an MS) OR a 3.0 (for a PhD) in coursework. (As mentioned above, Case School of Engineering PhD students must maintain a GPA of 3.2 or above.)
3. Plan A MS students must give a departmental seminar (as part of the student lecture series).
4. Plan B MS degrees are limited to non-fellowship students.
5. Coursework may be transferred from another university, subject to Graduate Committee approval if:
   - the courses duplicate requirements of the department;
   - the courses were in excess of the undergraduate degree requirements; or
   - the courses were taken in a graduate program elsewhere;
   - a grade of B or better was achieved in those courses;
   - a petition is made to and approved by the Graduate Committee of the Department
   - the transferred grades will not count in the GPA at CWRU

6. The Department reserves the right to withhold financial support to a student if that student takes an undue amount of time in completing his/her MS or PhD requirements (normally no longer than 3 years for MS and 5 years after initial registration of EMAC 701 Dissertation Ph.D.)
7. A PhD student must pass the written Qualifying Exam within 18 months after enrollment with an MS degree into the PhD program. A PhD student must pass the written Qualifying Exam within 24 months after enrollment with a BS degree into the PhD program. A student only has two chances to pass the Qualifying Exam. Students will be asked to answer 4 mandatory questions – one from each of the following five areas:

- Polymer Synthesis
- Polymer Physical Chemistry
- Polymer Physics
- Applied Polymer Science
- Seminars (from the previous year)

Two elective questions will be chosen from a number of questions from all elective courses offered in the Department. NOTE: The Qualifying Exam is given twice per year respectively on the first Friday in the beginning and the first Friday after the end of the Spring semester. For PhD students enrolled in a Spring semester, those with MS must pass the Qualifying Exam at the end of his/her second Spring semester, and those with BS must pass it at the beginning of his/her third Spring semester.

8. The Research Qualifying Exam (RQE) is designed to test the student’s knowledge of the chosen field as well as his/her originality and ability to perform high-quality, independent research. It consists of a written research proposal and an oral defense. All PhD students who hold an MS degree must pass the RQE within 2 years of enrolling in the PhD program, while students with a BS degree must do so within 2.5 years. Successful passing of the Written Qualifying Exam (not to be confused with the written portion of this RQE) is prerequisite to taking the RQE. Students have two chances to pass the RQE and no student will be allowed to continue on to a PhD degree if he/she has not successfully taken it. A conditional pass with major revision (see below) requires modification to the written or oral portion, at the examination committee discretion, within ten business days and following guidelines by the examination committee. A second exam, if required due to failure of the first exam, must be taken within six months of the first exam with at least one examination committee member remaining the same. Passing the exam constitutes advancement to candidacy and is required for enrolling in EMAC 701 Dissertation Ph.D.

9. At least three (3) weeks prior to the RQE oral defense, the student will submit to the graduate chairperson a research proposal title with a one-paragraph synopsis of the research problem and approach, along with suggestions for two members ((i) and (ii), below) of the three member examining committee. The examining committee will consist of three faculty members: (i) a member (or intended member) of the student’s Thesis Advisory Committee, (ii) an expert in the research proposal area and (iii) a faculty member selected systematically and in a neutral manner by the Graduate Committee. The student’s primary thesis advisor or co-advisors is/are excluded from the examining committee. Upon establishing the examining committee, the student will arrange with the committee for the date, time, and location of the RQE. The student will then distribute the written research proposal to the examining committee five full business days before the defense. It should be no less than 15 and no more than 20 pages of double-spaced text with 1” margins on all sides. No more than 5 pages can be devoted to the proposal introduction or background. Figures, tables, and schemes should not exceed five pages in total. Literature citations are in addition to this page count. The oral presentation will be chaired by a designated chairperson from the examining committee. It should contain only limited background material, focusing primarily on execution of the proposed research. The oral presentation should last 20-30 minutes, with questions from faculty being for clarification only. Following the presentation, the examining committee will ask questions for the student to answer concerning the proposal. On the basis of the written proposal and oral defense (presentation and question responses), the faculty will then confer and tender a decision of pass, conditional pass with major revision, or fail, immediately. The decision will be communicated to the student and graduate chairperson in writing within one business day.

10. All PhD students are required to fulfill their teaching requirement by registering for the three teaching courses, 400T, 500T, and 600T that will be posted to the departmental roster each semester. Completion of the teaching requirement will be monitored by Graduate Studies, and these three teaching courses must appear both on the Program of Study form and the student’s transcript.

11. It is expected that all students will present the results of their research in a Departmental Seminar. This is mandatory for students enrolled in the PhD program. Attendance and registration for these seminars EMAC 677 Colloquium in Macromolecular Science and Engineering. Colloquia Seminars is also mandatory.

12. The department requires the equivalent of six credit hours of departmental assistance. This requirement takes the form of grading, laboratory assistance and/or general departmental duties and is designed to utilize no more than three hours/week of a student’s time. The departmental service requirement must be completed within the first two semesters of study. However, the departmental service requirement form must be turned in at the end of each semester until the obligation is met.

13. Vacation Policy. Graduate students in the department who receive fellowship support for 12 months are normally entitled to two weeks vacation plus national holidays. Alternative arrangements may be made with the student’s advisor, giving ample advance notice. In certain situations, it is possible to take a leave of absence without financial support.

14. Prior to graduation, a student is required to clean out his/her laboratory space including a removal of waste solvents and hazardous material.

15. Failure to comply with all of the above course requirements may result in termination or delay graduation.

Facilities

The Kent Hale Smith Science and Engineering Building houses the Department of Macromolecular Science. The building was built in 1993, and specifically designed to meet the specific needs of polymer research. The facility consists of five floors, plus a basement. The laboratories for chemical synthesis are located principally on the top floor, the molecular and materials characterization laboratories on the middle floors, and the major engineering equipment on the ground floor, while the NMR, MALDI-TOF, and TA-InstrumentsThermal Characterization instrumentation are located in the basement. Modern, computer-interfaced classrooms are installed on the ground floor. Additional instrumentation available includes Small and Wide-Angle X-ray diffractometers; scanning electron microscopy; a complete range of molecular spectroscopic equipment including FTIR, laser Raman, and high resolution solution and solid-
state NMR (including imaging), as well as Raman and FTIR microscopes; and dynamic light scattering spectroscopy. There are also facilities for polymer characterization (molecular weight determination), optical microscopy, solution and bulk rheology, scanning calorimetry, and for testing and evaluating the mechanical properties of materials. A newly built-out processing lab provides the complete suite of Thermo-Fisher batch, single- and twin-screw mixing and extrusion equipment, as well as that manufacturer’s state of the art rheometers. The C. Richard Newpher polymer processing laboratory includes a high temperature Rheometrics RMS-800 dynamic mechanical spectrometer, a Bomem DA-3 FTIR with FT-Raman capabilities, a compression molding machine, a Brabender plasticcorder, a high speed Instron testing machine, and a vibrating sample magnetometer. The Charles E. Reed ’34 Laboratory is concerned with the mechanical analysis of polymeric materials. The major testing is done by Instron Universal testing instruments including an Instron model 1123 with numerous accessories such as an environmental chamber for high or low temperature experiments. Additional mechanical testing of fibers, films and injection-molded (Boy model 22-S) are provided by MTS universal testers which are used for both research and undergraduate teaching laboratory classes. The NSF Center for Layered Polymeric Systems (CLiPS) has its central facility within the department, with three cutting-edge multilayer extrusion systems as its centerpiece. CLiPS also operates a Bruckner KARO IV biaxial stretching unit, which allows controlled biaxial stretching of polymer films, and an Atomic Force Microscope which probes the morphological and mechanical properties of materials at the nanoscale. The Molecular Modeling Center provides access to various software packages for the rheological and molecular modeling of polymers.

Courses

EMAC 125. Freshman Research on Polymers. 1 Unit.
Freshman research in polymer chemistry, engineering, and physics. Students will be placed in active research groups and will participate in real research projects under the supervision of graduate students and faculty mentors.

EMAC 270. Introduction to Polymer Science and Engineering. 3 Units.

EMAC 276. Polymer Properties and Design. 3 Units.
The course reviews chemical and physical structures of a wide range of applications for synthetic and natural polymers, and addresses "Which polymer do we choose for a specific application and why?" We examine the polymer properties, the way that these depend on the chemical and physical structures, and reviews how they are processed. We aim to understand the advantages and disadvantages of the different chemical options and why the actual polymers that are used commercially are the best available in terms of properties, processibility and cost. The requirements include two written assignments and one oral presentation. Prereq: ENGR 145 and EMAC 270.

EMAC 303. Structure of Biological Materials. 3 Units.
Structure of proteins, nucleic acids, connective tissue and bone, from molecular to microscopic levels. An introduction to bioengineering biological materials and biomimetic materials, and an understanding of how different instruments may be used for imaging, identification and characterization of biological materials. Offered as: EBME 303 and EMAC 303. Recommended preparation: EBME 201, EBME 202, and EMAC 270.

EMAC 325. Undergraduate Research in Polymer Science. 1 - 3 Units.
Undergraduate laboratory research in polymer chemistry/physics/engineering. Students will undertake an independent research project, working under the mentoring of both a graduate student and a faculty member. A mid-term written progress report is required. A written report and oral presentation will be made at the end of the semester. Can be taken for 1-3 credits per semester, up to a total of 6 credit hours. Students are expected to spend approximately 5 hours/week in the laboratory per credit registered each semester. Recommended preparation: Sophomore/Junior standing and consent of instructor.

EMAC 351. Physical Chemistry for Engineering. 3 Units.
Principles of physical chemistry and their application to systems involving physical and chemical transformations. The nature of physical chemistry, properties of gases, overview of the laws of thermodynamics, thermochemistry, solutions, phases and chemical equilibrium, kinetics of chemical reaction, solutions of electrolytes and introduction to quantum mechanics, atomic structure and molecular statistics. Prereq: ENGR 145.

EMAC 352. Polymer Physics and Engineering. 3 Units.
Single chain statistics and thermodynamics of dilute polymer solutions (single chain statistics, Flory-Kringbaum theory, vapor pressure and osmotic pressure, light, small angle X-Ray, and small-angle neutron scattering), solid state properties of polymers (polymer viscoelasticity (time-temperature superposition; rubber thermodynamics and statistics), glasses and related mechanical properties (fracture mechanism), crystals and liquid crystals; structure property relationship, polymer blends, block copolymers and composites, transport phenomena (conversation of mass, momentum and energy, differential forms, integral forms, momentum transport, laminar and turbulent flow, Navier-Stokes equation, mass transport, diffusion, Fick’s law) and transport phenomena of polymer solutions (intrinsic viscosity, sedimentation and diffusion, dynamic light scattering, polyelectrolytes and block copolymers in solution, size exclusion chromatography). Prereq: EMAC 351

EMAC 355. Polymer Analysis Laboratory. 3 Units.
Experimental techniques in polymer synthesis and characterization. Synthesis by a variety of polymerization mechanisms. Quantitative investigation of polymer structure by spectroscopy, diffraction and microscopy. Molecular weight determination. Physical properties. Prereq: EMAC 276 and (CHEM 290 or CHEM 322).

EMAC 370. Polymer Chemistry. 3 Units.
The fundamentals of organic chemistry of polymer synthesis, suitable for laboratory and industrial polymer production. Prereq: EMAC 270 and (CHEM 224 or CHEM 324).

EMAC 372. Polymer Processing and Testing Laboratory. 3 Units.
Basic techniques for the rheological characterization of thermoplastic and thermoset resins; “hands-on” experience with the equipment used in polymer processing methods such as extrusion, injection molding, compression molding; techniques for mechanical characterization and basic principles of statistical quality control. Prereq: EMAC 377.
EMAC 375. Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology. 3 Units.
This course will involve the study of Rheology from the perspectives of rheological property measurement, phenomenological and molecular models, and applicability to polymer processing. In particular, students will be introduced to: 1) General concepts of Rheology and Newtonian Fluid Mechanics, 2) Standard flows and material functions; 3) The role of Rheology as a structural characterization tool, with an emphasis on polymeric systems; 4) Experimental methods in Rheology with quantitative descriptions of associated flows and data analyses; 5) Viscoelasticity and Non-Newtonian Fluid Mechanics, including the application of models, both phenomenological and molecular, to the prediction of rheological behavior and extraction of model parameters from real data sets; and 6) The relevance of rheological behavior of different systems to practical processing schemes, particularly with respect to plastics manufacturing. Offered as EMAC 375 and EMAC 475. Prereq: ENGR 225 or EMAC 404.

EMAC 376. Polymer Engineering. 3 Units.
Mechanical properties of polymer materials as related to polymer structure and composition. Viscoelastic behavior, yielding and fracture behavior including irreversible deformation processes. Recommended preparation: ENGR 200. Offered as EMAC 376 and EMAC 476. Prereq: EMAC 276.

EMAC 377. Polymer Processing. 3 Units.
Application of the principles of fluid mechanics, heat transfer and mass transfer to problems in polymer processing; elementary steps in polymer processing (handling of particulate solids, melting, pressurization and pumping, mixing); principles and procedures for extrusion, injection molding, reaction injection molding, secondary shaping. Prereq: EMAC 352 or ENGR 225.

EMAC 378. Polymer Engineer Design Product. 3 Units.
Uses material taught in previous and concurrent courses in an integrated fashion to solve polymer product design problems. Practicality, external requirements, economics, thermal/mechanical properties, processing and fabrication issues, decision making with uncertainty, and proposal and report preparation are all stressed. Several small exercises and one comprehensive process design project will be carried out by class members. Offered as EMAC 378 and EMAC 478. Counts as SAGES Senior Capstone.

EMAC 379. Advanced Polymer Engineering. 2 Units.
This Advanced Polymer Engineering course will focus on the ultimate engineering properties for polymers, including fracture mechanics, electrical, and optical properties of polymers. For polymer fracture mechanics, deformation and fracture behavior of polymers will be introduced. The electrical properties include both insulation and conduction/semiconduction properties for polymers. In the optical property section, we will introduce polymer photonics and polymers in liquid crystal displays. The goal of the course is to help students achieve fundamental understanding of advanced polymer properties. EMAC 479 students will do an additional project design. Offered as EMAC 379 and EMAC 479. Prereq: EMAC 376.

EMAC 396. Special Topics. 1 - 18 Units.
(Credit as arranged.)

EMAC 398. Polymer Science and Engineering Project I. 1 - 3 Units.
(Senior project). Research under the guidance of faculty. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Repeatable up to 3 credit hours. When taken for 3 credits it may be spread over two successive semesters. Counts as SAGES Senior Capstone. Prereq: Senior Standing.

EMAC 399. Polymer Science and Engineering Project II. 1 - 9 Units.
(Senior project.) Research under the guidance of staff, culminating in thesis. Recommended preparation: Majors only and senior standing.

EMAC 400T. Graduate Teaching I. 0 Unit.
This course will engage the Ph.D. students in teaching experiences that will include non-contact (such as preparation and grading of homeworks and tests) and direct contact (leading recitations and monitoring laboratory works, lectures and office hours) activities. The teaching experience will be conducted under the supervision of the faculty. All Ph.D. students will be expected to perform direct contact teaching during the course sequence. The proposed teaching experiences for EMAC Ph.D. students are outlined below in association with undergraduate classes. The individual assignments will depend on the specialization of the students. The activities include grading, recitation, lab supervision and guest lecturing. Recommended preparation: Ph.D. student in Macromolecular Science.

EMAC 401. Polymer Foundation Course I: Organic Chemistry. 3 Units.
The class is an introduction to the synthesis and organic chemistry of macromolecules. The course introduces the most important polymerization reactions, focusing on their reaction mechanisms and kinetic aspects. Topics include free radical and ionic chain polymerization, condensation (step-growth) polymerization, ring-opening, insertion and controlled addition polymerization. There is no limit on the number of students for the class as a whole.

EMAC 402. Polymer Foundation Course II: Physical Chemistry. 3 Units.
This class is an introduction to the physical chemistry of polymers in solution. Topics include: polymer statistics: (microstructure, chain configuration, and chain dimensions), thermodynamics and transport properties of polymers in solution, methods for molecular weight determination, physical chemistry of water-soluble polymers, and characterization of polymer microstructure (IR and NMR). There is no limit on the number of students for the class as a whole.

EMAC 403. Polymer Foundation Course III: Physics. 3 Units.
This class is an introduction to the physics of polymers in the bulk amorphous and crystalline states. Topics include: structural and morphological analysis using X-ray diffraction, electron microscopy and atomic force microscopy, characterization of thermal transitions, viscoelastic behavior and rubber elasticity, and dynamic mechanical analysis. There is no limit on the number of students for the class as a whole.

EMAC 404. Polymer Foundation Course IV: Engineering. 3 Units.
This class is an introduction to the engineering and technology of polymeric materials. Topics include: additives, blends and composites, natural polymers and fibers, thermoplastics, elastomers, and thermosets, polymer degradation and stability, polymers in the environment, polymer rheology and polymer processing, and polymers for advanced technologies (membrane science, biomedical engineering, applications in electronics, photonic polymers). There is no limit on the number of students for the class as a whole.

EMAC 405. Polymer Characterization Laboratory. 3 Units.
Laboratory experience through synthesis and characterization of polymers. Synthesis via addition and condensation polymerization. Characterization methods include size exclusion chromatography, infrared and NMR spectroscopy. Solid samples are characterized by x-ray diffraction, electron microscopy, thermal analysis, and physical properties. Fluid samples are characterized by melt rheology. Prereq: EMAC 401, EMAC 402, EMAC 403 and EMAC 404.
EMAC 410. Polymers Plus Self - Assembly and Nanomaterials. 2 Units.
The course focuses on the concepts of supramolecular chemistry and self-assembly specifically as it applies to nano-polymeric systems. After dealing with many of the fundamental aspects of supramolecular chemistry the focus of the class deals with how to access/utilize nanoscale features using such processes, namely the 'bottom-up' approach to nanomaterials/systems. Areas which will be addressed include block copolymers, DNA assemblies, nanotubes and dendrimers. Prereq: EMAC 401 or EMAC 370.

EMAC 413. Polymers Plus Green Chemistry and Engineering. 2 Units.
This course focuses on green chemistry and engineering, particularly as it relates to polymers. Specific topics to be covered in this course will include green chemistry, catalysis, alternative solvents, green processing, renewable materials, and life cycle analysis. Case studies will be utilized to connect lecture topics to real-world examples. Prereq: EMAC 401 and EMAC 404.

EMAC 414. Polymers Plus Advanced Composite and Nanocomposite Materials and Interfaces. 2 Units.
"Advanced Composite and Nanocomposite Materials and Interfaces" will aim at providing advanced concept in composite material structures, importance of interface on the property development, rheological background to be able to manufacture optimized materials, and appropriate processing techniques to choose for a specific product to be manufactured. Specifically, this course will discuss the following items:
1. Basic concept of heterogeneous materials including advantages and problems associated with making multiphase materials. 2. It will review broadly the materials used to make composites and nanocomposites. 3. Unique properties of composites/nanocomposites in rheological, mechanical, and physical properties will be discussed. 4. Various composite processing techniques will be discussed in detail. 5. Surface treatment of the reinforcing materials and interface/interphase structures of composites/nanocomposites will be discussed.

EMAC 415. Polymers Plus Structure and Morphology. 2 Units.
This special topic focuses on polymer structure and morphology and their applications. Topics include solid-state physics of various polymeric materials, ranging from crystalline polymers to liquid crystalline polymers, and block copolymers. First, symmetry operation, space groups, reciprocal spaces are introduced. Examples of the crystalline structures of industrially important polymers and typical polymer crystalline morphology such as lamellar and spherulitic crystals are discussed. Defects in crystalline polymer is also an important issue that determines their physical properties. Second, typical phase structure and transitions of liquid crystals and liquid crystalline polymers are introduced, including both thermotropic and lyotropic liquid crystals. Finally, nanostructure and morphology of block copolymers are discussed. Prereq: EMAC 402 and EMAC 403.

EMAC 417. Functional Polymers. 2 Units.
Polymers have traditionally been used for the so-called passive applications in many areas, ranging from engineering materials to electronics devices. Various functional polymers have now been synthesized with unusual electronic, optical, and mechanical properties. These properties allow polymers to be used as active components for various applications, where they play an active role in regulating the property of materials and performance of devices. Examples include, but not limited to, polymer sensors, polymer actuators, polymer light-emitting diodes, and polymer photovoltaic cells. The objective of this proposed course is to provide polymer engineering and polymer science students with the recent development in functional polymers and their device-related applications. Course Outline: 1). The Concept of Functional Polymers (0.5 week) 2). Electronically Active polymers (1 weeks) - Synthesis, Structure, Conduction Mechanism, and Property 3). Optically Active Polymers (1.5 weeks): Light-Emitting Polymers, Photovoltaic Polymers, Non-Linear Optical Polymers 4). Stimuli-Responsive Polymers (2 weeks): Solvent/Temperature/pH Responsive Polymers, Field Responsive Polymers 5). Functional Polymers for Device Applications (2 weeks): Polymer Sensors and Actuators, Plastic Electronics, Polymer Light-Emitting Diodes and Photovoltaic Cells, Polymeric Biomedical Devices

EMAC 421. Polymer Plus Hierarchical Structures and Properties. 2 Units.
Discuss the hierarchical solid state structure of synthetic and naturally occurring polymeric systems and relate these structures to their properties. Particular emphasis will be on natural systems containing collagen(s) and carbohydrate(s), and on synthetic crystalline, liquid crystalline, and reinforced composite polymeric materials. In order to prepare students for application of these concepts we will determine how mechanical, transport and optical (photonic) behavior can be controlled by structure manipulation. Prereq: EMAC 403 and EMAC 404.

EMAC 422. Polymers Plus Microscopy. 2 Units.
This course focuses on application of microscopy techniques to the analysis of the microstructure of polymeric materials. Specifically, atomic force microscopy, transmission and scanning electron microscopy, and optical microscopy will be discussed. Practical aspects of these techniques will be applied to a variety of systems, including block copolymers, nanocomposites, LC polymers, and multi-layered films. Prereq: EMAC 403.

EMAC 423. Polymers Plus Adhesives, Sealants and Coatings. 2 Units.
EMAC 425. Polymer Plus Energy. 2 Units.
Energy research has become the focus of the twenty-first century. This course is a special topic on polymers in the energy field and related applications. We primarily focus on polymers for solar cells, fuel cells, batteries, double layer electrochemical capacitors, dielectric capacitors, and wind energy. For solar cells, we will introduce conducting polymers and basic types of polymer solar cells. For fuel cells, we will introduce both proton- and hydroxide-exchange fuel cells. Fundamental issues of ion transport, water management, and fuel cell longevity will be introduced. For supercapacitors, we will introduce porous carbon structures and charge storage mechanism. For dielectric capacitors, we will introduce fundamental concepts in electrostatics, different types of polarization, and loss mechanism. For wind energy, we will introduce polymer composites for wind blades and polymer coatings. This course will combine lectures and contemporary literature reviews/essays.

EMAC 426. Biopolymers: Structure, Synthesis, and Application in Medicine. 2 Units.
An introduction to biomacromolecules including DNA, RNA, and proteins. The course will deal with the synthesis and manipulation of biological and synthetic macromolecules as it applies to topics in modern medicine. Topics covered will include nanoparticle gene and drug delivery systems, polymer hydrogels, polymer imaging agents, and protein-polymer conjugates. The purpose of this course is to provide a survey of important areas in medicine where a polymer chemist/engineer can intervene to make a meaningful contribution. Prereq: CHEM 323 and CHEM 324.

EMAC 427. Polymers Plus a Sustainable Economy. 2 Units.
This course is an interdisciplinary seminar-based course surveying the diverse roles played by polymers in a sustainable economy. Specific topics for discussion include: (i) Renewable Energy and the Sustainable Economy; (ii) Renewable Polymers and the Sustainable Economy; (iii) Challenges for Biotechnology in the Sustainable Economy; (iv) Lifetime Analysis of Polymers; Green Policy in the Sustainable Economy; (v) Sustainable Product Innovation in Northeast Ohio; (vi) Advanced Manufacturing for a Sustainable Economy in Northeast Ohio; (vii) Eco-conscious business models in the polymer industry; (viii) Bioethics in Biotechnology; (ix) Alternative Solvents and Processing; and (x) Polymers for Energy Storage and Delivery. Prereq: EMAC 401 and EMAC 404.

EMAC 436. Polymers in Advanced Packaging Systems. 2 Units.
This course serves as a graduate-level introduction to structure-property relationships for many important polymeric materials. Roughly one specific class of polymer will be studied in detail per week, with analysis and discussion that includes discovery history, physical structure (e.g., morphology) and processing, and how these relate to mechanical, thermal, optical, transport and other properties important in packaging. Examples of selected polymers include polyolefins, vinyl polymers, polyesters, ionomers, and bio-based plastics. A growing awareness of sustainability considerations for packaging with be addressed in the course. Prereq: EMAC 270 and EMAC 276 or Requisites Not Met permission.

EMAC 437. Advanced Polymeric Films. 2 Units.
This course is focused on processing structure and property relationships with particular emphasis on a variety of layered film systems. Two classes will be offered per week, emphasizing a large variety of layered film systems for advanced applications. These film systems exhibit unique properties that allow applications in 1) selective barrier films for food and packaging and flexible photocell protection; 2) optical and photonic characteristics for security-enhanced devices and systems; 3) transport phenomena and separation processes for battery separators and particle separation; and, 4) multilayer films for enhancement of mechanical and adhesive properties. Prereq: EMAC 270 and EMAC 276 or Requisites Not Met permission.

EMAC 438. Packaging Design and Innovation. 3 Units.
The course aims to introduce an enterprise-wide understanding of challenges and opportunities for innovation in packaging design. Students will be introduced to the discipline of packaging design in the area of advanced packaging systems with an emphasis on needs-based innovation, sustainability, and value creation that leverages technical considerations from a deep understanding of polymer science and engineering. This will be accomplished through an extensive team-based design project selected from a list of topics proposed by industry with fast-feedback via value creation forums and culminating with a functional prototype. An industry representative will co-mentor each team. In addition to a weekly drive toward design and execution of a compelling design project, one class each week will emphasize an important theme that connects to the overall design philosophy. Topics include human factors, sustainability, and marketing among others. Prereq: EMAC 436.

EMAC 450. The Business of Polymers. 2 Units.
This course will link polymer technology to business and management issues that need to be considered for successful technology commercialization. Topics include project management, finance, opportunity assessment, the voice of the customer, and protection of intellectual property. Case studies from both large and small companies will be used to illustrate key concepts. Recommended preparation: EMAC 270, EMAC 276.

EMAC 460. Polymers Plus Structure-Property Relationships: A Polymer Per Week. 2 Units.
This course serves as a graduate-level introduction to structure-property relationships for synthetic as biologically-derived macromolecules. One specific macromolecular system will be selected per week, with detailed analysis that includes historical considerations, synthesis, chemical and physical structure, and processing, and how these relate intimately to properties (e.g., mechanical, optical, thermal, electrical) and performance. Examples of selected polymers include polyethylene, vinyl polymers, biodegradable synthetic polystyres, high-performance fibers, biopolymers such as collagen and silk, and intrinsically conducting polymers. Discussions will also include emerging opportunities for polymers chosen and potential limitations to a broader range of applications. Grades will be determined from two detailed papers focusing on the molecular origins of structure-property relationships, a presentation on one of the papers, and in-class participation. Prereq: EMAC 270 or requisites not met permission.
EMAC 461. Chemistry of Fire Safe Polymers and Composites. 3 Units.
Chemistry of Fire Safe Polymers and Composites starts with the introduction of characterization techniques used for fire safe materials and combustion phenomena research. General discussion on how reduced flammability of polymers and composites are obtained, for example by additives and preparing intrinsically thermally stable chemical structure and some examples of smart approaches, will be discussed. It also discusses the synthetic methods of preparing high temperature stable polymers in addition to the raw materials used to prepare those materials. Special emphasis will be placed on the thermal stability data obtained by thermogravimetric analysis (TGA) and combustion calorimetry for those fire safe materials. Mechanistic aspects of the flammability of polymers will be explained with special emphasis on the molar contribution of chemical functionality to the heat release capacity. Theoretical derivation of thermokinetic parameters will be explained. In addition, a common sense build-up will be attempted by providing actual numbers associated with those thermokinetic parameters. Upon completion of background formation, a more advanced materials, composites and nanocomposites, will be discussed using the results recently reported. Preliminary attempts to explain flame retardation by nanocomposite structures will also be discussed. Offered as EMAC 461 and EMAE 461.

EMAC 463. Fire Dynamics. 3 Units.
This course introduces compartment fires and burning behavior of materials. Topics include: buoyant driven flow, fire plume, ceiling jet, vent flow, flashover and smoke movement as well as steady burning of liquids and solids; ignition, extinction and flame spread over solids. Recommended Preparation: Elementary knowledge in thermo-fluids is required. Offered as EMAE 463 and EMAC 463.

EMAC 464. Fire Protection Engineering. 3 Units.
This course introduces essentials of fire protection in industry and houses. Topics include: hazard identification (release of flammable gases and their dispersion), fire and explosion hazards, prevention and risk mitigation, fire detection systems, mechanisms of fire extinguishment, evaluation of fire extinguishing agents and systems. Offered as EMAC 464 and EMAE 464.

EMAC 471. Polymers in Medicine. 3 Units.
This course covers the important fundamentals and applications of polymers in medicine, and consists of three major components: (i) the blood and soft-tissue reactions to polymer implants; (ii) the structure, characterization and modification of biomedical polymers; and (iii) the application of polymers in a broad range of cardiovascular and extravascular devices. The chemical and physical characteristics of biomedical polymers and the properties required to meet the needs of the intended biological function will be presented. Clinical evaluation, including recent advances and current problems associated with different polymer implants. Recommended preparation: EBME 306 or equivalent. Offered as EBME 406 and EMAC 471.

EMAC 475. Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology. 3 Units.
This course will involve the study of Rheology from the perspectives of rheological property measurement, phenomenological and molecular models, and applicability to polymer processing. In particular, students will be introduced to 1) General concepts of Rheology and Newtonian Fluid Mechanics, 2) Standard flows and material functions; 3) The role of Rheology as a structural characterization tool, with an emphasis on polymeric systems; 4) Experimental methods in Rheology with quantitative descriptions of associated flows and data analyses; 5) Viscoelasticity and Non-Newtonian Fluid Mechanics, including the application of models, both phenomenological and molecular, to the prediction of rheological behavior and extraction of model parameters from real data sets; and 6) The relevance of rheological behavior of different systems to practical processing schemes, particularly with respect to plastics manufacturing. Offered as EMAC 375 and EMAC 475. Prereq: ENGR 225 or EMAC 404.

EMAC 476. Polymer Engineering. 3 Units.
Mechanical properties of polymer materials as related to polymer structure and composition. Visco-elastic behavior, yielding and fracture behavior including irreversible deformation processes. Recommended preparation: ENGR 200. Offered as EMAC 376 and EMAC 476.

EMAC 477. Elementary Steps in Polymer Processing. 3 Units.
This course is an application of principles of fluid mechanics and heat transfer to problems in polymer processing. In the first part of the course, basic principles of transport phenomena will be reviewed. In the second part, the elementary steps in polymer processing will be described and analyzed with application to a single screw extruder.

EMAC 478. Polymer Engineer Design Product. 3 Units.
Uses material taught in previous and concurrent courses in an integrated fashion to solve polymer product design problems. Practicality, external requirements, economics, thermal/mechanical properties, processing and fabrication issues, decision making with uncertainty, and proposal and report preparation are all stressed. Several small exercises and one comprehensive process design project will be carried out by class members. Offered as EMAC 378 and EMAC 478. Counts as SAGES Senior Capstone.

EMAC 479. Advanced Polymer Engineering. 2 Units.
This Advanced Polymer Engineering course will focus on the ultimate engineering properties for polymers, including fracture mechanics, electrical, and optical properties of polymers. For polymer fracture mechanics, deformation and fracture behavior of polymers will be introduced. The electrical properties include both insulation and conduction/semiconduction properties for polymers. In the optical property section, we will introduce polymer photonics and polymers in liquid crystal displays. The goal of the course is to help students achieve fundamental understanding of advanced polymer properties. EMAC 479 students will do an additional project design. Offered as EMAC 379 and EMAC 479. Prereq: EMAC 404.
EMAC 480. Writing an NSF-Style Scientific Proposal. 2 Units.
The aim of this course is to learn how to develop a National Science Foundation (NSF) grant proposal. The class will include all aspects of building an NSF proposal from the intellectual Merit of the scientific content to its Broader impacts. It will also focus on how to put together the other aspects required for an NSF proposal, such as budget, facilities, NSF-style bio, etc. The class will involve some lectures on the basics of putting the proposal together (best practices, etc.) followed by writing the NSF proposal using the NSF’s current Grant Proposal Guide (GPG). The class will meet once a week to discuss the progress of each of the student’s proposals. The students will be expected to come up with their own polymer-related scientific idea for the grant proposal (which has to be approved by the Macromolecular Sci & Eng Graduate Committee before the end of the second week of class). Toward the end of the class all proposals will be evaluated by the students (each student will be assigned as a primary reviewer for some of the proposals, a secondary reviewer and a scribe for others). The class will then hold a NSF-style proposal panel review. Each proposal will be awarded an NSF evaluation grade (Excellent, Very Good, Good, Fair, Poor) and a final review report for each proposal will be drafted by the students. The final grade for this course depends on the quality of the proposal as well as the students’ participation in the NSF-style panel review process.

EMAC 490. Polymers Plus Professional Development. 1 Unit.
This course focuses on graduate student professional development. The course involves weekly meetings and oral presentations with attention on the content and style of the presentation materials (PowerPoint, posters, etc.), oral presentation style and project management skills. This course can be taken for the total of 3 credits over three different semesters.

EMAC 491. Polymers Plus Literature Review. 1 Unit.
This course involves weekly presentations of the current polymer literature. It involves at least one presentation by the enrolled student and participation in all literature reviews (at least 10/semester). The course will focus on presentation skills (both oral and written), scientific interpretation, and development of peer-review skills. This course can be taken for a total of 3 credits over three different semesters.

EMAC 492. Carbon Nanoscience and Nanotechnology. 3 Units.
This course presents the fundamental aspects of nanoscience and nanotechnology with an emphasis on carbon nanomaterials and nanodevices. This proposed course intends to provide students with the fundamental aspects of nanoscience and nanotechnology. Nanotechnology draws on the strengths of all the basic sciences and is the engineering at the molecular level, which has the potential to lead to novel scientific discoveries as well as new industrial technologies. This course will give students insight into a new, exciting and rapidly developing field. The course has a good balance between basic knowledge and depth with a focus on some key application areas, which will enable students to work in a variety of scientific professions.

EMAC 500T. Graduate Teaching II. 0 Unit.
This course will engage the Ph.D. students in teaching experiences that will include non-contact and direct contact activities. The teaching experience will be conducted under the supervision of the faculty. The proposed teaching experiences for EMAC Ph.D. student in this course involve instruction in the operation of major instrumentation and equipment used in the daily research activities. The individual assignments will depend on the specialization of the students. Recommended preparation: Ph.D. student in Macromolecular Science.

This course aims to provide a broad overview of the structure and function of cellular macromolecules, with the major focus being an exploration biological cells as soft materials. Special emphasis is given to connections between cell material properties and macromolecular assemblies (e.g., viscoelasticity and cytoskeletal networks) and roles in determining mechanical, physical, electrical and transport properties. Material properties of collections of cells, namely selected tissues and organs, will be also discussed with special attention to irritability and motion and the design of smart materials and artificial cells using fundamental concepts from macromolecular science and engineering.

EMAC 600T. Graduate Teaching III. 0 Unit.
This course will engage the Ph.D. students in teaching experiences that will include non-contact and direct contact activities. The teaching experience will be conducted under the supervision of the faculty. The proposed teaching experiences for EMAC Ph.D. student in this course involve instruction in the operation of major instrumentation and equipment used in the daily research activities. The individual assignments will depend on the specialization of the students. Recommended preparation: Ph.D. student in Macromolecular Science.

EMAC 601. Independent Study. 1 - 18 Units.
(Credit as arranged.)

EMAC 651. Thesis M.S.. 1 - 18 Units.
(Credit as arranged.)

EMAC 673. Selected Topics in Polymer Engineering. 2 - 3 Units.
Timely issues in polymer engineering are presented at the advanced graduate level. Content varies, but may include: mechanisms of irreversible deformation: failure, fatigue and fracture of polymers and their composites; processing structure-property relationships; and hierarchical design of polymeric systems. Recommended preparation: EMAC 376 or EMAC 476.

EMAC 677. Colloquium in Macromolecular Science and Engineering. 0 - 1 Units.
Lectures by invited speakers on subjects of current interest in polymer science and engineering. This course can be taken for 3 credits over three different semesters.

EMAC 690. Special Topics in Macromolecular Science. 1 - 18 Units.

EMAC 695. Project M.S.. 1 - 9 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in the EMAC Plan B Program.

EMAC 701. Dissertation Ph.D.. 1 - 9 Units.
(Credit as arranged.) Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Department of Materials Science and Engineering
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Materials science and engineering is a discipline that extends from the microscopic structure and properties of materials to the design and evaluation of materials in engineering systems. Achievements in materials science underpin the revolutionary advances in technology that define the modern standard of living. The role of a materials engineer is
to understand why materials behave as they do under various conditions, to recognize the limits of performance that particular materials can attain, and to know what can be done during the manufacture of materials to meet the demands of a given application.

The Department of Materials Science and Engineering of the Case School of Engineering offers programs leading to the degrees of Bachelor of Science in Engineering, Master of Science, and Doctor of Philosophy. The technological challenges that materials engineers face demand a breadth of knowledge across a broad spectrum of engineering materials. The Department conducts academic and research activities with metals, ceramics, polymers, composites, and electronic materials. Timely research and education respond to the demands for new materials and improved materials performance in existing applications, often transcending the traditional materials categories.

While a discipline of engineering, the field brings basic science to bear on the technological challenges related to materials products and their manufacture. Materials science draws on chemistry in its concern for bonding, synthesis, and composition of engineering materials and their chemical interactions with the environment. Physics provides a basis for understanding the mechanical, thermal, optical, magnetic, and electrical properties of materials and provides the tools needed to ascertain the structure and properties of materials. Quantitative physical theories and modeling of fundamental materials science phenomena, microstructural analysis, materials design, and manufacturing processes are examples of the growing importance of mathematics and computation in materials science and engineering.

Mission
The Department of Materials Science and Engineering engages faculty, students, postdoctoral researchers, engineers, and staff in developing and understanding relationships between processing, structure, properties, and the performance of materials in engineering applications. The Department provides a research-intensive environment that encourages collaboration and underpins modern education of undergraduate and graduate students as well as professionals in the field. This environment provides a strong foundation for advancing the frontiers of materials research, developing important technical innovations, and preparing engineers and scientists for challenging leadership careers.

Research Areas
Deformation and Fracture
Relationships between structure and mechanical behavior of traditional and advanced materials: metals, ceramics, intermetallics, composites, and biological materials. State-of-the-art facilities are available for deformation processing as well as mechanical testing over a range of strain rates, test temperatures, stress states, and size scales for both monotonic and cyclic conditions.

Materials Processing
Alloy surface engineering, crystal growth, thin-film deposition, casting of metal alloys, metallic glasses by rapid solidification, powder synthesis, crystallization of amorphous alloys, consolidation processing, layered materials, plated metals and alloys, solution- and/or precipitation heat-treatments, thermo-mechanical processing, diffusion-bonding, brazing and welding of metals, glasses and ceramics, electrochemical and thermo-chemical oxidation/reduction conversion processing of metal/oxide surface layers.

Environmental Effects
Durability and lifetime extension of structural, energy-conversion, and energy-storage materials, including materials for solar energy. Corrosion, oxidation, stress-corrosion, low- and high-cycle fatigue, adhesion, decohesion, friction, and wear. Surface modification and coatings, adhesion, bonding, and dis-bonding of dissimilar materials, reliability of electronics, photonics, and sensors.

Surfaces and Interfaces
Material surfaces in vacuum, ambient and chemical environments, grain- and phase boundaries, hetero-interfaces (interfaces between different metals, ceramics, carbon/graphite, polymers, and combinations thereof).

Electronic, Magnetic, and Optical Materials
Materials for energy technologies, such as photovoltaics, organic and inorganic light-emitting diodes and displays, fuel cells, electrolytic capacitors, building-envelope materials, and wind turbines. Processing, properties, and characterization of magnetic materials and ferroelectric and piezoelectric ceramics.

Microcharacterization of Materials
Facilities for high-resolution imaging, spatially resolved chemical analysis, and diffractometry. Conventional, analytical, and high-resolution transmission electron microscopy, scanning electron microscopy, focused ion beam techniques, scanning probe microscopy, light-optical microscopy, optical spectrosocopies, surface analysis, and X-ray diffraction.

Materials Data Science
Rapid qualification of alloys, data science applications in polymers and coatings. Distributed computing, informatics, statistical analytics, exploratory data analysis, statistical modeling, and prediction. Hadoop, cloud computing, and computationally intensive research are supported through the operation of a scalable high-performance computing (HPC) system.

Faculty
Frank Ernst, Dr. rer. nat. habil. (University of Göttingen)
Leonard Case Jr. Professor of Engineering

William A. “Bud” Baeslack III, PhD (Rensselaer Polytechnic Institute)
Professor
Welding, joining of materials, and titanium and aluminum metallurgy.

Jennifer W. Carter, PhD (The Ohio State University)
Assistant Professor
Processing-structure-property relationships of crystalline and amorphous materials; development and implementation of novel multi-scale material characterization methods for correlating unique local microstructural features with particular mechanical and environmental responses in a variety of material systems.
Mark R. DeGuire, PhD  
(Massachusetts Institute of Technology)  
Associate Professor  

Roger H. French, PhD  
(Massachusetts Institute of Technology)  
Kyocera Professor of Ceramics  
Optical materials science, including optical properties, electronic structure, and radiation durability of optical materials, polymers, ceramics and liquids using vacuum ultraviolet and optical spectroscopies and spectroscopic ellipsometry. Lifetime and degradation science of photovoltaic materials, components and systems including solar radiation durability and degradation mechanisms and rates. Quantum electrodynamics and van der Waals – London dispersion interactions applied to wetting, and long range interactions for manipulation of nanoscale objects such as carbon nanotubes and biomolecular materials.

Peter Lagerlof, PhD  
(Case Western Reserve University)  
Associate Professor  
Mechanical properties of ceramics and metals. Of particular interest is to understand how low temperature deformation twinning is related to plastic deformation by dislocation slip at elevated temperatures. Deformation twinning models for both basal and rhombohedral twinning in sapphire, which are properly related to dislocation slip at elevated temperatures, have been established. The basal twinning model has been confirmed experimentally using TEM techniques. Current research involves studies on how to generalize this twinning model to other materials systems; i.e., metals, intermetallic compounds and other ceramics.

John J. Lewandowski, PhD  
(Carnegie Mellon University)  
Arthur P. Armington Professor of Engineering; Director, The Advanced Manufacturing and Mechanical Reliability Center (AMMRC)  
Mechanical behavior of materials; fracture and fatigue; micromechanisms of deformation and fracture; composite materials; bulk metallic glasses and composites; refractory metals; toughening of brittle materials; high-pressure deformation and fracture studies; hydrostatic extrusion; deformation processing.

David H. Matthiesen, PhD  
(Massachusetts Institute of Technology)  
Associate Professor; Director, Wind Energy Research and Commercialization (WERC) Center  
Materials for use in wind turbines; wind resource measurements onshore and offshore; materials interactions with ice; bulk crystal growth processing; process engineering in manufacturing; heat, mass, and momentum transport.

James D. McGuffin-Cawley, PhD  
(Case Western Reserve University)  
Arthur S. Holden Professor of Engineering  
Powder processing of ceramics; manufacturing and materials; additive manufacturing and rapid prototyping; aggregation phenomena; defects, diffusion, and solid state reactions; materials for optical devices.

Alp Sehirlioglu, PhD  
(University of Illinois at Urbana Champaign)  
Warren E. Rupp Assistant Professor  
Energy conversion materials including piezoelectrics and thermoelectrics, high temperature applications, bulk and thin film electro-ceramics, epitaxial oxide thin films.

Gerhard E. Welsch, PhD  
(Case Western Reserve University)  
Professor  
Metals and oxides; high temperature properties, mechanical and electrical properties. Materials for capacitive energy storage; metal sponges; high temperature materials, metal-cell composites. Synthesis of materials.

Matthew A. Willard, PhD  
(Carnegie Mellon University)  
Associate Professor; Director, Case Metals Casting Laboratory  
Magnetic materials, including their magnetic properties, microstructure evolution, phase formation, and processing conditions; critical materials and sustainability, especially reducing dependence on rare earths through novel alloy design; rapid solidification processing of materials, with an emphasis on nanostructured and amorphous alloys; soft magnetic materials for power conditioning, conversion, and generation technologies and permanent magnet materials for motor, generator, and actuator applications (especially in energy dense applications and in extreme environments); other magnetic related phenomena, including magnetic shape memory alloys, magnetocaloric effects, magnetic nanoparticles, and multiferoics.

Secondary Faculty

Burda Clemens, PhD  
Professor of Chemistry

Liming Dai, PhD  
Kent Hale Smith Professor

Walter Lambrecht, PhD  
Professor of Physics

Mohan Sankaran, PhD  
Professor in Chemical Engineering

Nicole F. Steinmetz, PhD  
Assistant Professor of Biomedical Engineering

Russell Wang, DDS  
Associate Professor of Dentistry

Xiong (Bill) Yu, PhD, PE  
Assistant Professor of Civil Engineering

Research Faculty

Laura S. Bruckman, PhD  
(University of South Carolina)  
Assistant Professor  
Electronic materials, lifetime and degradation science, data science.
Adjunct Faculty

Aron Chait, PhD
(The Ohio State University)
Adjunct Professor
NASA Lewis Research Center

Gopal Das, PhD
Adjunct Professor

George Fisher, PhD
Adjunct Professor
Ion Vacuum Technologies Corp.

N.J. Henry Holroyd, PhD
(Newcastle University)
Adjunct Professor
Luxfer Gas Cylinders, Riverside, CA

Jennie S. Hwang, PhD
(Case Western Reserve University)
Adjunct Professor
H-Technologies Group, Cleveland, OH

Ina Martin, PhD
(Colorado State University)
Adjunct Assistant Professor
Sr. Res. Assoc. CAS-Physics

Farrel Martin, PhD
Adjunct Professor
Science Applications International Corp.

Terence Mitchell, PhD
(University of Cambridge)
Adjunct Professor
Los Alamos National Laboratory, Los Alamos, NM

Badri Narayanan, PhD
(The Ohio State University)
Adjunct Assistant Professor
Lincoln Electric Co., Euclid, OH

Joe H. Payer, PhD
Adjunct Professor
University of Akron

Timothy Peshek, PhD
Adjunct Assistant Professor
NASA Glenn Research Center

Rudolph Podgornik, PhD
(University of Ljubljana)
Adjunct Professor

Gary Ruff, PhD
(Case Western Reserve University)
Adjunct Professor
Ruff Associates, Rochester Hills, MI

Ali Sayir, PhD
(Case Western Reserve University)
Adjunct Professor
Air Force Office of Scientific Research

Moshen Seifi, PhD
Adjunct Assistant Professor
Director Additive Manufacturing Programs

Undergraduate Programs

The curriculum leading to the Bachelor of Science in Engineering degree program with a major in Materials Science and Engineering, consists of the “Engineering Core”—basic courses in mathematics, physics, chemistry, and engineering, with electives in social sciences and humanities—plus materials courses, which also allow students to choose one of several areas of concentration within the major. A total of 129 credit hours is required.

Throughout the undergraduate curriculum in materials science and engineering, scientific fundamentals are integrated with coverage of current manufacturing, design, and applications of engineering materials.

The goal of the Department of Materials Science and Engineering is to prepare students for rewarding careers that provide creative, effective solutions to societal needs, through coursework and associated activities that emphasize:

- The interrelationships among the processing, structure, properties, and performance of engineering materials
- The mutual reinforcement of education and professional development throughout one’s career.

The undergraduate experience in Materials Science and Engineering at Case Western Reserve is marked by a high degree of hands-on experience and many opportunities for professional development before graduation. Lab courses, senior projects, and plant tours ensure that every student sees the field first-hand in current research and industrial settings.

The Bachelor of Science in Engineering degree program with a major in Materials Science and Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Program Educational Objectives

1. Graduates will take an active part in professional organizations.
2. Graduates will assume leadership positions in materials science related industries.
3. Graduates will be effectively involved in solving technical problems.
4. Graduates may successfully enter and complete graduate and professional degree programs.

Student Outcomes

As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Materials Science and Engineering is designed so that students attain:

- 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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- 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 engineering solutions in a global, economic, environmental, 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

Bachelor of Science in Engineering
Required Courses for Major in Materials Science and Engineering
In addition to Engineering Core (http://bulletin.case.edu/undergraduatestudies/csedegree) and CWRU General Education (http://bulletin.case.edu/undergraduatestudies/degreeprograms) requirements, the major requires the following courses.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>EMSE 110</td>
<td>Transitioning Ideas to Reality I - Materials in Service of Industry and Society</td>
<td>1</td>
</tr>
<tr>
<td>EMSE 120</td>
<td>Transitioning Ideas to Reality II - Manufacturing Laboratory</td>
<td>2</td>
</tr>
<tr>
<td>EMSE 220</td>
<td>Materials Laboratory I</td>
<td>2</td>
</tr>
<tr>
<td>EMSE 228</td>
<td>Mathematical and Computational Methods for Materials Science and Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EMSE 276</td>
<td>Materials Properties and Design</td>
<td>3</td>
</tr>
<tr>
<td>EMSE 319</td>
<td>Processing and Manufacturing of Materials</td>
<td>3</td>
</tr>
<tr>
<td>EMSE 320</td>
<td>Materials Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>EMSE 327</td>
<td>Thermodynamic Stability and Rate Processes</td>
<td>3</td>
</tr>
<tr>
<td>EMSE 328</td>
<td>Mesoscale Structural Control of Functional Materials</td>
<td>3</td>
</tr>
<tr>
<td>EMSE 330</td>
<td>Materials Laboratory III</td>
<td>2</td>
</tr>
<tr>
<td>EMSE 343</td>
<td>Processing of Electronic Materials</td>
<td>3</td>
</tr>
<tr>
<td>EMSE 345</td>
<td>Materials for Biological and Medical Technology</td>
<td>3</td>
</tr>
<tr>
<td>EMSE 349</td>
<td>Materials for Energy and Sustainability</td>
<td>3</td>
</tr>
<tr>
<td>EMSE 372</td>
<td>Structural Materials by Design</td>
<td>4</td>
</tr>
<tr>
<td>EMSE 379</td>
<td>Design for Lifetime Performance</td>
<td>3</td>
</tr>
<tr>
<td>EMSE 398</td>
<td>Senior Project in Materials I</td>
<td>1</td>
</tr>
<tr>
<td>EMSE 399</td>
<td>Senior Project in Materials II</td>
<td>2</td>
</tr>
<tr>
<td>EMAC 270</td>
<td>Introduction to Polymer Science and Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 276</td>
<td>Polymer Properties and Design</td>
<td>3</td>
</tr>
</tbody>
</table>

Total Units: 48

Concentrations
The undergraduate program includes courses that expose students to greater depth in areas related to materials science and engineering. These concentration sequences are of two types:

• Students may select an area of concentration that is based on an application or subfield of engineering materials. Each concentration will be a coherent set of courses that, in conjunction with one or more of the courses already required for all EMSE majors plus a specified mathematics/natural science/statistics course, will provide significant depth in an area of materials specialization.
• Students also have the option of designing a concentration — Advanced Materials Science and Engineering — in consultation with their advisors and subject to approval by the department’s Undergraduate Studies Committee.

The concentrations are below. All concentrations equal 12 credit hours (four courses).

Biomaterials

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 201</td>
<td>Physiology-Biophysics I *</td>
<td>3</td>
</tr>
<tr>
<td>EBME 202</td>
<td>Physiology-Biophysics II *</td>
<td>3</td>
</tr>
<tr>
<td>EBME/EMAC 303</td>
<td>Structure of Biological Materials</td>
<td></td>
</tr>
<tr>
<td>EBME 305</td>
<td>Materials for Prosthetics and Orthotics</td>
<td></td>
</tr>
<tr>
<td>EBME 306</td>
<td>Introduction to Biomedical Materials</td>
<td></td>
</tr>
<tr>
<td>EBME 316</td>
<td>Biomaterials for Drug Delivery</td>
<td></td>
</tr>
<tr>
<td>EBME 325</td>
<td>Introduction to Tissue Engineering</td>
<td></td>
</tr>
<tr>
<td>EBME 406/EMAC 471</td>
<td>Polymers in Medicine</td>
<td></td>
</tr>
<tr>
<td>EBME/EECS 480B</td>
<td>The Human Body</td>
<td></td>
</tr>
</tbody>
</table>

Electronic Materials

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>PHYS 221</td>
<td>Introduction to Modern Physics *</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 315</td>
<td>Introduction to Solid State Physics</td>
<td></td>
</tr>
<tr>
<td>PHYS 326</td>
<td>Physical Optics</td>
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</tr>
<tr>
<td>PHYS 327</td>
<td>Laser Physics</td>
<td></td>
</tr>
<tr>
<td>PHYS 331</td>
<td>Introduction to Quantum Mechanics I</td>
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</tbody>
</table>

Plus three of the following (from either or both categories):

Emphasis on solid state physics:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>CHEM 340</td>
<td>Solar Energy Conversion</td>
<td></td>
</tr>
<tr>
<td>ECHE 383</td>
<td>Chemical Engineering Applied to Microfabrication and Devices</td>
<td></td>
</tr>
<tr>
<td>EECS 309</td>
<td>Electromagnetic Fields I</td>
<td></td>
</tr>
<tr>
<td>EECS 321</td>
<td>Semiconductor Electronic Devices</td>
<td></td>
</tr>
<tr>
<td>EECS 322</td>
<td>Integrated Circuits and Electronic Devices</td>
<td></td>
</tr>
<tr>
<td>EMSE 405</td>
<td>Dielectric and Electrical Properties of Materials</td>
<td></td>
</tr>
<tr>
<td>EMSE 427</td>
<td>Defects in Solids</td>
<td></td>
</tr>
<tr>
<td>EMSE 463</td>
<td>Magnetism and Magnetic Materials</td>
<td></td>
</tr>
</tbody>
</table>
### Polymers

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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</thead>
<tbody>
<tr>
<td>CHEM 223</td>
<td>Introductory Organic Chemistry I *</td>
</tr>
<tr>
<td>or</td>
<td></td>
</tr>
<tr>
<td>CHEM 323</td>
<td>Organic Chemistry I *</td>
</tr>
</tbody>
</table>

Plus three of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 351</td>
<td>Physical Chemistry for Engineering</td>
</tr>
<tr>
<td>EMAC 355</td>
<td>Polymer Analysis Laboratory</td>
</tr>
<tr>
<td>EMAC 372</td>
<td>Polymer Processing and Testing Laboratory</td>
</tr>
<tr>
<td>EMAC 375</td>
<td>Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology</td>
</tr>
<tr>
<td>EMAC 376</td>
<td>Polymer Engineering</td>
</tr>
<tr>
<td>EMAC 377</td>
<td>Polymer Processing</td>
</tr>
</tbody>
</table>

Completion of this concentration (including EMAC 270 and EMAC 276, as required for the major in Materials Science and Engineering) satisfies the requirements for a minor in Polymer Science and Engineering.

### Structural Materials and Mechanical Behavior

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>STAT 312</td>
<td>Basic Statistics for Engineering and Science *</td>
</tr>
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</table>

Plus three of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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</thead>
<tbody>
<tr>
<td>ECHE 481</td>
<td>Corrosion Fundamentals</td>
</tr>
<tr>
<td>ECIV 310</td>
<td>Strength of Materials</td>
</tr>
<tr>
<td>EMAE 370</td>
<td>Design of Mechanical Elements</td>
</tr>
<tr>
<td>EMSE 417</td>
<td>Properties of Materials in Extreme Environments</td>
</tr>
<tr>
<td>EMSE 421</td>
<td>Fracture of Materials</td>
</tr>
<tr>
<td>EMSE 422</td>
<td>Failure Analysis</td>
</tr>
<tr>
<td>EMSE 427</td>
<td>Defects in Solids</td>
</tr>
<tr>
<td>EMAE 480</td>
<td>Fatigue of Materials</td>
</tr>
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</table>

* Satisfies the Mathematics/Science/Statistics requirement of the Case School of Engineering.

### Materials Data Science

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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</thead>
<tbody>
<tr>
<td>STAT 312R</td>
<td>Basic Statistics for Engineering and Science Using R Programming</td>
</tr>
<tr>
<td>DSCI 351M</td>
<td>Exploratory Data Science</td>
</tr>
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</table>

Plus two of the following, of which one should be a DSCI course:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>DSCI 352M</td>
<td>Applied Data Science Research</td>
</tr>
<tr>
<td>DSCI 353M</td>
<td>Data Science: Statistical Learning, Modeling and Prediction</td>
</tr>
<tr>
<td>MATH 307</td>
<td>Linear Algebra</td>
</tr>
<tr>
<td>MATH 304</td>
<td>Discrete Mathematics</td>
</tr>
<tr>
<td>EECS 321</td>
<td>Semiconductor Electronic Devices</td>
</tr>
<tr>
<td>EECS 322</td>
<td>Integrated Circuits and Electronic Devices</td>
</tr>
</tbody>
</table>

### Advanced Materials Science and Engineering

Students may satisfy the concentration requirement by taking nine credits of courses from engineering, math, statistics, or natural sciences departments (beyond those specifically required in the curriculum) at the 300 level or above, plus a course to satisfy the Mathematics/Natural Sciences/Statistics requirement in the Engineering Core. The courses are to be selected in consultation with the student's advisor and will be subject to approval by the department's Undergraduate Studies Committee. This option is appropriate for students who desire further study in topics relevant to materials science and engineering that are not represented in the specializations listed above.

### Bachelor of Science in Engineering

#### Suggested Program of Study: Major in Materials Science and Engineering

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

#### First Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
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<tbody>
<tr>
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<table>
<thead>
<tr>
<th>Course Title</th>
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<tbody>
<tr>
<td>SAGES First year Seminar*</td>
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<tr>
<td>PHED 1xx Physical Education Activities*</td>
</tr>
<tr>
<td>Transitioning Ideas to Reality I - Materials in Service of Industry and Society (EMSE 110)</td>
</tr>
<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
</tr>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
</tr>
<tr>
<td>Elementary Computer Programming (ENGR 131)**</td>
</tr>
<tr>
<td>or Introduction to Programming in Java (EECS 132)</td>
</tr>
<tr>
<td>SAGES University Seminar I</td>
</tr>
<tr>
<td>PHED 1xx Physical Education Activities*</td>
</tr>
<tr>
<td>Calculus for Science and Engineering II (MATH 122)**</td>
</tr>
<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
</tr>
<tr>
<td>General Physics I - Mechanics (PHYS 121)**</td>
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<tr>
<td>or Physics and Frontiers I - Mechanics (PHYS 123)</td>
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<td>Transitioning Ideas to Reality II - Manufacturing Laboratory (EMSE 120)b</td>
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<td>Year Total:</td>
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#### Second Year

<table>
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</table>

<table>
<thead>
<tr>
<th>Course Title</th>
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<tbody>
<tr>
<td>SAGES University Seminar 2*</td>
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<tr>
<td>Calculus for Science and Engineering III (MATH 223)**</td>
</tr>
<tr>
<td>or Calculus III (MATH 227)</td>
</tr>
<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
</tr>
<tr>
<td>or Physics and Frontiers II - Electricity and Magnetism (PHYS 124)</td>
</tr>
<tr>
<td>Materials Properties and Design (EMSE 276)</td>
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<tr>
<td>Introduction to Polymer Science and Engineering (EMAC 270)</td>
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<tr>
<td>Professional Communication for Engineers (ENGL 398)**</td>
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<tr>
<td>Professional Communication for Engineers (ENGR 398)**</td>
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<tr>
<td>Breadth elective I**</td>
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<tr>
<td>Elementary Differential Equations (MATH 224)**</td>
</tr>
<tr>
<td>or Differential Equations (MATH 228)</td>
</tr>
<tr>
<td>Statics and Strength of Materials (ENGR 200)**</td>
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<tr>
<td>Materials Laboratory I (EMSE 220)</td>
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</table>

* Satisfies the Mathematics/Science/Statistics requirement of the Case School of Engineering.
Mathematical and Computational Methods for Materials Science and Engineering (EMSE 228)  3

Year Total:  16  17

Third Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
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<tr>
<td>Materials Laboratory II (EMSE 320)</td>
<td>1</td>
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<tr>
<td>Mesoscale Structural Control of Functional Materials (EMSE 328)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Structural Materials by Design (EMSE 372)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Concentration Ia</td>
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</tr>
<tr>
<td>Breadth elective II**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Polymer Properties and Design (EMAC 276)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Thermodynamic Stability and Rate Processes (EMSE 327)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Materials Laboratory III (EMSE 330)</td>
<td>2</td>
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<td>Concentration IIa</td>
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Fourth Year

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<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td>Senior Project in Materials I (EMSE 398)c</td>
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</tr>
<tr>
<td>Breadth elective III**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Processing of Electronic Materials (EMSE 343)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Materials for Biological and Medical Technology (EMSE 345)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Materials for Energy and Sustainability (EMSE 349)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Concentration IIIa</td>
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<td></td>
</tr>
<tr>
<td>Senior Project in Materials II (EMSE 399)c</td>
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<tr>
<td>Breadth elective IV**</td>
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<td></td>
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<tr>
<td>Processing and Manufacturing of Materials (EMSE 319)</td>
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<td></td>
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<tr>
<td>Design for Lifetime Performance (EMSE 379)</td>
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<td></td>
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<tr>
<td>Concentration IVa</td>
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<tr>
<td>Year Total:</td>
<td>16</td>
<td>14</td>
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</tbody>
</table>

Total Units in Sequence:  129

Hours required for graduation: 129

a  University general education requirement
b  Actual courses and sequence will vary depending on the concentration chosen; see "Concentrations."

Minor in Materials Science and Engineering

In addition to the Bachelor of Science in Engineering degree program with a major in Materials Science and Engineering, the department also offers a minor in Materials Science and Engineering. This sequence is intended primarily for a student majoring in science or engineering, but it is open to any student with a sound background in introductory calculus, chemistry, and physics. This program requires the completion of EMSE 276 Materials Properties and Design and a minimum of 12 additional credit hours of EMSE courses, including no more than 3 credits of EMSE 125 Freshman Research in Materials Science and Engineering and EMSE 325 Undergraduate Research in Materials Science and Engineering, and no more than 6 credits of one- or two-credit courses. Professor Mark De Guire (mark.deguire@case.edu) (510 White, 368.4221) will assist EMSE minors with course selection.

Minor in Applied Data Science

This undergraduate Minor in Applied Data Science (ADS), based in the Case School of Engineering, is available as a minor to students across CWRU. The minor is directed to students studying in the domains of Engineering and Physical Sciences (including Energy and Manufacturing, Astronomy, Geology, Physics), Health (including Translational and Clinical), and Business (including Finance, Marketing, and Economics). Successful completion of the ADS minor requirements leads to a "Minor in Applied Data Science" for the graduating student. The ADS minor represents that the students have developed knowledge of the essential
Elements of the Minor:
The minor is structured so that the students who qualify for the minor have a working understanding of the basic ADS tools and their application in their domain area. This includes:

- Data Management: datastores, sources, streams;
- Distributed Computing: local computer, distributed computing such as Hadoop or other cloud computing;
- Informatics, Ontology, Query: including search, data assembly, annotation; and
- Statistical Analytics: tools such as R statistics and high level scripting languages (such as Python).

The data types found in these domains are diverse. They include time series and spectral data for Energy and Astronomy, and sensor and production data and image and volumetric data for Manufacturing. In Health, Translational ADS includes Genomic, Proteomic and other Omics data, while Clinical ADS includes patient data, medical data, physiological time series, and mobile data. Business data types include stock and other financial market data for Finance, time series and cross section data for Economics, and operations and consumer behavior data for Marketing.

Students will develop comprehensive experience in the steps of data analysis. Can the steps be formatted as a bulleted or numbered list?

- Define the Applied Data Science questions, and
- Identify, locate, and/or generate the necessary data, including defining the ideal data set and variables of interest, determining and obtaining accessible data and cleaning the data in preparation for analysis.
- Exploratory data analysis to start identifying the significant characteristics of the data and information it contains.
- Statistical modeling and prediction, including interpretation of results, challenging results, and developing insights and actions.
- Synthesizing the results in the context of the domain and the initial questions, and writing this up.
- The creation of reproducible research, including code, datasets, documentation and reports, which are easily transferable and verifiable.

The ADS minor curriculum
The curriculum is based on five 3-credit courses, with one class chosen from each of Levels 1 through Level 5, which cover the spectrum of learning needed to achieve domain area expertise in data science and analytics. The courses are chosen to be both cross-cutting, i.e., intermixing students from across the university in the fundamental concepts such as scripting and statistics (Levels 1, 2, and 4), and domain-focused (Levels 3 and 5). For the Level 4 undergraduate research course, the research topic will be approved by the minor advisor, and will also be a 3-credit project. This will provide minor students both the domain focused learning they need, and a broadening perspective on applications, methods, and uses of ADS in other domains.

Courses Counted Toward Minor Requirements
Established courses included in the Minor are found in Case School of Engineering (Materials Science, Electrical Engineering and Computer Science, Manufacturing), College of Art & Science (Mathematics, Astronomy, Philosophy), School of Medicine, School of Nursing, and Weatherhead School of Management (Marketing, Finance, Operations, and Economics).

The courses that meet the requirements for the Minor can also be taken by students to meet requirements in Major programs, and therefore serve a dual purpose in our academic offerings. However, each program, department and school may have its own criteria on whether a given course could be "double counted" towards major and minor requirements.

Level 5:
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>BAFI 361</td>
<td>Empirical Analysis in Finance</td>
<td>3</td>
</tr>
<tr>
<td>ECON 327</td>
<td>Advanced Econometrics</td>
<td>3</td>
</tr>
<tr>
<td>MKMR 308</td>
<td>Measuring Marketing Performance</td>
<td>3</td>
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<tr>
<td>MKMR 310</td>
<td>Marketing Analytics</td>
<td>3</td>
</tr>
<tr>
<td>SYBB 459</td>
<td>Bioinformatics for Systems Biology</td>
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Level 4:
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<tr>
<td>ASTR 369</td>
<td>Undergraduate Research</td>
<td>1 - 3</td>
</tr>
<tr>
<td>DSCI 352</td>
<td>Applied Data Science Research</td>
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</tr>
<tr>
<td>EMSE 325</td>
<td>Undergraduate Research in Materials Science and Engineering</td>
<td>1 - 3</td>
</tr>
<tr>
<td>SYBB 387</td>
<td>Undergraduate Research in Systems Biology</td>
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Level 3:
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<tr>
<td>DSCI 351</td>
<td>Exploratory Data Science</td>
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<tr>
<td>MKMR 201</td>
<td>Marketing Management</td>
<td>3</td>
</tr>
<tr>
<td>SYBB 311A</td>
<td>Survey of Bioinformatics: Technologies in Bioinformatics</td>
<td>1</td>
</tr>
<tr>
<td>SYBB 311B</td>
<td>Survey of Bioinformatics: Data Integration in Bioinformatics</td>
<td>1</td>
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<tr>
<td>SYBB 311C</td>
<td>Survey of Bioinformatics: Translational Bioinformatics</td>
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<tr>
<td>SYBB 421</td>
<td>Fundamentals of Clinical Information Systems</td>
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<tr>
<td>SYBB 412</td>
<td>Survey of Bioinformatics: Programming for Bioinformatics</td>
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Level 2:
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<tr>
<td>PQHS 431</td>
<td>Statistical Methods I</td>
<td>3</td>
</tr>
<tr>
<td>OPRE 207</td>
<td>Statistics for Business and Management Science I</td>
<td>3</td>
</tr>
<tr>
<td>STAT 201R</td>
<td>Basic Statistics for Social and Life Sciences Using R Programming</td>
<td>3</td>
</tr>
<tr>
<td>STAT 312R</td>
<td>Basic Statistics for Engineering and Science Using R Programming</td>
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Level 1:
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<td>ENGR 131</td>
<td>Elementary Computer Programming</td>
<td>3</td>
</tr>
<tr>
<td>EEECS 132</td>
<td>Introduction to Programming in Java</td>
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</tr>
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The Applied Data Science Minor (p. 59) is based in the Case School of Engineering, and includes from schools across the university.
Complete list of DSCI (p. 68) courses.

**Bachelor of Science in Data Science and Analytics**

A Bachelor of Science in Data Science and Analytics (p. 68) is administered in the Electrical Engineering and Computer Science Department.

**Graduate Programs**

The Department of Materials Science and Engineering offers programs leading to the degrees of Master of Science and Doctor of Philosophy degrees. The programs address: structure-property relationships; processing methodologies; comprehensive characterization; theory, computational methods, and analytics; and engineering behavior of a broad array of materials and material systems.

**MS Degree Requirements**

The MS degree in Materials Science and Engineering is awarded through either the Master's Thesis (Plan A) or Master's Comprehensive (Plan B). Both require a total of 30 credit hours distributed between courses and independent research. Plan A involves a thesis based on individual research, totaling no fewer than 9 credit hours, with a final oral defense; this plan is appropriate for full-time graduate students. Plan B involves a major project, typically 3 credit hours and completed in a single semester, and a final comprehensive oral exam; this route is usually followed by part-time graduate students who are currently employed as materials engineers. The examining committee consists of three faculty members of the department for either Plan A or Plan B. Additional committee members may be added at the discretion of the student in consultation with his or her advisor.

The Master's Thesis (Plan A) requires successful completion of 7 courses (21 credit hours) and at least 9 credit hours of EMSE 651 Thesis M.S. The Master's Comprehensive (Plan B) requires the successful completion of 9 courses (27 credit hours) as well as 3 credit hours of EMSE 649 Special Projects.

The six courses for Plan A and the eight courses for Plan B may include a maximum of two courses from an engineering or science curriculum outside the department. No more than one course at the 300 level can be included; all other courses must be at the 400 level or higher. A cumulative GPA of 3.0 or higher is required for graduation. Students with a cumulative GPA less than 3.0 will be placed on academic probation. Transfer of credit from another university is limited to six credit hours of graduate level courses (with grade B or better) taken in excess of the student's cumulative GPA of 3.0 or higher for courses taken at Case Western Reserve University.

A Planned Program of Study (PPOS) must be submitted by the end of the second semester for Plan A and for Plan B students. The PPOS should be prepared by the student and his/her advisor and submitted online to the School of Graduate Studies.

**Accelerated, 1-Year MS in Materials Science and Engineering with a Focus on Data Science**

Materials science and engineering is a discipline that extends from the basic science of materials micro-structure and properties to the design and evaluation of materials in engineering systems. Data science and analytics seek to identify statistically significant relationships, model development, and predictive behavior of large data sets generated by e.g. manufacturing technologies. This suggested course of study, which extends classical education in materials science and engineering with data science and analytics, can be completed in one calendar year.

The Department of Materials Science and Engineering (DMSE) at Case Western Reserve University (CWRU) is a research-centered educational environment whose mission is to enhance the productivity, quality, and benefit of materials-related learning to its students, faculty, and community. DMSE bears a commitment to the improvement of materials technology, DMSE is equipped with state-of-the-art facilities for mechanical characterization as well as micro-characterization of materials (conventional and advanced methods of electron microscopy and spatially resolved surface analysis). The synergy of these facilities and applying them to a broad spectrum of cutting-edge materials research consistently thrust us among the top tiers of materials research institutions in the nation.

The suggested course program of study includes ten (10) courses taken over three semesters: Fall Semester, Spring Semester and Summer Semester.

- **Fall Semester:** EMSE 504 Thermodynamics of Solids, EMSE 503 Structure of Materials, EMSE 413 Fundamentals of Materials Engineering and Science, and EMSE 599 Materials Science and Engineering Colloquium for either 1 or 2 credit hours.

- **Spring Semester:** EMSE 505 Phase Transformations, Kinetics, and Microstructure, EMSE 417 Properties of Materials in Extreme Environments, EMSE 435 Strategic Metals and Materials for the 21st Century, DSCI 453 Data Science: Statistical Learning, Modeling and Prediction, and EMSE 599 Materials Science and Engineering Colloquium for either 1 or 2 credit hours, adding up to a total of 3 credit hours of EMSE 599.

- **Summer Semester:** DSCI 452 Applied Data Science Research, and EMSE 515 Analytical Methods in Materials Science.

The 3 credit hours of EMSE 599 can be replaced by an additional course of 3 credit hours, e.g. EMSE 468 Scientific Writing in Materials Science and Engineering.

**PhD Degree Requirements**

Immediately upon entering the department, the PhD candidate normally will:

- Fill out and submit the first part of the Planned Program of Study (PPOS) & Supplementary Form
- Register for 2 classes during the first semester
- Register for EMSE 701 Dissertation Ph.D. (usually 3 credit hours) during the first semester. Note that registration for EMSE 701 is not permitted before the Planned Program of Study form is turned in.

As specified in the University General Bulletin section of the School of Graduate Studies: “In order to meet the requirements for the doctorate, a student must pass satisfactorily a general examination (or a series of examinations covering different fields) specified and administered by the student’s department or supervising committee.”

Candidates for a PhD degree in Materials Science and Engineering must pass a two-part General Exam. The first part is a Comprehensive Exam and the second part is a Thesis Proposal Evaluation. A cumulative GPA of 3.0 or higher is required to take the Comprehensive Exam.

**PhD Comprehensive Exam**

Full-time students entering with an MS degree are required to take the PhD Comprehensive Exam within one year. Full-time students entering with a BS degree must take the PhD Comprehensive Exam within two
years of entering the PhD program. Part-time students must complete the exam prior to accumulating ten or more credit hours. The exam will be offered twice per year at roughly six-month intervals, typically in January and June. The exam will consist of a written test covering specific areas of materials science and engineering.

The exam has multi-part questions that cover the following four areas:

1. EMSE 503 Structure of Materials
2. EMSE 504 Thermodynamics of Solids
3. EMSE 505 Phase Transformations, Kinetics, and Microstructure
4. A Synthesis Area, which combines concepts from the first three areas as they apply to performance of materials

Students who achieve a score of 70 or above on three of the completed questions and an overall average of 75 or above will pass outright. Students who do not achieve this on their first attempt of the written exam will have one more opportunity to take the Comprehensive Exam the next time the department offers it.

**Thesis Proposal Evaluation**

The Thesis Proposal Evaluation must occur in the semester immediately following the successful completion of the PhD Comprehensive Exam unless a petition, supported by their research advisor, is approved by the graduate studies committee. The Thesis Proposal Evaluation tests the more specific knowledge of the PhD candidate concerning the science underlying the proposed research and the candidate’s intellectual maturity. It is composed of a written and an oral evaluation, both dealing with the candidate’s proposed research project and specialized courses taken in support of their research program. Both should include a literature search, analysis of the research problem, suggested research procedures, and the general results to be expected. The student’s dissertation advisory committee will examine the document for this purpose. The written document must be submitted to the student’s dissertation advisory committee at least one week prior to the oral evaluation. Both parts of the Thesis Proposal Evaluation will be graded Pass/Fail.

Upon passing both the Comprehensive Exam and the Thesis Proposal Evaluation, a student will advance to PhD Candidacy.

**PhD Program of Study (Course Requirements)**

A PhD student must take a minimum of 18 credit hours of EMSE 701 Dissertation Ph.D. and must continue registration each subsequent regular semester (Fall and Spring) until the dissertation is complete, unless granted a leave of absence. The time limit for the PhD program is 5 years for full-time students, starting with the first semester of EMSE 701 Dissertation Ph.D. registration.

The minimum course requirement for a PhD degree is 12 courses (36 credit hours) beyond the BS level, out of which at least 6 courses (18 credit hours) must be taken at Case Western Reserve University. Of these 12 courses, 4 courses must satisfy the Breadth Requirement and 2 courses must satisfy the Basic Science Requirement for the department as outlined below. In the case of a student entering with a MS degree from another discipline, additional courses may be required at the discretion of the student’s academic advisor. A GPA of 3.0 is required for graduation. Students with a cumulative GPA below 3.0 will be placed on academic probation.

**MSE Core Sequence:** The Materials Science and Engineering Core sequence consists of:

- EMSE 503 Structure of Materials
- EMSE 504 Thermodynamics of Solids
- EMSE 505 Phase Transformations, Kinetics, and Microstructure

The Core is a required part of the Program of Study for all PhD students. Transfer credit for comparable graduate courses taken at another institution will be allowed on a case-by-case basis. Students may find it helpful to complete the core sequence prior to taking the PhD comprehensive exam.

**Breadth Requirement:**

The Breadth Requirement for the PhD can be fulfilled by taking a total of 4 courses (12 credit hours) within the Case School of Engineering selected in consultation with the student’s advisor.

**Basic Science Requirements:**

A minimum depth in basic science of 2 courses (6 credit hours) is required for a PhD degree. This requirement can be fulfilled by taking 2 courses at the 400 or 500 level selected from Physics, Chemistry, Biology, Mathematics and/or Statistics, and/or certain engineering curricula approved by the department Graduate Studies Committee. Engineering courses used to meet this requirement must be approved prior to enrolling in the course (the deadline being the conclusion of add/drop in any given semester). Students making such a request are required to submit a petition to the department Graduate Studies Committee that justifies the role of the stipulated course as basic, rather than applied, science. Such petitions are expected to be brief. Courses that are not approved as meeting the basic science requirement may be applicable to the breadth requirement.

The **PPOS**, a list of the courses the student will take to fulfill the PhD requirements, will be discussed and updated if needed at the time of the Thesis Proposal Evaluation.

Upon successful completion of all requirements and research, the PhD candidate must submit a written dissertation as evidence for their ability to conduct independent research at an advanced level. The PhD candidate must pass a final oral exam in defense of the dissertation. The dissertation committee must consist of at least three faculty members from the department and one non-departmental member. The candidate must provide each committee member with a copy of the completed dissertation at least 10 days before the exam, so that the committee members may have an opportunity to read and discuss it in advance.

**Facilities**

**Materials Processing**

The department’s processing laboratories include facilities which permit materials processing from the liquid state (casting) as well as in the solid state (powder processing). The department has its own foundry that houses mold making capabilities (green and bonded sand, permanent mold, and investment casting), induction melting furnaces of various capabilities for air melting of up to 1500 pounds of steel, electrical resistance furnaces for melting and casting up to 800 pounds of aluminum, and 500 pounds of magnesium under protective atmosphere, a dual chamber vacuum induction melting unit with a capacity of up to 30 pounds of superalloys, a 350 ton squeeze casting press, and state-of-the-art thermal fatigue testing and characterization equipment. The Crystal Growth Laboratory has facilities for production of high purity electronic single crystals using a variety of furnaces with the additional capability of solidifying under large magnetic fields. In addition, a CVD
and MOCVD reactor has been set up to do research on the growth of SiC and GaN on Si, sapphire, and other substrates. Secondary processing and working can be accomplished using a high-speed hot and cold rolling mill, swaging units, and a state-of-the-art hydrostatic extrusion press. The department has heat treatment capabilities including numerous box, tube, and vacuum furnaces. For the processing of powder, metals, or ceramics the department possesses a 300,000 pound press, a vacuum hot press (with capabilities of up to 7 ksi and 2300 C), a hot isostatic press (2000 C and 30 ksi), a 60 ksi wet base isostatic press, and glove boxes. Sintering can be performed in a variety of controlled atmospheres while a microcomputer-controlled precision dilatometer is available for sintering studies. Several ball mills, shaker mills, and a laboratory model attritor are also available for powder processing. In addition, facilities are available for sol-gel processing, glass melting, and diamond machining; a spray dryer is available for powder granulation.

A Deformation Processing Laboratory has recently been commissioned that contains two dual hydraulic MTS presses. The first press is designed to evaluate the stretching and drawing properties of materials in sheet form. Its maximum punch and hold down forces are 150,000 each. Its maximum punch velocity is 11.8 inch/sec. The second press is designed to evaluate the plastic flow behavior of materials in an environment that simulates modern manufacturing processing. The press can deliver up to five consecutive impacts to a material in less than five seconds with a punch velocity as high as 110 inch/sec. The maximum punch force is 110,000 pounds.

Advanced Manufacturing and Mechanical Reliability Center (AMMRC)

The Advanced Manufacturing and Mechanical Reliability Center (AMMRC) permits the determination of mechanical behavior of materials under loading rates ranging from static to impact, with the capability of testing under a variety of stress states under either monotonic or cyclic conditions. A variety of furnaces and environmental chambers are available to enable testing at temperatures ranging from -196 C to 1800 C. The facility is operated under the direction of a faculty member and under the guidance of a full-time engineer. The facility contains one of the few laboratories in the world for high-pressure deformation and processing, enabling experimentation under a variety of stress states and temperatures. The equipment in this state-of-the-art facility includes:

**High Pressure Deformation Apparatus**: These units enable tension or compression testing to be conducted under conditions of high hydrostatic pressure. Each apparatus consists of a pressure vessel and diagnostics for measurement of load and strain on deforming specimens, as well as instantaneous pressure in the vessel. Pressures up to 1.0 GPa loads up to 10 kN, and displacements of up to 25 mm are possible. The oil based apparatus is operated at temperatures up to 300°C room temperature while a gas (i.e. Ar) based apparatus is used at room temperature.

**Hydrostatic Extrusion Apparatus**: Hydrostatic extrusion (e.g. pressure-to-air, pressure-to-pressure) can be conducted at temperatures up to 300 C on manually operated equipment interfaced with a computer data acquisition package. Pressures up to 2.0 GPa are possible, with reduction ratios up to 6 to 1, while various diagnostics provide real time monitoring of extrusion pressure and ram displacement.

**Advanced Forging Simulation Rig**: A multi-actuator: MTS machine based on a 330 kip, four post frame, enables sub-scale forging simulations over industrially relevant strain rates. A 110 kip forging actuator is powered by five nitrogen accumulators enabling loading rates up to 120 inches/sec on large specimens. A 220 kip indexing actuator provides precise deformation sequences for either single, or multiple, deformation sequences. Date acquisition at rates sufficient for analysis is available. Testing with heated dies is possible.

**Advanced Metal Forming Rig**: A four post frame with separate control of punch actuator speed and blank hold down pressure enables determination of forming limit diagrams. Dynamic control of blank hold down pressure is possible, with maximum punch actuator speeds of 11.8 inches/sec. A variety of die sets are available.

The remainder of the equipment in the AMMRC is summarized below:

**Servo-hydraulic Machines**: Four MTS Model 810 computer-controlled machines with load capacities of 3 kip, 20 kip, 50 kip, and 50 kip, permit tension, compression, and fatigue studies to be conducted under load-, strain-, or stroke control. Fatigue crack growth may be monitored via a dc potential drop technique as well as via KRAK gages applied to the specimen surfaces. Fatigue studies may be conducted at frequencies up to 30 Hz. In addition, an Instron Model 1331 20 kip Servo-hydraulic machine are available for both quasi-state and cyclic testing.

**Universal Testing Machines**: Three INSTRON screw-driven machines, including two INSTRON Model 1125 units permit tension, compression, and torsion testing.

**Electromechanical Testing Machine**: A computer-controlled INSTRON Model 1361 can be operated under load-, strain-, or stroke control. Stroke rates as slow as 1 micrometer/hour are possible.

**Fatigue Testing Machines**: Three Sonntag fatigue machines and two R. R. Moore rotating-bending fatigue machines are available for producing fatigue-life (S-N) data. The Sonntag machines may be operated at frequencies up to 60 Hz.

**Creep Testing Machines**: Three constant load frames with temperature capabilities up to 800 C permit creep testing, while recently modified creep frames permit thermal cycling experiments as well as slow cyclic creep experiments.

**Impact Testing Machines**: Two Charpy impact machines with capacities ranging from 20 ft-lbs to 240 ft-lbs are available. Accessories include a Dynatup instrumentation package interfaced with an IBM PC, which enables recording of load vs. time traces on bend specimens as well as on tension specimens tested under impact conditions.

**Instrumented Microhardness Tester**: A Nikon Model QM High-Temperature Microhardness Tester permits indentation studies on specimens tested at temperatures ranging from -196 C to 1600 C under vacuum and inert gas atmospheres. This unit is complemented by a Zwick Model 3212 Microhardness Tester as well as a variety of Rockwell Hardness and Brinell Hardness Testing Machines.

**The Swagelok Center for Surface Analysis of Materials (SCSAM)**

The Swagelok Center for Surface Analysis of Materials (SCSAM) is a multi-user facility providing cutting-edge major instrumentation for microcharacterization of materials. SCSAM's instruments encompass a wide and complementary range of characterization techniques, which provide a comprehensive resource for high-resolution imaging, diffractometry, and spatially-resolved compositional analysis.

Current capabilities for SEM (scanning electron microscopy) include four scanning electron microscopes, three of which are equipped for FIB (focused ion beam) micromachining, XEDS (X-ray energy-dispersive
techniques include the following: grain boundaries, stacking faults) in crystalline materials. Advanced TEM to analyze line defects (dislocations) and planar defects (interfaces, electron diffraction, or weak-beam dark-field imaging are used routinely. Conventional TEM techniques, such as bright-field and dark-field imaging, for grain-orientation mapping and related techniques.

Energy-loss spectrometry) with an energy resolution down to below 1 eV. The enabling technologies, integrated onto a single platform, further include high-volume milling capabilities, an ESEM differential-pumping variable-pressure vacuum system (oil-free), gaseous secondary and backscattered electron detectors for imaging and analysis in a gaseous chamber environment, a high-precision specimen goniometer with 50 mm travel along the x- and y-axis, and automation serving unattended sectioning with full access to e-beam, i-beam, and patterning.

• High-resolution TEM. This technique enables imaging the projected atomistic structure of extended crystal defects, such as heterophase interfaces, grain boundaries, or dislocations.

• CBED (convergent-beam electron diffraction). This technique can be used to obtain crystallographic information (space group) and to determine orientation relationships between small (even nanoscopic) crystallites.

• EFTEM (energy-filtering TEM). This denotes a suite of techniques enabled by an imaging energy filter. In particular, the techniques include zero (energy)-loss filtering for improved contrast in images and diffraction patterns and ESI (electron spectroscopic imaging), a technique that enables rapid elemental mapping with high spatial resolution based on element-characteristic energy losses of the primary electrons in the specimen. Specimen preparation facilities for TEM, in addition to the FIB systems described above, consist of two dimple-grinders, two electropolishing units, two state-of-the-art PIPS (precision ion polishing systems) by Gatan, and a Fischione NanoMill 1040 for highest-quality specimens by post-processing of FIB-prepared foils.

SCSAM is administered directly by the CSE (Case School of Engineering) and is central to much of the research carried out by CSE’s seven departments. However, the facility is also extensively used by the CAS (College of Arts and Sciences) Departments of Physics, Chemistry, Biology, and Earth, Environmental, and Planetary Sciences, as well as many departments within the School of Medicine and the School of Dental Medicine. In addition to CWRU clients, many external institutions utilize SCSAM’s facilities, including NASA Glenn Research Center, the Cleveland Clinic, and numerous Ohio universities. More than 250 users utilize the facility in any given year.

SCSAM’s instruments are housed in a centralized area, allowing users convenient access to state-of-the-art tools for their research.

Transmission Electron Microscopy Laboratory

A transmission electron microscope is available that provides virtually all conventional and advanced microscopy techniques required for state-of-the-art materials research and involves an installed capacity worth $2,500,000. The FEI Tecnai F30 300 kV field-emission gun energy-filtering high-resolution analytical and imaging scanning transmission electron microscope has a point resolution below 0.20 nm and an information resolution limit of 0.14 nm. The instrument is equipped with an EDAX system with a high-energy resolution Si-Li detector for XEDS (X-ray energy-dispersive spectrometry), a HAADF (high-angle annular dark-field) detector for STEM (scanning transmission electron microscopy), and a Gatan GIF 2002 imaging energy filter including a 2 k-by-2 k pixel slow-scan CCD camera. The GIF in conjunction with the field-emission gun enable EELS (electron energy-loss spectrometry) with an energy resolution down to below 1 eV. Further, the instrument is equipped with a NanoMegas TopSpin system for grain-orientation mapping and related techniques.

Conventional TEM techniques, such as bright-field and dark-field imaging, electron diffraction, or weak-beam dark-field imaging are used routinely to analyze line defects (dislocations) and planar defects (interfaces, grain boundaries, stacking faults) in crystalline materials. Advanced TEM techniques include the following:

• The xT Nova Nanolab 200 (FEI), a dual-beam system providing a FIB (focused ion beam) and a scanning electron beam. The focused ion beam is used for preparing thin foils suitable for TEM directly out of the specimen surface. At the same time, enabled by the scanning electron beam, this instrument includes a complete and very-high-quality scanning electron microscope. This construction has the advantage that the specimen can be observed by (high-resolution) SEM while being milled by the ion beam. Moreover, the Nova includes an internal "lift-out-" system for transferring the thin film generated by ion-beam milling onto a special Cu support grid, which can then be loaded into the specimen holder of a TEM. For elemental and crystallographic analysis, the system is equipped with a state-of-the-art Oxford AZtec system with a X-max 50mm² detector and a NORDLYS EBSP camera. EBSD mapping of phase and orientation relies on evaluating EBSP patterns of every scan point and can be run on bulk materials and in transmission mode on TEM samples.

• The FEI Quanta 200 3D. This is a versatile low-vacuum SEM/FIB for 2D and 3D material characterization and analysis. It features three imaging modes: high-vacuum, low-vacuum, and ESEM, and can accommodate a wide range of samples. The instrument is equipped with a field-emission Ga ion source and a thermal electron emitter. The enabling technologies, integrated onto a single platform, further include high-volume milling capabilities, an ESEM differential-pumping variable-pressure vacuum system (oil-free), gaseous secondary and backscattered electron detectors for imaging and analysis in a gaseous chamber environment, a high-precision specimen goniometer with 50 mm travel along the x- and y-axis, and automation serving unattended sectioning with full access to e-beam, i-beam, and patterning.

Scanning Electron Microscopy Laboratory

SEM (scanning electron microscopy) provides valuable specimen information by enabling imaging with particularly great depth of field and stereo-imaging with resolutions down to the nanometer range. The topography of nearly any solid surface is possible with SEM. Spectrochemical studies are enabled by XEDS (X-ray energy-dispersive spectrometry) systems capable of detecting elements from boron to uranium. The laboratory houses the following instruments:

• The xT Nova Nanolab 200 (FEI), a dual-beam system providing a FIB (focused ion beam) and a scanning electron beam. The focused ion beam is used for preparing thin foils suitable for TEM directly out of the specimen surface. At the same time, enabled by the scanning electron beam, this instrument includes a complete and very-high-quality scanning electron microscope. This construction has the advantage that the specimen can be observed by (high-resolution) SEM while being milled by the ion beam. Moreover, the Nova includes an internal "lift-out-" system for transferring the thin film generated by ion-beam milling onto a special Cu support grid, which can then be loaded into the specimen holder of a TEM. For elemental and crystallographic analysis, the system is equipped with a state-of-the-art Oxford AZtec system with a X-max 50mm² detector and a NORDLYS EBSP camera. EBSD mapping of phase and orientation relies on evaluating EBSP patterns of every scan point and can be run on bulk materials and in transmission mode on TEM samples.

• The FEI Quanta 200 3D. This is a versatile low-vacuum SEM/FIB for 2D and 3D material characterization and analysis. It features three imaging modes: high-vacuum, low-vacuum, and ESEM, and can accommodate a wide range of samples. The instrument is equipped with a field-emission Ga ion source and a thermal electron emitter. The enabling technologies, integrated onto a single platform, further include high-volume milling capabilities, an ESEM differential-pumping variable-pressure vacuum system (oil-free), gaseous secondary and backscattered electron detectors for imaging and analysis in a gaseous chamber environment, a high-precision specimen goniometer with 50 mm travel along the x- and y-axis, and automation serving unattended sectioning with full access to e-beam, i-beam, and patterning.
A Helios NanoLab™ 650, features FEI’s most recent advances in field-emission SEM and FIB (focused ion beam) technologies and their combined use. It is designed to access a “new world” of extremely high-resolution 2D and 3D characterization, 3D nanoprotyping, and higher quality TEM sample preparation. The Helios’s capability of robust and precise FIB slicing, combined with a high-precision piezo stage (150 x 150 mm2), superb SEM performance, and advanced software allow unattended sample preparation or 3D characterization and analysis. The outstanding imaging capabilities of the Helios NanoLab begin with its Elstar™ FESEM. Thanks to its integrated monochromator (UC) and beam deceleration, it delivers sub-nanometer resolution across the whole 1-30 kV range. The Elstar features other unique technologies such as constant power lenses for higher thermal stability and electrostatic scanning for higher deflection linearity and speed. Its through-the-lens detector, set for highest collection efficiency of SE (secondary electrons) and on-axis BSE (backscattered electrons), is complemented by FEI’s advanced detection suite including three novel detectors: two multi-segment solid state detectors: CBS retractable detector for backscattered electron imaging able to detect low kV BSE, a scanning transmission electron mode retractable detector able to record simultaneously BF, DF and HAADF images, and a third dedicated to FIB/SE and -SI (secondary ion) imaging. The Helios system is equipped with a state-of-the-art XEDS X-Max 80 mm2 silicon drift detector (SDD) system by Oxford with an energy resolution of 125 eV at Mn Ka (5.899 keV) at full width at half maximum. The extremely large active area significantly increases the collection solid angle. This results in a detector that performs measurements either more quickly at conditions at which traditional systems would be used or at higher energy resolution. The increased sensitivity allows the system to operate at much lower beam currents. This reduces the risk of sample damage.

Surface Science Laboratories

SCSAM’s tools for surface science include three instruments for surface analysis in UHV (ultra-high vacuum), two scanning probe systems, and a dedicated nanoindenter, all detailed below:

- A PHI 680 scanning Auger electron microscope. This system consists of a field-emission scanning electron microscope with a Schottky emission cathode, a secondary electron detector, and an axial cylindrical mirror analyzer with a multi-channel detector to collect Auger electrons produced during electron imaging. Very small spot sizes can be realized with this instrument, down to 7 nm. This is useful for high-resolution imaging and for Auger data acquisition using low beam currents. Inert gas sputtering (using a PHI 06-350 ion gun) is used to clean surface contamination from samples and to remove material from a small area on the surface for depth profiling. Several modes of operation are available to the user, including survey, line, profile, and elemental mapping. Capable of multi-point analysis, the instrument is a powerful tool for routine failure analysis and quality control of inorganic samples. An additional device permits in situ fracture of samples, at liquid nitrogen temperature, if necessary.

- A PHI VersaProbe XPS Microprobe. Based on XPS (X-ray photoelectron spectrometry, also known as ESCA – electron spectrometry for chemical analysis), this is a multi-technique surface analysis instrument based on PHI’s highly developed scanning X-ray microprobe technology. The most important advantage of this instrument is that the VersaProbe can produce a focused, highly monochromatic X-ray beam that can be scanned over the specimen surface. In this instrument, a point source of X-rays is created by focusing an electron beam onto an Al anode. A monochromator, consisting of an ellipsoid-shaped crystal, collects X-rays from the point source and focuses them on the surface of the specimen. The focused X-ray beam can be scanned across the specimen surface by correspondingly scanning the electron beam across the surface of aluminum anode. A major advantage of this design is that most of the photoelectrons generated by the focused X-ray beam are actually collected by the electron energy analyzer, whereas in the conventional design, most of the photoelectrons are lost. With the VersaProbe, the spot size can be varied between less than 10 µm diameter (for highest spatial resolution) to 100 µm (for highest sensitivity).

- A TRIFT V nanoTOF made by PHI. This is a time-of-flight secondary-ion mass spectrometer. This instrument is from the latest generation of PHI’s surface analysis line of ToF-SIMS instruments, utilizing a newly developed, high-quality “TRIFT” analyzer. It is equipped with a Au-, a C60-, and an Ar gun. An innovative new sample handling platform enables analysis of samples with complex geometries. In addition, the system has state-of-the-art charge compensation and ion gun performance.

ToF-SIMS (time-of-flight secondary-ion mass spectrometry) provides sub-micrometer 3D (!) elemental mapping. It can also be used to image the topography of solid surfaces. Different from D-SIMS (“dynamic” SIMS), ToF-SIMS enables analyzing the outermost one or two mono-layers of a sample while basically preserving molecular integrity. While D-SIMS provides primarily elemental information, ToF-SIMS surface analysis yields chemical and molecular information. ToF-SIMS is ideal for both organic and inorganic materials and can be used to characterize both insulating and conductive samples. With detection limits in the ppm to ppb range, shallow depth profiling capabilities, and automated analysis, the nanoTOF can be used to study surface contamination, trace impurities, films, delamination failures etc. It is also a valuable tool to investigate surface modification chemistry and catalyst surface composition.

- A Dimension 3100 (Veeco Digital Instruments). This is a state-of-the-art multi-mode scanning probe microscope (SPM), equipped with a NanoScope IIIa controller and Quadrex signal processor for 16-bit resolution on all 3 axes. The tool works under atmospheric pressure at room temperature and can work in air and in liquids so that a full range of materials (metals, insulators, ceramics, polymers, and biological specimens) can be investigated with minimal sample preparation. It can accept samples up to 20 cm in diameter, with a height limitation of < 1.5 cm and a surface roughness limitation of < 5.5 mm. The instrument is equipped with an in-line optical zoom microscope with color CCD camera, with a maximum magnification of 800X for precise placement of the SPM probe onto the sample. The Dimension 3100 can operate in numerous imaging modes, the primary operation being atomic force microscopy (AFM) in contact mode, tapping mode, and phase imaging mode. Other data collection techniques include conductive-AFM to characterize conductivity variations, magnetic force microscopy, which uses a ferromagnetic-coated tip to probe magnetic fields, and force-distance measurements, which are performed to study attractive and repulsive forces on a tip as it approaches and retracts from the sample surface. Further, the Dimension 3100 SPM has been upgraded by a “TriboScope,” an attachment for nanomechanical testing, made by Hysitron. The TriboScope is a quantitative, depth-sensing nanoindentation and nanoscratch system that interfaces with the SPM. This attachment enables quantitative characterization.
of mechanical properties (hardness, scratch resistance, wear resistance) on the nanometer length scale and in situ AFM imaging of the surface topography before and after mechanical testing. The capability of in situ imaging allows the user to choose the exact area, with sub-nm precision, for each nanoindentation/nanoscratch investigation, and to fully characterize the local specimen surface.

- An RHK 7500 UHV VT. This system includes a variable-temperature ultra-high vacuum scanning probe microscope, made by RHK Technologies. This instrument is part of a complete UHV (ultra-high vacuum) system, which includes a separately pumped specimen preparation chamber and a load-lock chamber in addition to the actual SPM (scanning probe microscopy) chamber. The base pressure of the system is specified to $2 \times 10^{-12}$ Pa. In the preparation chamber, an electron gun combined with a hemispherical electron energy analyzer is attached to enable chemical analysis of the specimen surface via AES (Auger electron spectroscopy). A specimen manipulator installed on the vertical axis of the chamber allows precise positioning of the specimen in front of the electron energy analyzer. The manipulator can be connected to a cryostat via a differentially-pumped rotary stage, permitting cooling the specimen down to 25 K. By resistive or electron-beam heating, it will also be possible to heat the specimen up to temperatures of 1500 K.

To be able to clean the specimen surface, the system includes an Ar sputter gun. Evaporators installed at ports in the lower half of the chamber enable the deposition of metals onto the specimen surface. A gas dosing system facilitates gas adsorption experiments without backfilling the entire chamber or opening the main chamber to change gases. A mass spectrometer constantly detects and analyzes residual gas in the chamber. Finally, the preparation chamber includes a port large enough for a retractable reverse view LEED (low-energy electron diffraction) system for studying the surface structure of the specimen.

Using a magnetic transfer arm, the specimen can be moved from the preparation chamber into the actual SPM chamber. This chamber houses a cantilever atomic force microscope combined with a scanning tunneling microscope, suitable to image the surface structure of conducting as well as non-conducting materials. Both instruments are capable of atomic-resolution imaging. The scanning tunneling microscope also permits probing the local work function and the local density of states in the specimen surface by STS (scanning tunneling spectroscopy). All modes of SPM will work over a very broad range of specimen temperatures: 25 to 750 K. The SPM chamber accepts thermal evaporators, a sputter gun and a gas dosing system that can perform their functions while the sample is actively being studied by any of the available scanning probe techniques.

- An Agilent Nano Indenter G200. This is a very accurate, flexible, user-friendly instrument for nanomechanical testing. Electromagnetic actuation allows unparalleled dynamic range in force and displacement and measurement of deformation over six orders of magnitude (from nanometers to millimeters). Potential applications include a wide scope of materials, e.g. semiconductors, films, MEMs (wafer applications), coatings and DLC films, composite materials, fibers, polymers, metals, ceramics, and biomaterials.

### X-Ray Diffractometry Laboratory

The XRD (X-ray diffractometry) laboratory contains equipment for studying the atomicistic structures of mainly crystalline inorganic materials. Three instruments are available:

- A Scintag X1 diffractometer system. This includes a theta/theta wide-angle goniometer, a 4.0 kW X-ray generator with Cu tube, a third axis stress attachment, a thermoelectrically cooled Peltier Ge detector, a film analysis system, a dedicated PC for data acquisition, and a turbomolecular-pump evacuated furnace attachment permitting sample temperatures up to 1700 K.

- A Bruker Discover D8 X-ray diffractometer. This instrument has a monochromated X-ray source (normally used with a Co-Kα X-ray tube), configured in point-focus mode. X-ray collimators are available for spot sizes from 200 μm to 800 μm, with 500 μm typical. The instrument includes a four-circle Huber goniometer equipped with an xyz stage and a laser video system to allow precision alignment of samples. Enabled by the small spot size of the incident X-ray beam and the precision alignment, small samples sizes can be evaluated and the instrument achieves much higher spatial resolution than conventional X-ray diffractometers. The 2D solid-state detector (VANTEC-500) allows a wide range of XRD techniques to be executed in short time. The detector has high sensitivity and is useful for detecting trace phases that might be missed by a conventional diffractometer. In addition, the detector allows rapid measurements of both stress and texture in a wide variety of materials. Software includes Diffrac.EVA for phase identification with the ICDD database and Diffrac.LEPTOS for stress measurement.

- The Rigaku D/Max 2200 Powder X-ray Diffractometer is equipped with a horizontal goniometer, capable of performing typical 8–28 scans. The scanning speed can be varied from 0.002 °/min to 100 °/min. The divergence, scattering, and receiving slits are fully automated and controlled through a graphical user interface within the software. The D/Max 2200 complements SCSM's two other XRD units as it is equipped with a Cr anode. The wavelength of Cr-Kα X-rays (0.229 nm) is suitable for steel alloys that exhibit heavy fluorescence with Cu-Kα X-rays (0.154 nm). In addition, the larger wavelength is preferred when trying to determine small changes in the lattice parameters, as peaks are shifted to higher 28 values, which provide greater sensitivity to small changes in the lattice parameter. The sensitivity of the peak shift is ideal for measuring residual stress and determining solvus curves in binary phase diagrams.

### Electronic Properties Laboratory

#### Crystal Growth and Analysis Laboratory

The Crystal Growth and Analysis Laboratory is equipped for research studies and characterization of bulk semiconductor and photonic materials. The growth facilities include a high pressure Czochralski system, low pressure Czochralski system, and a Vertical Bridgman system with magnetic field stabilization. The characterization facilities include capabilities for sample preparation, a Hall effect system, and an Infrared microscope.

### Magnetometry Laboratory

The Magnetometry Laboratory has facilities used to investigate the magnetic properties of materials. This laboratory has two instruments:

- A Lake Shore Cryotronics Model 7410 Vibrating Sample Magnetometer for measurement of hysteresis loops (at constant temperature) and thermomagnetic measurements (at constant magnetic field). The maximum applied field at room temperature
(without furnace in place) is 3.1 Tesla. For high temperature measurements, the maximum applied field is 2.5 Tesla over the temperature range from room temperature to 1000°C.

- A home-built magnetostriction measurement system has been designed and built to measure the shape change of magnetic materials under applied magnetic fields. Better than 1 ppm sensitivity is possible by this strain gage technique. An applied field of ~0.2 Tesla is used to saturate samples.

**Fuel Cell Testing Laboratory**

Facilities (located in the A. W. Smith Building) for testing of solid oxide fuel cells include:

- 2 test stands for 4” cells and small stacks (Fuel Cell Technologies); test temperatures to 1000°C; professional turnkey LabView interface for system control and data acquisition
- 2 test stands for 1” cells; test temperatures to 1000°C; LabView interface for complete system control and data acquisition; Omega mass flow controllers; Keithley and Amrel electronics; AutoLab Electrochemical Analyzer for I-V, galvanostatic or amperometric testing and AC impedance spectroscopy
- All test stands contained in dedicated enclosures rated for use with hydrogen, hydrogen sulfide, and carbon monoxide with ventilation system, leak detection, tank pressure monitors, alarm system
- Dedicated furnaces and ovens for preparing cells for testing

**SDLE Research Center**

The SDLE Research Center was established in 2011 with funding from Ohio Third Frontier, and is dedicated to advancing the field of lifetime and degradation science. The research center activities focus on durability and degradation of environmentally exposed, long lived materials and technologies such as photovoltaics (PV), energy efficient lighting, and building envelope applications. The Center develops real-time and accelerated protocols for exposure to solar radiation and related environmental stressors to enable the evaluation of the environmental durability and lifetime of materials, components, and products. Data scientists identify statistically significant relationships using a data analytics platform (Energy-CRADLE) developed in the center. Researchers perform post-exposure optical and thermo-mechanical measurements to develop quantitative mechanistic models of degradation processes. The SDLE Research Center’s capabilities and equipment include:

- Outdoor solar exposures: SunFarm with 14 dual-axis solar trackers with multi-sun concentrators, and power degradation monitoring
- Solar simulators for 1-1000X solar exposures
- Multi-factor environmental test chambers with temperature, humidity, freeze/thaw, and cycling
- A full suite of optical, interfacial, thermo-mechanical and electrical evaluation tools for materials, components, and systems

**The Wind Energy Research and Commercialization (WERC) Center**

The WERC Center is a multidisciplinary center for use by students, faculty, and industry providing instrumentation for wind resource characterization and research platforms in operating wind turbines. The WERC Center was established in 2010 with funding from the Ohio Department of Development Third Frontier Wright Project and the Department of Energy. Additional support was provided by the following inaugural industrial partners: Cleveland Electric Laboratories, The Lubrizol Corporation, Parker Hannifin Corporation, Azure Energy LLC, Rockwell Automation, Inc., Swiger Coil Systems LLC, and Wm. Sopko & Sons Co.

The instruments in the WERC Center include:

- A continuous scan ZephIR LiDAR, manufactured by Natural Power. This instrument measures horizontal and vertical wind velocity along with wind direction at 1 Hz frequency at five user set heights up to 200 m.
- Five meteorological measurement systems: 3 on campus; 1 with the off campus wind turbines; and one at the City of Cleveland’s water intake crib located 3.5 miles offshore in Lake Erie.
- An ice thickness sensor that is deployed at the bottom of Lake Erie each fall and retrieved in the spring.
- A NorthWind 100 wind turbine manufactured by Northern Power Systems in Barre, VT USA. This 100kW community scale wind turbine has a direct drive generator with full power inverters, stall control blades with a 21 m rotor diameter, and a 37 m hub height. This wind turbine is located on campus just east of Van Horn field and began operation in November 2010.
- A Vestas V-27 wind turbine originally manufactured by Vestas in Denmark. This 225kW medium scale wind turbine has a gearbox drive generator, pitch controlled blades with a 27 m rotor diameter, and a 30 m hub height. In addition, it has a 50kW generator for low wind generation. This wind turbine is located at an industrial site just east of Van Horn field and began operation in March 2012.
- A Nordex N-54 wind turbine originally manufactured by Nordex in Germany. This 1.0MW utility-scale wind turbine has a gearbox drive generator, stall control blades with a 54 m rotor diameter, and a 70 m hub height. In addition, it has a 200kW generator for low wind generation. This wind turbine is located at an industrial site in Euclid, OH about 15 minutes from campus and began operation in March 2012.

**Courses**

**EMSE 110. Transitioning Ideas to Reality I - Materials in Service of Industry and Society. 1 Unit.**

In order for ideas to impact the lives of individuals and society they must be moved from "blue sky" to that which is manufacturable. Therein lies true creativity - design under constraint. Greater Cleveland is fortunate to have a diverse set of industries that serve medical, aerospace, electric, and advanced-materials technologies. This course involves trips to an array of work sites of leading companies to witness first-hand the processes and products, and to interact directly with practitioners. Occasional in-class speakers with demonstrations will be used when it is not logistically reasonable to visit off-site.

**EMSE 120. Transitioning Ideas to Reality II - Manufacturing Laboratory. 2 Units.**

This course complements EMSE 110. In that class students witness a diverse array of processing on-site in industry. In this class students work in teams and as individuals within processing laboratories working with an array of "real materials" to explore the potential of casting, machining, and deformation processes to produce real parts and/or components. An introduction to CAD as a means of communication is provided. The bulk of the term is spent in labs doing hands-on work. Planned work is carried out to demonstrate techniques and potential. Students have the opportunity to work independently or in teams to produce articles as varied as jewelry, electronics, transportation vehicles, or novel components or devices of the students’ choosing.
EMSE 125. Freshman Research in Materials Science and Engineering. 1 Unit.
Freshman students conduct independent research in the area of material science and engineering, working closely with graduate student(s) and/or postdoctoral fellow(s), and supervised by an EMSE faculty member. An average of 5-6 hr/wk in the laboratory, periodic updates, and an end of semester report is required. Prereq: Limited to freshman, with permission of instructor.

EMSE 220. Materials Laboratory I. 2 Units.

EMSE 228. Mathematical and Computational Methods for Materials Science and Engineering. 3 Units.
The course combines fundamental topics of material science and engineering with underlying mathematical methods and coding for computation. Focusing on the mathematics of vectors and using Mathematica as computational framework, the course teaches how to solve problems drawn from crystallography, diffraction, imaging of materials, and image processing. Students will develop a fundamental understanding of the basis for solving these problems including understanding the constituent equations, solution methods, and analysis and presentation of results. Prereq: (ENGR 131 or EECS 132) and ENGR 145

EMSE 276. Materials Properties and Design. 3 Units.
Relation of crystal structure, microstructure, and chemical composition to the properties of materials. The role of materials processing in controlling structure so as to obtain desired properties, using examples from metals, ceramics, semiconductors, and polymers. Design content includes exercises in materials selection, and in design of materials to meet specified performance requirements. Prereq: MATH 121 and ENGR 145. Prereq or Coreq: PHYS 122 or PHYS 124.

EMSE 300. Welding Metallurgy. 3 Units.
Introduction to arc welding and metallurgy of welding. The course provides a broad overview of different industrial applications requiring welding, the variables controlling critical property requirements of the weld and a survey of the different types of arc welding processes. The course details the fundamental concepts that govern the different aspects of arc welding including the welding arc, weld pool solidification, precipitate formation and solid state phase transformations. Offered as EMSE 308 and EMSE 408. Coreq. EMSE 327.

EMSE 319. Processing and Manufacturing of Materials. 3 Units.
Introduction to processing technologies by which materials are manufactured into engineering components. Discussion of how processing methods are dependent on desired composition, structure, microstructure, and defects, and how processing affects material performance. Emphasis will be placed on processes and treatments to achieve or improve chemical, mechanical, physical performance and/or aesthetics, including: casting, welding, forging, cold-forming, powder processing of metals and ceramics, and polymer and composite processing. Coverage of statistics and computational tools relevant to materials manufacturing. Prereq: EMSE 276.

EMSE 320. Materials Laboratory II. 1 Unit.
Measurement of thermophysical properties of materials emphasizing thermal and electrical properties of materials. Laboratory teams are selected for all experiments. Statistical analysis of experimental results also emphasized. Recommended preparation or corequisite: EMSE 276.

EMSE 325. Undergraduate Research in Materials Science and Engineering. 1 - 3 Units.
Undergraduate laboratory research in materials science and engineering. Students will undertake an independent research project alongside graduate student(s) and/or postdoctoral fellow(s), and will be supervised by an EMSE faculty member. Written and oral reports will be given on a regular basis, and an end of semester report is required. The course can be repeated up to four (4) times for a total of six (6) credit hours. Prereq: Sophomore or Junior standing and consent of instructor.

EMSE 327. Thermodynamic Stability and Rate Processes. 3 Units.
An introduction to thermodynamics of materials as applied to metals, ceramics, polymers and optical/radiant heat transfer for photovoltaics. The laws of thermodynamics are introduced and the general approaches used in the thermodynamic method are presented. Systems studied span phase stability and oxidation in metals and oxides; nitride ceramics and semiconductors; polymerization, crystallization and block copolymer domain formation; and the thermodynamics of systems such as for solar power collection and conversion. Recommended preparation: EMSE 228 and ENGR 225 or equivalent. Prereq: EMSE 276 or EMSE 201.

EMSE 328. Mesoscale Structural Control of Functional Materials. 3 Units.
The course focuses on mesoscale structure of materials and their interrelated effects on properties, mostly in electrical in nature. The mesoscale science covers the structures varying from electronic- to micro-structure. In each scale, fundamental science will be complimented by examples of applications and how the structure is exploited both to modify and enable function. The student will develop an understanding of how the structure across multiple scales are interrelated and how to tailor them for desired outcomes. Offered as: EMSE 328 and EMSE 428. Prereq: (MATH 223 or MATH 227) and (EMSE 276 or EMSE 201).

EMSE 330. Materials Laboratory III. 2 Units.

EMSE 335. Strategic Metals and Materials for the 21st Century. 3 Units.
This course seeks to create an understanding of the role of mineral-based materials in the modern economy focusing on how such knowledge can and should be used in making strategic choices in an engineering context. The history of the role of materials in emerging technologies from a historical perspective will be briefly explored. The current literature will be used to demonstrate the connectedness of materials availability and the development and sustainability of engineering advances with examples of applications exploiting structural, electronic, optical, magnetic, and energy conversion properties. Processing will be comprehensively reviewed from source through refinement through processing including property development through application of an illustrative set of engineering materials representing commodities, less common metals, and minor metals. The concept of strategic recycling, including design for recycling and waste stream management will be considered. Offered as EMSE 335 and EMSE 435. Prereq: Senior standing or graduate student.
EMSE 343. Processing of Electronic Materials. 3 Units.
The class will focus on the processing of materials for electronic applications. Necessary background into the fundamentals and applications will be given at the beginning to provide the basis for choices made during processing. MOSFET will be used as the target application. However, the processing steps covered are related to many other semiconductor based applications. The class will include both planar and bulk processing. Offered as: EMSE 343 and EMSE 443. Prereq: (PHYS 122 or PHYS 124) and EMSE 276.

EMSE 345. Materials for Biological and Medical Technology. 3 Units.
A survey of natural biomaterials and synthetic biomedical materials from the perspective of materials science and engineering, focusing on how processing/synthesis, structure, and properties determine materials performance. Structure and properties of bones and teeth, soft tissue, and cartilage. Introduction to properties and applications of materials for medical technologies, such as orthopedic implants, sensors, transducers, and materials for biomedical imaging and drug delivery. Selected case studies. Biomimetics as a design strategy for synthetic materials. Prereq: ENGR 200 and (ENGR 145 or EMSE 146).

EMSE 349. Materials for Energy and Sustainability. 3 Units.
Levels and categories of energy usage in the U.S. and the world. Availability of raw materials, including strategic materials; factors affecting global reserves and annual world production. Design strategies, and how the inclusion of environmental impacts as design criteria can alter materials selections. Resource demand (energy and water) of materials production, fabrication, and recycling. Roles of engineered materials in renewable or advanced energy technologies: photovoltaics, fuel cells, wind, batteries, capacitors, thermoelectrics. Energy harvesting. Role of magnetic materials in energy technology. Materials in energy-efficient lighting. Energy return on energy invested. Semester projects will enable students to explore related topics (e.g. geothermal; biomass; solar thermal; advances in energy-efficient manufacturing) in greater depth. Offered as EMSE 349 and EMSE 449. Prereq: ENGR 225 and ENGR 145 and (PHYS 122 or PHYS 124) or Requisites Not Met permission.

EMSE 365. Surface Engineering of Materials. 3 Units.
Introduction to surface engineering of materials, understood as a treatment that allows the surface to perform functions different from those performed by the bulk. This may include engineering the mechanical, chemical, electrical, magnetic, or optical properties of the surface and near-surface regions for specific applications. For a variety of technologically important classes of materials, the course reviews general concepts of surface engineering, the underlying physical and materials science principles, technical implementations, and typical applications. Recommended for graduate students and advanced undergraduate students. Offered as EMSE 365 and EMSE 465. Prereq: (EMSE 276 and ENGR 225) or Requisites Not Met permission.

EMSE 368. Scientific Writing in Materials Science and Engineering. 3 Units.
For writing a thesis (or a publication) in the field of materials science and engineering, students need a diverse set of skills in addition to mastering the scientific content. Generally, scientific writing requires proficiency in document organization, professional presentation of numerical and graphical data, literature retrieval and management, text processing, version control, graphical illustration, mathematical typesetting, the English language, elements of style, etc. Scientific writing in materials science and engineering, specifically, requires additional knowledge about e.g. conventions of numerical precision, error limits, mathematical typesetting, proper use of units, proper digital processing of micrographs, etc. Having to acquire these essential skills at the beginning of thesis (or publication) writing may compromise the outcome by distracting from the most important task of composing the best possible scientific content. This course properly prepares students for scientific writing with a comprehensive spectrum of knowledge, skills, and tools enabling them to fully focus on the scientific content of their thesis or publication when the time has come to start writing. Similar to artistic drawing, where the ability to "see" is as (or more!) important as skills of the hand, the ability of proper scientific writing is intimately linked to the ability of critically reviewing scientific texts. Therefore, students will practice both authoring and critical reviewing of material science texts. To sharpen students' skills of reviewing, examples of good and less good scientific writing will be taken from published literature of materials science and engineering and analyzed in the context of knowledge acquired in the course. At the end of the course, students will have set up skills and a highly functional work environment to start writing their role thesis or article with full focus on the scientific content. While the course mainly targets students of materials science and engineering, students of other disciplines of science and engineering may also benefit from the course material. Offered as EMSE 368 and EMSE 468.

EMSE 372. Structural Materials by Design. 4 Units.

EMSE 379. Design for Lifetime Performance. 3 Units.
EMSE 396. Special Project or Thesis. 1 - 18 Units.
Special research projects or undergraduate thesis in selected material areas.

EMSE 398. Senior Project in Materials I. 1 Unit.
Independent Research project. Projects selected from those suggested by faculty; usually entail original research. The EMSE 398 and 399 sequence form an approved SAGES capstone. Counts as SAGES Senior Capstone.

EMSE 399. Senior Project in Materials II. 2 Units.
Independent Research project. Projects selected from those suggested by faculty; usually entail original research. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Counts as SAGES Senior Capstone.

EMSE 400T. Graduate Teaching I. 0 Unit.
To provide teaching experience for all Ph.D-bound graduate students. This will include preparing exams/quizzes, homework, leading recitation sessions, tutoring, providing laboratory assistance, and developing teaching aids that include both web-based and classroom materials. Graduate students will meet with supervising faculty member throughout the semester. Grading is pass/fail. Students must receive three passing grades and up to two assignments may be taken concurrently. Recommended preparation: Ph.D. student in Materials Science and Engineering.

EMSE 405. Dielectric and Electrical Properties of Materials. 3 Units.

EMSE 408. Welding Metallurgy. 3 Units.
Introduction to arc welding and metallurgy of welding. The course provides a broad overview of different industrial applications requiring welding, the variables controlling critical property requirements of the weld and a survey of the different types of arc welding processes. The course details the fundamental concepts that govern the different aspects of arc welding including the welding arc, weld pool solidification, precipitate formation and solid state phase transformations. Offered as EMSE 308 and EMSE 408.

EMSE 409. Deformation Processing. 3 Units.
Flow stress as a function of material and processing parameters; yielding criteria; stress states in elastic-plastic deformation; forming methods: forging, rolling, extrusion, drawing, stretch forming, composite forming.

EMSE 413. Fundamentals of Materials Engineering and Science. 3 Units.
Provides a background in materials for graduate students with undergraduate majors in other branches of engineering and science: reviews basic bonding relations, structure, and defects in crystals. Lattice dynamics; thermodynamic relations in multi-component systems; microstructural control in metals and ceramics; mechanical and chemical properties of materials as affected by structure; control of properties by techniques involving structure property relations; basic electrical, magnetic and optical properties.

EMSE 414. Electrical, Magnetic, Optical, and Thermal Properties of Materials. 3 Units.
Reviews quantum mechanics as applied to materials, energy bands, and density of states; Electrical properties of metals, semiconductors, insulators, and superconductors; Optical properties of materials, including: metallic luster, color, and optoelectronics; Magnetic properties of materials, including: Types of magnetic behavior, theory, and applications; Thermal properties of materials, including: heat capacity, thermal expansion, and thermal conductivity. Prereq: EMSE 398.

EMSE 417. Properties of Materials in Extreme Environments. 3 Units.
Fundamentals of degradation pathways of materials under extreme conditions; thermodynamic stability of microstructures, deformation mechanisms, and failure mechanisms. Extreme conditions that will typically be addressed include: elevated temperatures, high-strain rates (ballistic), environmental effects, nuclear radiation, and small scales. Examples will be drawn from recent events as appropriate.

EMSE 421. Fracture of Materials. 3 Units.

EMSE 422. Failure Analysis. 3 Units.
Methods and procedures for determining the basic causes of failures in structures and components. Recognition of fractures and excessive deformations in terms of their nature and origin. Development and full characterization of fractures. Review of essential mechanical behavior concepts and fracture mechanics concepts applied to failure analyses in inorganic, organic, and composite systems. Legal, ethical, and professional aspects of failures from service. Prereq: EMSE 372 or EMAE 372 or Requisites Not Met permission.

EMSE 427. Defects in Solids. 3 Units.
Defects in solids control many properties of interest to the materials scientist or engineer. This course focuses on point, line, and interfacial defects in crystals and their interactions, including calculations of defect energies and interaction forces. Crystallographic defects presented include point defects (e.g., vacancies, interstitials, substitutional and interstitial impurities), line defects (e.g., dislocations), and planar defects (e.g., grain boundaries). The consequence of point defects on diffusion as well as on optical and electronic properties is discussed. Dislocation motion and dislocation dissociation are treated, and the influence of dislocation dynamics on yield phenomena, work hardening, and other mechanical properties are discussed. The role of grain boundaries and inter-phase boundaries in determining the physical properties of the material are presented. Experimental techniques for characterizing defects are integrated throughout the course. Recommended preparation: MATH 223 (or equivalent) and EMSE 276 (or equivalent).

EMSE 428. Mesoscale Structural Control of Functional Materials. 3 Units.
The course focuses on mesoscale structure of materials and their interrelated effects on properties, mostly in electrical in nature. The mesoscale science covers the structures varying from electronic- to micro-structure. In each scale, fundamental science will be complimented by examples of applications and how the structure is exploited both to modify and enable function. The student will develop an understanding of how the structure across multiple scales are interrelated and how to tailor them for desired outcomes. Offered as: EMSE 328 and EMSE 428.
EMSE 430. Additive Manufacturing of Metals, Polymers, and Ceramics. 3 Units.
Additive manufacturing, though rooted in well-established unit operations, has emerged as a distinctive approach to the production of components and assemblies. This course will cover the conceptual approach, its history, the current state of the art, and analysis of projections of its future role. The respective advances in digital description of parts and digital control of processes will be described as machine design and construction. The emphasis, however, will be on the processing-structure-property relationships. Polymers, metals, and ceramics will be treated separately and contrasted. The course will make extensive use of current literature. Prereq: EMSE 276 or Requisites Not Met permission.

EMSE 435. Strategic Metals and Materials for the 21st Century. 3 Units.
This course seeks to create an understanding of the role of mineral-based materials in the modern economy focusing on how such knowledge can and should be used in making strategic choices in an engineering context. The history of the role of materials in emerging technologies from a historical perspective will be briefly explored. The current literature will be used to demonstrate the connectedness of materials availability and the development and sustainability of engineering advances with examples of applications exploiting structural, electronic, optical, magnetic, and energy conversion properties. Processing will be comprehensively reviewed from source through refinement through processing including property development through application of an illustrative set of engineering materials representing commodities, less common metals, and minor metals. The concept of strategic recycling, including design for recycling and waste stream management, will be considered. Offered as EMSE 335 and EMSE 435. Prereq: Senior standing or graduate student.

EMSE 443. Processing of Electronic Materials. 3 Units.
The class will focus on the processing of materials for electronic applications. Necessary background into the fundamentals and applications will be given at the beginning to provide the basis for choices made during processing. MOSFET will be used as the target application. However, the processing steps covered are related to many other semiconductor based applications. The class will include both planar and bulk processing. Offered as: EMSE 343 and EMSE 443. Prereq: (PHYS 122 or PHYS 124) and EMSE 276.

EMSE 449. Materials for Energy and Sustainability. 3 Units.
Levels and categories of energy usage in the U.S. and the world. Availability of raw materials, including strategic materials; factors affecting global reserves and annual world production. Design strategies, and how the inclusion of environmental impacts as design criteria can alter materials selections. Resource demand (energy and water) of materials production, fabrication, and recycling. Roles of engineered materials in renewable or advanced energy technologies: photovoltaics, fuel cells, wind, batteries, capacitors, thermoelectrics. Energy harvesting. Role of magnetic materials in energy technology. Materials in energy-efficient lighting. Energy return on energy invested. Semester projects will enable students to explore related topics (e.g. geothermal; biomass; solar thermal; advances in energy-efficient manufacturing) in greater depth. Offered as EMSE 349 and EMSE 449. Prereq: ENGR 225 and (ENGR 145 or EMSE 146) and (PHYS 122 or PHYS 124) or requisites not met permission.

EMSE 463. Magnetism and Magnetic Materials. 3 Units.
This course covers the fundamentals of magnetism and application of modern magnetic materials especially for energy and data storage technologies. The course will focus on intrinsic and extrinsic magnetic properties, processing of magnetic materials to achieve important magnetic performance metrics, and the state-of-the-art magnetic materials used today. The topics related to intrinsic properties, include: magnetic dipole moments, magnetization, exchange coupling, magnetic anisotropy and magnetostriiction. Topics related to extrinsic properties, include: magnetic hysteresis, frequency dependent magnetic response and magnetic losses. Technologically important permanent magnets (including rare earth containing alloys and magnetic oxides), soft magnets (including electrical steels, amorphous, ferrites, and nanocrystalline alloys), and thin film materials (including iron platinum) will be discussed in the context of their technological interest. Throughout the course, experimental techniques and data analysis will be discussed. The course is suitable for most graduate students and advanced undergraduates in engineering and science.

EMSE 465. Surface Engineering of Materials. 3 Units.
Introduction to surface engineering of materials, understood as a treatment that allows the surface to perform functions different from those performed by the bulk. This may include engineering the mechanical, chemical, electrical, magnetic, or optical properties of the surface and near-surface regions for specific applications. For a variety of technologically important classes of materials, the course reviews general concepts of surface engineering, the underlying physical and materials science principles, technical implementations, and typical applications. Recommended for graduate students and advanced undergraduate students. Offered as EMSE 365 and EMSE 465.

EMSE 468. Scientific Writing in Materials Science and Engineering. 3 Units.
For writing a thesis (or a publication) in the field of materials science and engineering, students need a diverse set of skills in addition to mastering the scientific content. Generally, scientific writing requires proficiency in document organization, professional presentation of numerical and graphical data, literature retrieval and management, text processing, version control, graphical illustration, mathematical typesetting, the English language, elements of style, etc. Scientific writing in materials science and engineering, specifically, requires additional knowledge about e.g. conventions of numerical precision, error limits, mathematical typesetting, proper use of units, proper digital processing of micrographs, etc. Having to acquire these essential skills at the beginning of thesis (or publication) writing may compromise the outcome by distracting from the most important task of composing the best possible scientific content. This course properly prepares students for scientific writing with a comprehensive spectrum of knowledge, skills, and tools enabling them to fully focus on the scientific content of their thesis or publication when the time has come to start writing. Similar to artistic drawing, where the ability to “see” is as (or more!) important as skills of the hand, the ability of proper scientific writing is intimately linked to the ability of critically reviewing scientific texts. Therefore, students will practice both authoring and critical reviewing of material science texts. To sharpen students’ skills of reviewing, examples of good and less good scientific writing will be taken from published literature of materials science and engineering and analyzed in the context of knowledge acquired in the course. At the end of the course, students will have set up skills and a highly functional work environment to start writing their role thesis or article with full focus on the scientific content. While the course mainly targets students of materials science and engineering, students of other disciplines of science and engineering may also benefit from the course material. Offered as EMSE 368 and EMSE 468.
EMSE 499. Materials Science and Engineering Colloquium. 0 - 1 Units.
Invited speakers deliver lectures on topics of active research in materials science. Students conduct research at universities, government laboratories, and industry. Course is offered both of 1 credit and 0 credits. Attendance is required for both, and graded coursework in the form of a term paper is required when registering for 1 credit. Offered as EMSE 499 and EMSE 599.

EMSE 500T. Graduate Teaching II. 0 Unit.
To provide teaching experience for all Ph.D.-bound graduate students. This includes preparing exams/quizess/homework, leading recitation sessions, tutoring, and developing teaching aids that include both web-based and classroom materials. Graduate students will meet with supervising faculty member throughout the semester. Grading is pass/fail. Students must receive three passing grades and up to two assignments may be taken concurrently. Recommended preparation: Ph.D. student in Materials Science and Engineering.

EMSE 503. Structure of Materials. 3 Units.
The structure of materials and physical properties are explored in terms of atomic bonding and the resulting crystallography. The course will cover basic crystal chemistry, basic crystallography (crystal symmetries, point groups, translation symmetries, space lattices, and crystal classes), basic characterization techniques, and materials-related properties. Recommended preparation: Consent of instructor.

EMSE 504. Thermodynamics of Solids. 3 Units.

EMSE 505. Phase Transformations, Kinetics, and Microstructure. 3 Units.
Phase diagrams are used in materials science and engineering to understand the interrelationships of composition, microstructure, and processing conditions. The microstructure and phases of metallic and nonmetallic systems arising from thermal and mechanical driving forces and reaction pathways. In this course, solution thermodynamics, the energetics of surfaces and interfaces, and both diffusion and diffusionless phase transformations are reviewed. The development of the laws of diffusion and its application for both melts and solids is covered. Phase equilibria and microstructure in multicomponent systems will also be discussed.

EMSE 509. Conventional Transmission Electron Microscopy. 3 Units.
Introduction to transmission electron microscopy-theoretical background and practical work. Lectures and laboratory experiments cover the technical construction and operation of transmission electron microscopes, specimen preparation, electron diffraction by crystals, electron diffraction techniques of TEM, conventional TEM imaging, and scanning TEM. Examples from various fields of materials research illustrate the application and significance of these techniques. Recommended preparation: Consent of instructor.

EMSE 512. Advanced Techniques of Transmission Electron Microscopy. 3 Units.
Theory and laboratory experiments to learn advanced techniques of transmission electron microscopy, including high-resolution transmission electron microscopy (HRTEM), convergent-beam electron diffraction (CBED), microanalysis using X-ray energy-dispersive spectroscopy (XEDS) and electron energy-loss spectroscopy (EELS), and electron-spectroscopic imaging (ESI) for elemental mapping. Recommended preparation: EMSE 509.

EMSE 515. Analytical Methods in Materials Science. 3 Units.
Microcharacterization techniques of materials science and engineering: SPM (scanning probe microscopy), SEM (scanning electron microscopy), FIB (focused ion beam) techniques, SIMS (secondary ion mass spectrometry), EPMA (electron probe microanalysis), XPS (X-ray photoelectron spectrometry), and AES (Auger electron spectrometry), ESCA (electron spectrometry for chemical analysis). The course includes theory, application examples, and laboratory demonstrations.

EMSE 599. Materials Science and Engineering Colloquium. 0 - 1 Units.
Invited speakers deliver lectures on topics of active research in materials science. Students conduct research at universities, government laboratories, and industry. Course is offered both of 1 credit and 0 credits. Attendance is required for both, and graded coursework in the form of a term paper is required when registering for 1 credit. Offered as EMSE 499 and EMSE 599.

EMSE 600T. Graduate Teaching III. 0 Unit.
To provide teaching experience for all Ph.D.-bound graduate students. This includes preparing exams/quizess/homework, leading recitation sessions, tutoring, and developing teaching aids that include both web-based and classroom materials. Graduate students will meet with supervising faculty member throughout the semester. Grading is pass/fail. Students must receive three passing grades and up to two assignments may be taken concurrently. Recommended preparation: Ph.D. student in Materials Science and Engineering.

EMSE 601. Independent Study. 1 - 18 Units.

EMSE 649. Special Projects. 1 - 18 Units.

EMSE 651. Thesis M.S.. 1 - 18 Units.
Required for Master's degree. A research problem in metallurgy, ceramics, electronic materials, biomaterials, or archeological and art historical materials, culminating in the writing of a thesis.

EMSE 695. Project M.S.. 1 - 9 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in the EMSE Plan B MS Program.

EMSE 701. Dissertation Ph.D.. 1 - 9 Units.
Required for Ph.D. degree. A research problem in metallurgy, ceramics, electronic materials, biomaterials, or archeological and art historical materials, culminating in the writing of a thesis. Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Department of Mechanical and Aerospace Engineering
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Robert X. Gao, Cady Staley Professor of Engineering and Department Chair
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The Department of Mechanical and Aerospace Engineering of the Case School of Engineering offers programs leading to bachelor's, master's, and doctoral degrees. It administers the programs leading to the degrees of Bachelor of Science in Engineering with a major in Aerospace Engineering and Bachelor of Science in Engineering with a major in Mechanical Engineering. Both curricula are based on four-year programs of preparation for productive engineering careers or further academic training.
Mission
The mission of the Mechanical and Aerospace Engineering Department is to educate and prepare students at both the undergraduate and graduate levels for leadership roles in the fields of Mechanical Engineering and Aerospace Engineering and to conduct research for the benefit of society.

The undergraduate program emphasizes fundamental engineering science, analysis and experiments to insure that graduates will be strong contributors in their work environment, be prepared for advanced study at top graduate schools and be proficient lifelong learners. The graduate programs emphasize advanced methods of analysis, mathematical modeling, computational and experimental techniques applied to a variety of mechanical and aerospace engineering specialties including, applied mechanics, dynamic systems, robotics, biomechanics, fluid mechanics, heat transfer, propulsion and combustion. Leadership skills are developed by infusing the program with current engineering practice, design, and professionalism (including engineering ethics and the role of engineering in society) led by concerned educators and researchers.

The academic and research activities of the department center on the roles of mechanics, thermodynamics, heat and mass transfer, robotics, mechatronics, data analytics, sustainability in manufacturing, and engineering design in a wide variety of applications such as aeronautics, astronautics, biomechanics and orthopedic engineering, biomimetics and biologically-inspired robotics, energy, environment, machinery dynamics, mechanics of advanced materials, nanotechnology and tribology. Many of these activities involve strong collaborations with the Departments of Biology, Electrical Engineering and Computer Science, Materials Science and Engineering, and Orthopaedics of the School of Medicine.

The significant constituencies of the Mechanical and Aerospace Engineering Department are the faculty, the students, the alumni and the external advisory boards. The educational program objectives are established and reviewed continuously, based on the feedback from the various constituencies as well as archival information about the program graduates. The faculty engages in continuing discussions of the academic programs in the regularly scheduled faculty meetings throughout the academic year. Periodic surveys of alumni provide data regarding the preparedness and success of the graduates as well as guidance in program development. Archival data include the placement information for graduating seniors, which provides direct information regarding the success of the graduates in finding employment or being admitted to graduate programs.

Mastery of Fundamentals
- A strong background in the fundamentals of chemistry, physics and mathematics.
- Methods of mechanical engineering analysis, both numerical and mathematical, applied to mechanics, dynamic systems and control, thermodynamics, fluid mechanics and heat transfer.
- Methods of modern experimental engineering analysis and data acquisition.

Creativity
- Ability to identify, model, and solve mechanical and aerospace engineering design problems.
- Ability to design experiments to resolve mechanical and aerospace engineering issues.
- Ability to perform an individual senior project that demonstrates original research and/or design content.

Societal Awareness
- Issues of environmental impact, efficient use of energy and resources, benefits of recycling.
- An awareness of the multidisciplinary nature of mechanical and aerospace engineering.
- Impact of economic, product liability and other legal issues on mechanical and aerospace engineering manufacturing and design.

Leadership Skills
- An ability to work in teams.
- Ethical considerations in engineering decisions.
- Proficiency in oral and written communication.
- Professionalism
- Students are encouraged to develop as professionals through participation in the student chapters of the American Society of Mechanical Engineers (ASME) and the American Institute of Aeronautics and Astronautics (AIAA).
- Students are encouraged to augment their classroom experiences with the cooperative education program and the strong graduate research program of the department.
- Students are encouraged to take the Fundamentals of Engineering Examination as the first step in the process of becoming a registered professional engineer.
- The bachelor’s candidate must complete an independent design project with an oral and written final report.
- The master’s candidate must demonstrate independent research resulting in a thesis or project suitable for publication and/or presentation in peer reviewed journals and/or conferences.
- The doctoral candidate must complete a rigorous independent thesis containing original research results appropriate for publication in archival journals and presentation at leading technical conferences.

Aerospace Engineering
Aerospace engineering has grown dramatically with the rapid development of the computer in experiments, design and numerical analysis. The wealth of scientific information developed as a result of aerospace activity forms the foundation for the aerospace engineering major.

Scientific knowledge is being developed each day for programs to develop reusable launch vehicles (RLV), the International Space Station (ISS), High Speed Transport (HST), Human Exploration and Development of Space (HEDS) and micro-electro-mechanical sensors and control systems for advanced flight. New methods of analysis and design for structural, fluid, and thermodynamic applications are required to meet these challenges.

The aerospace engineering major has been developed to address the needs of those students seeking career opportunities in the highly specialized and advancing aerospace industries.

Mechanical Engineering
Civilization, as we know it today, depends on the intelligent and humane use of our energy resources and machines. The mechanical engineer’s function is to apply science and technology to the design, analysis, development, manufacture, and use of machines that convert and transmit energy, and to apply energy to the completion of useful operations. The top ten choices of the millennium committee of the National Academy of Engineering, asked to select the 20 top engineering
accomplishments of the 20th century, was abundant with mechanical engineering accomplishments, electrification (large scale power generation and distribution), automobiles, air travel (development of aircraft and propulsion), mechanized agriculture, and refrigeration and air conditioning.

Research

Aerospace Technology and Space Exploration
Flow in turbomachinery, molecular dynamics simulation of rarefied gas flow, two phase flow, supersonic combustion and propulsion, thermoacoustic refrigeration, in-situ resource utilization from space. Gravitational effects on transport phenomena, fluids and thermal processes in advance life support systems for long duration space travel, interfacial processes, g-jitter effects on microgravity flows, two phase flow in zero and reduced gravity.

Combustion and Fire Engineering
Hydrogen ignition and safety, catalytic combustion, flame spread, fire research and protection, combustion in micro- and partial gravity.

Data Analytics
Multi-domain signal decomposition and analysis, wavelet transform and other transformation methods, data fusion, stochastic modeling and statistical methods for defect detection, root cause diagnosis, and remaining service life prognosis, multi-scale analysis.

Dynamics of Rotating Machinery
Forced and instability vibration of rotor/bearing/seal systems, nonlinear rotor dynamics, torsional rotor vibration, rotor dynamic characteristics of bearings and seals (computational and experimental approach), control of rotor system dynamics, rub-impact studies on bearings and compressor/turbine blading systems. Advanced rotating machinery monitoring and diagnostics.

Engineering Design
Optimization and computer-aided design, feasibility studies of kinematic mechanisms, kinematics of rolling element-bearing geometries, mechanical control systems, experimental stress analysis, failure analysis, development of biologically inspired methodologies.

Heat Transfer
Analysis of heat transfer in complex systems such as biological organisms, multi-functional materials and building enclosures.

Sustainable and Additive Manufacturing
Modeling, characterization and manufacturing of next-generation lithium ion batteries for electric vehicles and perovskite solar cells for low-cost solar power generation, multiphysics electrochemistry modeling, atomic layer deposition, scalable nano-manufacturing, life cycle assessment of lithium ion batteries on environmental sustainability, agile manufacturing work cells based on coordinated, multiple robots, additive manufacturing, in-process sensing and control.

Materials
Development of novel experimental techniques to investigate material response at elevated temperatures and high rates of deformation. Constitutive modeling of damage evolution, shear localization and failure of advanced engineering materials. Fabrication of mechanical properties of composite materials; creep, rupture, and fatigue properties of engineering materials at elevated temperatures.

Multiphase Flow
Application of non-intrusive laser based diagnostic techniques and ultrasound techniques including pulsed ultrasound Doppler velocimetry to study solid-liquid, solid-gas, liquid-gas and solid-liquid-gas, multiphase flows encountered in slurry transport and bio-fluid mechanics.

Nanotechnology
Research related to various nanotechnology applications with particular emphasis on energy conversion, generation and storage in nanostructured materials including the synthesis of polymer-based nanocomposites. Current research projects include investigation of nanocomposites for thermoelectric devices, molecular simulation of thermal transport across interfacial regions, and biomimetic research on protein-based shark gel.

Musculoskeletal Mechanics and Materials
Design, modeling, and failure analysis of orthopaedic prostheses and material selection; mechanical properties of, and transport processes in, bone and soft tissue; tribology of native and tissue engineered cartilage; nondestructive mechanical evaluation of tissue engineered cartilage.

Robotics
Biologically inspired and biologically based design and control of legged robots. Dynamics, control and simulation of animals and robots. Distributed intelligence, swarm robotics, social robots, wearable telesensors, and tangible game interface.

Sensing and Metrology
Signal transduction mechanisms, design, modeling, functional characterization, and performance evaluation of mechanical, thermal, optical, and magnetic-field sensors, multi-physics sensing, and precision instrumentation.

Tribology and Seals
Time-resolved friction on nano- and microsecond time scale with applications to high speed machining and mechanics of armor penetration. Study of gas lubricated foil bearing systems with application to oil-free turbomachinery. Evaluation of advanced seal concepts and configurations for high temperature applications in gas turbine engines.

Turbomachinery
Vibration characteristics of seals and bearings and measurement of chaotic motion. Rub impact studies of blade tip/casing interactions, particle-blade/casing interactions in centrifugal pumps.

Faculty
Robert X. Gao, PhD
(Technical University of Berlin, Germany)
Cady Staley Professor of Engineering and Department Chair

Alexis R. Abramson, PhD
(University of California at Berkeley)
Milton and Tamar Maltz Professor of Engineering and Director, Great Lakes Energy Institute

Macro/micro/nanoscale heat transfer and energy transport
Ozan Akkus, PhD  
(Case Western Reserve University)  
**Leonard Case Jr. Professor of Engineering**  
Nano biomechanics, biomedical devices, biomaterials, fracture mechanics

Richard J. Bachmann, PhD  
(Case Western Reserve University)  
**Assistant Professor**  
Biologically inspired robotics

Paul Barnhart, PhD, PE  
(Case Western Reserve University)  
**Professor**  
Aerospace engineering, aerospace design

Sunniva Collins, PhD, FASM  
(Case Western Reserve University)  
**Associate Professor, Director of Undergraduate Studies and Online Programs**  
Design for manufacturing, steel metallurgy, heat treatment, surface engineering, fatigue analysis, fatigue of metals, welding, material analytical methods

Malcolm N. Cooke, PhD  
(Case Western Reserve University)  
**Associate Professor**  
Advanced manufacturing systems, computer integrated manufacturing

Kathryn Daltorio, PhD  
(Case Western Reserve University)  
**Assistant Professor**  
Biologically-inspired robotics, control, learning, kinetics, and kinematics for robots design

Umut A. Gurkan, PhD  
(Purdue University)  
**Assistant Professor**  
Micro-and nano-scale technologies, biomanufacturing, cell mechanics, and microfluidics

Yasuhiro Kamotani, PhD  
(Case Western Reserve University)  
**Professor**  
Experimental fluid dynamics, heat transfer, microgravity fluid mechanics

Chirag Kharangate, PhD  
(Purdue University)  
**Assistant Professor**  
Thermal management, two-phase flows, computational fluid dynamics, microgravity

Kiju Lee, PhD  
(John Hopkins University)  
**Nord Distinguished Assistant Professor**  
Robotics, distributed system design and control, modular robotics, multi-body dynamical systems

Be Li, PhD  
(California Institute of Technology)  
**Assistant Professor**  
Solid and computational mechanics, meshfree methods, failure processes in solids, biomechanics, thermal-fluid structure interaction and high performance computing

Ya-Ting T. Liao, PhD  
(Case Western Reserve University)  
**Assistant Professor**  
Fire dynamics, computational fluid dynamics, thermal fluids

Vikas Prakash, PhD  
(Brown University)  
**Professor**  
Experimental and computational solid mechanics, dynamic deformation and failure, time resolved high-speed friction, nanomechanics, energy storage

Roger D. Quinn, PhD  
(Virginia Polytechnic Institute & State University)  
**Arthur P. Armington Professor of Engineering**  
Biologically inspired robotics, agile manufacturing systems, structural dynamics, vibration and control

Clare M. Rimnac, PhD  
(Lehigh University)  
**Wilbert J. Austin Professor of Engineering**  
Biomechanics; fatigue and fracture mechanics

Fumiaki Takahashi, PhD  
(Keio University)  
**Professor**  
Combustion, fire science and engineering

Chris Yingchun Yuan, PhD  
(University of California at Berkeley)  
**Associate Professor**  
Sustainable manufacturing, lithium ion battery, modeling and characterization for energy storage

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**Research Faculty**

R. Balasubramaniam, PhD  
(Case Western Reserve University)  
**Research Associate Professor, National Center for Space Exploration Research**  
Microgravity fluid mechanics

Uday Hegde, PhD  
(Georgia Institute of Technology)  
**Research Associate Professor, National Center for Space Exploration Research**  
Combustion, turbulence and acoustics

Mohammad Kassemi, PhD  
(University of Akron)  
**Research Professor, National Center for Space Exploration Research**  
Computational fluid mechanics

Vedha Nayagam, PhD  
(University of Kentucky)  
**Research Associate Professor, National Center for Space Exploration Research**  
Low gravity combustion and fluid physics
Associated Faculty

James Drake, BSE  
(Case Western Reserve University)  
*Adjunct Instructor*  
Manufacturing processes

Kenneth Loparo, PhD  
(Case Western Reserve University)  
*Professor of Electrical Engineering and Computer Science*  
Control; robotics; stability of dynamical systems; vibrations

David Matthiesen, PhD  
(Massachusetts Institute of Technology)  
*Associate Professor of Materials Science Engineering*  
Microgravity crystal growth

Wyatt S. Newman, PhD  
(Massachusetts Institute of Technology)  
*Professor of Electrical Engineering and Computer Science*  
Mechatronics; high-speed robot design; force and vision-based machine control; artificial reflexes for autonomous machines; rapid prototyping; agile manufacturing

Mario Garcia Sanz, PhD  
(University of Navarra)  
*Professor of Electrical Engineering and Computer Science*  
Systems and control, spacecraft controls, automated manufacturing

Ravi Vaidyanathan, PhD  
(Case Western Reserve University)  
*Adjunct Assistant Professor; Imperial College*  
Robotics and control

Xiong Yu, PhD, PE  
(Purdue University)  
*Associate Professor*  
Geotechnical engineering, non-destructive testing, intelligent infrastructures

Emeritus Faculty

Maurice L. Adams, PhD  
(University of Pittsburgh)  
*Professor Emeritus*  
Dynamics of rotating machinery, nonlinear dynamics, vibration, tribology, turbomachinery

Dwight T. Davy, PhD, PE  
(University of Iowa)  
*Professor Emeritus*  
Musculo-skeletal biomechanics; applied mechanics

Isaac Greber, PhD  
(Massachusetts Institute of Technology)  
*Professor Emeritus*  
Fluid dynamics; molecular dynamics and kinetic theory; biological fluid mechanics; acoustics

Jaikrishnan R. Kadambi, PhD  
(University of Pittsburgh)  
*Professor Emeritus*  
Experimental fluid mechanics, laser diagnostics, bio-fluid mechanics, turbomachinery

Joseph M. Mansour, PhD  
(Rensselaer Polytechnic Institute)  
*Professor Emeritus*  
Biomechanics and applied mechanics

Thomas P. Kicher, PhD  
(Case Institute of Technology)  
*Arthur P. Armington Professor Emeritus of Engineering*  
Elastic stability; plates and shells; composite materials; dynamics; design; failure analysis

Eli Reshotko, PhD  
(California Institute of Technology)  
*Kent H. Smith Emeritus Professor of Engineering*  
Fluid Dynamics; heat transfer; propulsion; power generation

James S. Tien, PhD  
(Princeton University)  
*Professor Emeritus*  
Combustion, propulsion, and fire research

Undergraduate Programs

Bachelor of Science in Engineering

Program Educational Objectives: Aerospace Engineering
- Graduates will enter and successfully engage in careers in Aerospace Engineering and other professions appropriate to their background, interests, and skills.
- Graduates will engage in continued learning through post-baccalaureate education and/or professional development in engineering or other professional fields.
- Graduates will develop as leaders in their chosen professions.

Program Educational Objectives: Mechanical Engineering
- Graduates will enter and successfully engage in careers in Mechanical Engineering and other professions appropriate to their background, interests, and skills.
- Graduates will engage in continued learning through post-baccalaureate education and/or professional development in engineering or other professional fields.
- Graduates will develop as leaders in their chosen professions.

Student Outcomes
As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree programs with majors in Aerospace Engineering and Mechanical Engineering are designed so that students attain:
- 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 within realistic constraints such as economic, environmental,
social, political, ethical, health and safety, manufacturability, and sustainability
• 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, economic, environmental, 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.

The Bachelor of Science in Engineering degree program with a major in Aerospace Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

The Bachelor of Science in Engineering degree program with a major in Mechanical Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Bachelor of Science in Engineering
Major in Aerospace Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

<table>
<thead>
<tr>
<th>Major Courses</th>
<th>Units</th>
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<tbody>
<tr>
<td>EMAE 160 Mechanical Manufacturing</td>
<td>3</td>
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<tr>
<td>EMAE 181 Dynamics</td>
<td>3</td>
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<tr>
<td>EMAE 250 Computers in Mechanical Engineering</td>
<td>3</td>
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<td>EMAE 251 Thermodynamics</td>
<td>3</td>
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<td>EMAE 252 Fluid Mechanics</td>
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<tr>
<td>EMAE 285 Mechanical Engineering Measurements Laboratory</td>
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<td>EECS 304 Control Engineering I with Laboratory</td>
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<td>ECIV 310 Strength of Materials</td>
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<td>EMAE 350 Mechanical Engineering Analysis</td>
<td>3</td>
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<td>EMAE 353 Heat Transfer</td>
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<td>EMAE 355 Design of Fluid and Thermal Elements</td>
<td>3</td>
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<tr>
<td>EMAE 359 Aero/Gas Dynamics</td>
<td>3</td>
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<tr>
<td>EMAE 376 Aerostuctures</td>
<td>3</td>
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<tr>
<td>EMAE 383 Flight Mechanics</td>
<td>3</td>
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<tr>
<td>EMAE 384 Orbital Dynamics</td>
<td>3</td>
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<tr>
<td>EMAE 356 Aerospace Design</td>
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<td>EMAE 382 Propulsion</td>
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For the Engineering Core natural science and math requirement

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<tbody>
<tr>
<td>PHYS 221 Introduction to Modern Physics</td>
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Technical Electives by Program
• All 200-, 300-, and 400-level courses from the following areas: EMAE all, EMAE cross-listed, EBME all, EBME cross-listed, ECIV all, ECES all, ECES cross-listed, EMAC all, EMSE all, EMSE cross-listed
• All 300- and 400-level courses in ECHE
• All 300-level MATH and STAT courses with the concurrence of the advisor

Bachelor of Science in Engineering
Suggested Program of Study: Major in Aerospace Engineering

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

First Year

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Second Year

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<td>Introduction to Modern Physics (PHYS 221)**,d</td>
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<td>Elementary Differential Equations (MATH 224)**,d</td>
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<td>Fluid Mechanics (EMAE 252)</td>
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**Total Units in Sequence:** 129

**Hours required for graduation:** 129

* University general education requirement  
** Engineering general education requirements  
<sup>d</sup> May be taken fall or spring semester.

---

**Bachelor of Science in Engineering**  
**Major in Mechanical Engineering**

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

#### Major Courses

<table>
<thead>
<tr>
<th>EMAE 160</th>
<th>Mechanical Manufacturing</th>
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<tr>
<td>EMAE 181</td>
<td>Dynamics</td>
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<td>Computers in Mechanical Engineering</td>
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<td>EMAE 251</td>
<td>Thermodynamics</td>
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<td>EMAE 252</td>
<td>Fluid Mechanics</td>
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<td>EMAE 260</td>
<td>Design and Manufacturing I</td>
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<td>EMAE 285</td>
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<td>EMAE 355</td>
<td>Design of Fluid and Thermal Elements</td>
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<td>EMAE 360</td>
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<td>Four Technical Electives</td>
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**Technical Electives by Program**

- All 200-, 300-, and 400-level courses from the following areas: EMAE all, EMAE cross-listed, EBME all, EBME cross-listed, ECIV all, EECS all, EECS cross-listed, EMAC all, EMSE all, EMSE cross-listed
- All 300- and 400-level courses in ECHE
- All 300-level MATH and STAT courses with the concurrence of the advisor

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**Science Electives for Mechanical Engineering Majors**

The Student Information System is currently set up to accept PHYS 221 Introduction to Modern Physics or STAT 312 Basic Statistics for Engineering and Science as a science elective. Other courses for individual students can be selected with the approval of the student’s advisor and the chair using an Academic Advisement Requirement Form (https://case.edu/ugstudies/media/caseedu/undergraduate-studies/forms--applications/advisement-report-correction.pdf).

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**Bachelor of Science in Engineering**  
**Suggested Program of Study: Major in Mechanical Engineering**

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

#### First Year

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<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
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<td></td>
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<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)&lt;sup&gt;**,d&lt;/sup&gt;</td>
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<tr>
<td>Calculus for Science and Engineering I (MATH 121)&lt;sup&gt;**,d&lt;/sup&gt;</td>
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<td>General Physics I - Mechanics (PHYS 121)&lt;sup&gt;**,d&lt;/sup&gt;</td>
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<tr>
<td>First Seminar (FSCC 100)&lt;sup&gt;*&lt;/sup&gt;</td>
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<td>PHED (two half semester classes)&lt;sup&gt;*&lt;/sup&gt;</td>
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<td>Calculus for Science and Engineering II (MATH 122)&lt;sup&gt;**,d&lt;/sup&gt;</td>
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* University general education requirement  
** Engineering general education requirements  
<sup>d</sup> May be taken fall or spring semester.
**Department of Mechanical and Aerospace Engineering**

Year Total: 16  

**Second Year**

<table>
<thead>
<tr>
<th>Units</th>
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<td>Mechanical Manufacturing (EMAE 160)^d</td>
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<td>Computers in Mechanical Engineering (EMAE 250)^d</td>
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<td>SAGES University Seminar^*^d</td>
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<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**^d</td>
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<td>Elementary Differential Equations (MATH 224)**^d</td>
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Year Total: 15 16

**Third Year**

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Year Total: 16 18

**Fourth Year**

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Year Total: 15 15

Total Units in Sequence: 129

Hours required for graduation: 129

^ University general education requirement
** Engineering general education requirement
^d May be taken fall or spring semester.

**Double Major Mechanical and Aerospace Engineering**

The department also offers a double major in Mechanical and Aerospace Engineering. Students completing this plan of study meet the requirements for both the Aerospace Engineering program and the Mechanical Engineering program. The course selection details are provided in the course listing section.

**Suggested Program of Study: Double Major in Mechanical and Aerospace Engineering**

**First Year**

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Year Total: 16 18

**Second Year**

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Year Total: 15 16

**Third Year**

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Year Total: 16 18

**Fourth Year**

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<td>Senior Project (EMAE 398)^d</td>
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<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGL 398)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)**</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Year Total: 15 15

Total Units in Sequence: 129
Application to this program is initiated in the spring of the junior year aerospace engineering. This typically takes 5 years or slightly longer.

A thesis, a student may earn a Master of Science degree in mechanical or Science in Engineering degree in any one of the department's two degree programs. By completing the remaining graduate credit hours and a thesis, if appropriate.

The combined bachelors/masters program allows a student to double count 9 credit hours of graduate course work towards the Bachelor of Science in Engineering degree in any one of the department's two degree programs. By completing the remaining graduate credit hours and a thesis, a student may earn a Master of Science degree in mechanical or aerospace engineering. This typically takes 5 years or slightly longer. Application to this program is initiated in the spring of the junior year.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 350</td>
<td>Mechanical Engineering Analysis</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 260d</td>
<td>Design and Manufacturing I</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 353</td>
<td>Heat Transfer</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 359</td>
<td>Aero/Gas Dynamics</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 370</td>
<td>Design of Mechanical Elements</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 376</td>
<td>Aerostructures</td>
<td>3</td>
</tr>
<tr>
<td>EECS 304</td>
<td>Control Engineering I with Laboratory</td>
<td>3</td>
</tr>
</tbody>
</table>

Year Total: 16 18

**Fourth Year**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Aerospace Design (EMAE 356)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Propulsion (EMAE 382)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Senior Project (EMAE 398)**,d</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>&amp; Professional Communication for Engineers (ENGL 398)**</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Breath elective **,d</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Breath elective *d</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Year Total: 15 18

Total Units in Sequence: 132

Hours required for graduation: 132

* University general education requirement
** Engineering general education requirement
*d May be taken fall or spring semester.

**Cooperative Education** ([http://engineering.case.edu/coop](http://engineering.case.edu/coop))

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition, but maintain their full-time student status while earning a salary. Learn more at [engineering.case.edu/coop](http://engineering.case.edu/coop).

Alternatively or additionally, students may obtain employment as summer interns.

**BS/MS Program**

The combined bachelors/masters program allows a student to double count 9 credit hours of graduate course work towards the Bachelor of Science in Engineering degree in any one of the department's two degree programs. By completing the remaining graduate credit hours and a thesis, a student may earn a Master of Science degree in mechanical or aerospace engineering. This typically takes 5 years or slightly longer. Application to this program is initiated in the spring of the junior year with the department's graduate student programs office. A minimum grade point of 3.2 is required for consideration for this accelerated program. Review the Office of Undergraduate Studies BS/MS program requirements here ([http://bulletin.case.edu/undergraduatestudies/gradprofessional/#acceleratetowardgraduatedegreestext](http://bulletin.case.edu/undergraduatestudies/gradprofessional/#acceleratetowardgraduatedegreestext)).

**BS/MS Program of Study Details**

The current regulations for the MS degree by the School of Graduate Studies ([http://www.case.edu/provost/gradstudies](http://www.case.edu/provost/gradstudies)) require a minimum of 18 credit hours of coursework at the 400-level (or higher). Please note that any 400-level course taken prior to admission to the BS/MS Program cannot typically be counted as part of the MS degree. However, EMAE 398 Senior Project may be included in the double counted credit hours toward the MS Thesis, if appropriate.

Follow the links below to learn more about the components of the BS/MS Program.

- BS/MS Application Process ([https://engineering.case.edu/emaes/bsms/application-process](https://engineering.case.edu/emaes/bsms/application-process))
- BS/MS Graduation ([https://engineering.case.edu/emaes/bsms/graduation](https://engineering.case.edu/emaes/bsms/graduation))

If you have additional questions, please contact either:

- Professor Kiju Lee kiju.lee@case.edu
- Student Affairs Coordinator Carla Wilson cxw75@case.edu

**Master of Engineering and Management Program**

Another option is the 5 year TiME Program taught in conjunction with the Weatherhead School of Management in which a student completes a BS in Aerospace or Mechanical Engineering and earns a Master of Engineering and Management.

**Minor in Mechanical Design and Manufacturing**

A minor in Mechanical Design and Manufacturing is offered to students in other departments with an interest in design and manufacturing. The minor consists of an approved set of five EMAE courses.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 160</td>
<td>Mechanical Manufacturing</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 260</td>
<td>Design and Manufacturing I</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 370</td>
<td>Design of Mechanical Elements</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 290</td>
<td>Computer-Aided Manufacturing</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 372</td>
<td>Structural Materials by Design</td>
<td>4</td>
</tr>
<tr>
<td>EMAE 390</td>
<td>Advanced Manufacturing Technology</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 397</td>
<td>Independent Laboratory Research</td>
<td>1 - 3</td>
</tr>
</tbody>
</table>

(can be used as an elective in this minor sequence under the following conditions)
Graduate Programs

Master of Science in Aerospace Engineering or Mechanical Engineering

Research- or Project-Oriented

For a research-oriented MS, each candidate must complete a minimum of 30 hours of graduate-level credits, including at least 21 hours of graduate-level courses and 9 credit hours of MS thesis research.

For the project-oriented option, students must complete 30 credit hours distributed in either of three ways: 24, 27 or 30 credit hours (8, 9 or 10 courses) of approved graduate course work and 6, or 3 credit hours of project replacing the MS thesis.

List of Required Graduate Courses

Depending on the area of interest, students should select courses from this list with the approval of their advisor. Courses with double asterisks are required for the specific track.

I. Biomechanics

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 414</td>
<td>Nanobiomechanics in Biology</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 415</td>
<td>Introduction to Musculo-skeletal Biomechanics **</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 456</td>
<td>Micro-Electro-Mechanical Systems in Biology and Medicine (BioMEMS) **</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 466</td>
<td>Mechanics of Biological Fluids</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 480</td>
<td>Fatigue of Materials</td>
<td>3</td>
</tr>
</tbody>
</table>

II. Dynamics, Control and Manufacturing

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 475</td>
<td>Applied Control **</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 481</td>
<td>Advanced Dynamics I **</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 487</td>
<td>Vibration Problems in Engineering **</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 488</td>
<td>Advanced Robotics</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 540</td>
<td>Advanced Dynamics II</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 560</td>
<td>Sustainable Manufacturing **</td>
<td>3</td>
</tr>
</tbody>
</table>

III. Fluids and Thermal Sciences

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 453</td>
<td>Advanced Fluid Dynamics I **</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 454</td>
<td>Advanced Fluid Dynamics II</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 455</td>
<td>Advanced Thermodynamics **</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 457</td>
<td>Combustion</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 459</td>
<td>Advanced Heat Transfer **</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 471</td>
<td>Computational Fluid Dynamics</td>
<td>3</td>
</tr>
</tbody>
</table>

IV. Solid Mechanics

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECIV 411</td>
<td>Elasticity, Theory and Applications **</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 420</td>
<td>Finite Element Analysis **</td>
<td>3</td>
</tr>
</tbody>
</table>

EMAE 401 Mechanics of Continuous Media ** 3
EMAE 689 Special Topics 1 - 18

V. Online and other Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 450</td>
<td>Advanced Mechanical Engineering Analysis</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 460</td>
<td>Theory and Design of Fluid Power Machinery</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 461</td>
<td>Chemistry of Fire Safe Polymers and Composites</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 494</td>
<td>Energy Systems</td>
<td>3</td>
</tr>
</tbody>
</table>

** Required courses for the given track

In addition, a BS/MS program and a 5-year BS/MEM (Master of Engineering Management) are also offered for our undergraduate students as indicated in the preceding section.

A Master of Science in Mechanical Engineering is also available exclusively online. Visit http://online-engineering.case.edu/mechanical/ for more details.

Master of Engineering

The Department of Mechanical and Aerospace Engineering participates in the practice-oriented Master of Engineering Program offered by the Case School of Engineering. In this program, students complete a core program consisting of five courses and select a four-course sequence in an area of interest.

The Master of Engineering degree is also available exclusively online. Visit http://online-engineering.case.edu/masters for more details.

Master of Science in Mechanical Engineering with Specialization

Fire Science and Engineering

The Case School of Engineering at Case Western Reserve University offers an MS graduate program in Fire Science and Engineering. Students will choose either a Master of Science in Mechanical Engineering or a Master of Science in Macromolecular Science and Engineering, both with a concentration in fire science. Case Western Reserve offers a unique intersection of expertise in macromolecular and combustion science and mechanical and chemical engineering, making us singularly suited to cover all aspects of fire protection, safety, and flammability.

Through a 30-credit-hour curriculum, students explore and learn how to apply the fundamental principles of fire behavior and dynamics, protection and suppression systems, polymeric materials structure, properties and selection and more. The program is designed to be completed in 12 months, but can be spread out over multiple years.

The Fire Science and Engineering program at Case Western Reserve covers all aspects of combustion and fire suppression. After graduating from this degree program, students will be ready to apply their thorough understanding of:

- The chemistry of fire and materials
- Flammability logistics
- Fire dynamics and fire behavior
- Fire risk assessment
- Fire protection engineering
• Combustion
• Fire and safety-related codes
• Human behavior and life safety analysis
• Structural fire protection
• Passive fire protection systems
• Polymer engineering

Elective tracks:
• Mechanical Engineering track to focus on mechanical engineering and combustion related to fire protection and suppression
• Macromolecular Science and Engineering track to focus on polymer chemistry and materials, and the chemistry of flammability and fire suppression

Fire Science and Engineering
Degree Options
The Fire Science and Engineering master's degree program comprises 30 credit hours, which may be all coursework or include an MS thesis (9 credit hours) or a project (3 to 6 credit hours). Students can choose to receive a Master of Science in Mechanical Engineering with a concentration in Fire Science and Engineering, or a Master of Science in Macromolecular Science and Engineering with a concentration in Fire Science and Engineering.

Six core fire protection engineering courses are required. Other courses can be chosen from the elective track for mechanical engineering or macromolecular science and engineering. The mechanical track follows a traditional mechanical engineering/combustion approach to fire protection and suppression, but with specialization classes in polymers. The macromolecular science and engineering track focuses on polymer chemistry and materials, and the chemistry of flammability and fire suppression.

The degree can be finished in one year or in multiple years. Students have the option of completing a thesis or research project at their employers' laboratories with Case Western Reserve faculty members as co-advisors.

This fire protection engineering degree is offered over three semesters: 12 credits in the fall semester; 12 credits in the spring semester; and 6 credits in the summer. See the university’s academic calendar (https://case.edu/registrar/dates-deadlines/academic-calendar).

Core Course Requirements

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 404</td>
<td>Polymer Foundation Course IV: Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 457</td>
<td>Combustion</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 461</td>
<td>Chemistry of Fire Safe Polymers and Composites</td>
<td>3</td>
</tr>
<tr>
<td>or EMAE 461</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMAC 463</td>
<td>Fire Dynamics</td>
<td>3</td>
</tr>
<tr>
<td>or EMAE 463</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMAC 464</td>
<td>Fire Protection Engineering</td>
<td>3</td>
</tr>
<tr>
<td>or EMAE 464</td>
<td></td>
<td></td>
</tr>
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</table>

Elective Tracks

Elective Track I: Mechanical Engineering

Choose 3 or more courses from the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 453</td>
<td>Advanced Fluid Dynamics I</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 459</td>
<td>Advanced Heat Transfer</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 558</td>
<td>Conduction and Radiation</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 424</td>
<td>Structural Dynamics</td>
<td>3</td>
</tr>
</tbody>
</table>

Elective Track II: Macromolecular Science and Engineering

Choose 3 or more courses from the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 401</td>
<td>Polymer Foundation Course I: Organic Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 402</td>
<td>Polymer Foundation Course II: Physical Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 403</td>
<td>Polymer Foundation Course III: Physics</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 405</td>
<td>Polymer Characterization Laboratory</td>
<td>3</td>
</tr>
</tbody>
</table>

Minimum requirements for the MS degree with the Fire Science and Engineering concentration are:

Plan A

1. Completion of at least 18 hours of graduate coursework at or above the 400 level. The coursework should consist of the following:
   • Two of the three core courses from the Fluids and Thermal Sciences area in Mechanical and Aerospace Engineering.
   • Four of the six core courses from the Fire Science and Engineering concentration.

2. Completion of nine hours of thesis work culminating in a thesis examination given by at least three professors, plus approval by the chair of the department offering the degree.

3. Completion of another three credit hours of MS thesis, or taking a three-credit-hour graduate class, or taking the 1 credit seminar course for 3 semesters.

Plan B

Completion of at least 30 hours of graduate coursework at or above the 400 level. The coursework should consist of the following:

• Two of the three core courses from the Fluids and Thermal Sciences area in Mechanical and Aerospace Engineering.
• Six of the six core courses from the Fire Science and Engineering concentration. Among these courses, up to two can be replaced by Special Problem coursework (i.e. project).
• The Special Problem topic needs to be in Fire Science and Engineering field and be approved by the chair of the department offering the degree. The Special Problem course may be carried out at the student’s place of employment with nominal supervision by a faculty advisor or in the school’s laboratories under direct supervision.
• One additional course at or above the 400 level. Students should consult their advisor regarding selection of this course.
• Completion of another three credit hours of MS thesis, or taking a three-credit-hour graduate class, or taking the 1 credit seminar course for 3 semesters.

For additional information, please contact:

David Schiraldi, Chair of the Department of Macromolecular Science and Engineering

Ya-Ting Liao, Assistant Professor in the Department of Mechanical and Aerospace Engineering

Learn more about the faculty who teach these courses. (http://engineering.case.edu/fire/faculty)

**How to Apply**

Application to the Fire Science and Engineering program is handled through the university's School of Graduate Studies. Students will need to know whether they wish to apply for the MS in Mechanical Engineering or the MS in Macromolecular Science and Engineering.

Students interested in applying to the Fire Science and Engineering program should already have a bachelor's degree in Chemistry, Chemical Engineering, Mechanical Engineering or Materials Science & Engineering and have taken the GRE. Additional application requirements include a statement of objectives, academic transcripts, and three letters of recommendation. International students will also need to take the Test of English as a Foreign Language (TOEFL). Read more about the university's full application procedure requirements here (http://www.case.edu/gradstudies/prospective-students/admissions-information).

When you are ready to apply, electronic applications can be submitted here (https://app.applyyourself.com/AYApplicantLogin/ fl_ApplicantConnectLogin.asp?id=case-gr).

**Doctor of Philosophy Program**

Students wishing to pursue the doctoral degree in mechanical and aerospace engineering must successfully pass the doctoral qualifying examination consisting of both written and oral components. Qualifying exams are offered on applied mechanics, dynamics and design or fluid and thermal engineering sciences. Students can choose to take it in the fall or spring semesters. The minimum course requirements for the PhD degree are as follows:

**Depth Courses**

All programs of study must include 6 graduate level mechanical courses in mechanical engineering or aerospace engineering. Usually, these courses follow a logical development of a branch of mechanics, dynamics, and design or fluid and thermal engineering science determined in conjunction with the student’s dissertation advisor to meet the objectives of the dissertation research topic.

**Breadth and Basic Science Courses**

A minimum of six graduate courses are required to fulfill the breadth and basic science courses. The basic science requirement is satisfied by taking two courses in the area of science and mathematics. Four additional courses are needed to provide the breadth outside the student's area of research.

**Dissertation Research**

All doctoral programs must include a minimum of 18 credit hours of thesis research, EMAE 701 Dissertation Ph.D.

**List of Required Ph.D. Courses**

Courses in bold are required for the specific track.

**I. Biomechanics**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 414</td>
<td>Nanobiomechanics in Biology</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 415</td>
<td>Introduction to Musculo-skeletal Biomechanics</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 456</td>
<td>Micro-Electro-Mechanical Systems in Biology and Medicine (BioMEMS)</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 466</td>
<td>Mechanics of Biological Fluids</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 480</td>
<td>Fatigue of Materials</td>
<td>3</td>
</tr>
</tbody>
</table>

**II. Dynamics, Control and Manufacturing**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 475</td>
<td>Applied Control</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 481</td>
<td>Advanced Dynamics I</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 487</td>
<td>Vibration Problems in Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 488</td>
<td>Advanced Robotics</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 540</td>
<td>Advanced Dynamics II</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 560</td>
<td>Sustainable Manufacturing</td>
<td>3</td>
</tr>
</tbody>
</table>

**III. Fluids and Thermal Sciences**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 453</td>
<td>Advanced Fluid Dynamics I</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 454</td>
<td>Advanced Fluid Dynamics II</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 455</td>
<td>Advanced Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 457</td>
<td>Combustion</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 459</td>
<td>Advanced Heat Transfer</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 471</td>
<td>Computational Fluid Dynamics</td>
<td>3</td>
</tr>
</tbody>
</table>

**IV. Solid Mechanics**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECIV 411</td>
<td>Elasticity, Theory and Applications</td>
<td>3</td>
</tr>
<tr>
<td>ECIV 420</td>
<td>Finite Element Analysis</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 401</td>
<td>Mechanics of Continuous Media</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 501</td>
<td>Constitutive Modeling of Solids</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 689</td>
<td>Special Topics</td>
<td>1 - 18</td>
</tr>
</tbody>
</table>

**V. Online and other Courses**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 450</td>
<td>Advanced Mechanical Engineering Analysis</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 460</td>
<td>Theory and Design of Fluid Power Machinery</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 461</td>
<td>Chemistry of Fire Safe Polymers and Composites</td>
<td>3</td>
</tr>
<tr>
<td>EMAE 494</td>
<td>Energy Systems</td>
<td>3</td>
</tr>
</tbody>
</table>

**Residence and Teaching Requirements**

All doctoral programs must meet the residency requirements of the School of Graduate Studies and the teaching requirements of the Case School of Engineering.

**Facilities**

The education and research philosophy of the Department of Mechanical and Aerospace Engineering for both the undergraduate and graduate programs is based on a balanced operation of analytical, experimental, and computational activities. All three of these tools are used in a fundamental approach to the professional activities of research, development, and design. Among the major assets of the department
are the experimental facilities maintained and available for the faculty, students, and staff.

The introductory undergraduate courses are taught through the Robert M. Ward ’41 Laboratory, the Bingham Student Workshop, the Reinberger Product and Process Development Laboratory, and the Reinberger Design Studio. The Ward Laboratory is modular in concept and available to the student at regularly scheduled class periods to conduct a variety of prepared experimental assignments. The lab is equipped with a variety of instruments ranging from classic analog devices to modern digital computer devices for the collection of data and the control of processes. Advanced facilities are available for more specialized experimental tasks in the various laboratories dedicated to each specific discipline. Most of these laboratories also house the research activities of the department, so students are exposed to the latest technology in their prospective professional practice. Finally, every undergraduate and graduate degree program involves a requirement, i.e., Project, Thesis or Dissertation, in which the student is exposed to a variety of facilities of the department.

The following is a listing of the major laboratory facilities used for the advanced courses and research of the department.

**Biorobotics Laboratory Facilities**
The Biorobotics Laboratory (http://biorobots.cwru.edu/) consists of approximately 1080 square feet of laboratory and 460 square feet of office space. The lab includes two CNC machines for fabrication of smaller robot components. The lab’s relationship with CAISR (Center for Automation and Intelligent Systems Research) provides access to a fully equipped machine shop where larger components are fabricated. The laboratory hardware features several biologically inspired hexapod robots including two cockroach-like robots, Robot III and Robot IV. Both are based on the Blaberus cockroach and have 24 actuated revolute joints. They are 17 times larger than the insect (30 inches long). Robot IV is actuated with pneumatic artificial muscles. A compressed air facility has been installed to operate the robots. In addition, the lab contains structural dynamic testing equipment (sensors, DAQ boards, shakers) and an automated treadmill (5 feet by 6 feet) for developing walking robots. The Biorobotics Laboratory contains 20 PCs, and a dedicated LAN connected to the campus. Algor Finite Element Analysis software, Mechanical Desktop, and Pro/Engineer are installed for mechanical design and structural analysis. Also, the lab has developed dynamic simulation software for analyzing walking animals and designing walking robots.

**Distributed Intelligence and Robotics Laboratory**
The Distributed Intelligence and Robotics Laboratory (DIRL) is a new laboratory in the Department of Mechanical and Aerospace Engineering that facilitates research activities on robotics and mechatronics. The primary research focuses on distributed intelligence, multi-agent systems, biologically-inspired robotics and medical applications. The laboratory is currently being constructed to house self-sufficient facilities and equipment for designing, testing, and preliminary manufacturing. The DIRL also conduct theoretical research related to design methodology and control algorithms based on information theory, complexity analysis, and group theory.

**Mechanics of Materials Experimental Facility**
The major instructional, as well as research facility for experimental methods in mechanics of materials, is the Daniel K. Wright Jr. Laboratory. Presently, the facility houses a single-stage gas-gun along with tension/compression split Hopkinson bar and torsional Kolsky bar apparatus for carrying out fundamental studies in dynamic deformation and failure of advanced material systems. Hewlett Packard and Tektronix high speed, wide bandwidth digitizing oscilloscopes along with strain-gage conditioners and amplifiers are available for data recording and processing. The facility houses state-of-the-art laser interferometry equipment for making spatial and temporal measurements of deformation. High-speed Hg-Cd-Te detector arrays are available for making time-resolved multi-point non-contact temperature measurements.

A Schenck Pegasus digital servo-controlled hydraulic testing system with a 20kN Universal testing load frame equipped with hydraulic grips and instrumentation is available for quasi-static mechanical testing under load or displacement control. A newly developed moiré microscope is available for studying large-scale inelastic deformation processes on micron size scales. CCD camera along with the appropriate hardware/software for image acquisition, processing and analyzing of full field experimental data from optical interferometers such as moiré microscope, photo-elasticity, and other laser based spatial interferometers are available.

**Multiphase Flow and Laser Diagnostics Laboratory**
A laser diagnostics laboratory is directed toward investigation of complex two-phase flow fields involved in energy-related areas, bio-fluid mechanics of cardiovascular systems, slurry flow in pumps and thermoacoustic power and refrigeration systems. The laboratory is equipped with state-of-the-art Particle Image Velocimetry (PIV) equipment, Pulsed Ultrasound Doppler Velocimeter, Ultrasound concentration measurement instrumentation and modern data acquisition and analysis equipment including PCs. The laboratory houses a clear centrifugal slurry flow pump loop and heart pump loop. Current research projects include investigation of flow through microchip devices, CSF flow in ventricles, investigation of solid-slurry flow in centrifugal pumps using ultrasound technique and PIV, thermo-acoustic refrigeration for space application.

**Rotating Machinery Dynamics and Tribology Laboratory**
This laboratory focuses on rotating machinery monitoring and diagnostic methods relating chaos content of dynamic non-linearity and model-based observers’ statistical measures to wear and impending failure modes. A double-spool-shaft rotor dynamics test rig provides independent control over spin speed and frequency of an adjustable magnitude circular rotor vibration orbit for bearing and seal rotor-dynamic characterizations.

Simultaneous radial and axial time-varying loads on any type of bearing can be applied on a second test rig. Real-time control of rotor-mass unbalance at two locations on the rotor while it is spinning up to 10,000 rpm, simultaneous with rotor rubbing and shaft crack propagation, can be tested on a third rig. Self-excited instability rotor vibrations can be investigated on a fourth test rig.

**Musculoskeletal Mechanics and Materials Laboratories**
These laboratories are a collaborative effort between the Mechanical and Aerospace Engineering Department of the Case School of Engineering and the Department of Orthopaedics of the School of Medicine that has been ongoing for more than 40 years. Research activities have ranged from basic studies of mechanics of skeletal tissues and skeletal structures, experimental investigation of prosthetic joints and implants, measurement of musculoskeletal motion and forces, and theoretical modeling of mechanics of musculoskeletal systems. Many studies are collaborative, combining the forces of engineering, biology, biochemistry, and surgery. The Biomechanics Test labs include Instron mechanical test
machines with simultaneous axial and torsional loading capabilities, a non-contacting video extensometer for evaluation of biological materials and engineering polymers used in joint replacements, acoustic emission hardware, and software, and specialized test apparatus for analysis of joint kinematics. The Bio-imaging Laboratory includes microscopes and three-dimensional imaging equipment for evaluating tissue microstructure and workstations for three-dimensional visualization, measurement, and finite element modeling. An Orthopaedic Implant Retrieval Analysis lab has resources for characterization and analysis of hard tissues and engineering polymers, as well as resources to maintain a growing collection of retrieved total hip and total knee replacements that are available for the study of implant design. The Soft Tissue Biomechanics lab includes several standard and special test machines. Instrumentation and histology facilities support the activities within the Musculoskeletal Mechanics and Materials Laboratories.

nanoEngineering Laboratory

The nanoEngineering Laboratory focuses on research related to various nanotechnology applications with particular emphasis on energy conversion, generation, and storage in nanostructured and bio-inspired materials. Synthesis of polymer-based nanocomposites, nanofluids, and individual nanostructures is accomplished with tools available in the laboratory. Furthermore, the laboratory houses various pieces of equipment for thermal and electrical characterization of these materials. Research projects include investigation of nanocomposites for thermoelectric devices, molecular simulation of thermal transport across interfacial regions, characterization of nanomaterials for thermal management (of electronics and buildings) as well as thermal insulation applications, and biomimetic research on a protein-based shark gel.

Other Experimental Facilities

The department facilities also include several specialized laboratories.

Engineering Services Fabrication Center offers complete support to assist projects from design inception to completion of fabrication. Knowledgeable staff is available to assist Faculty, Staff, Students, Researchers, and personnel associated with Case Western Reserve University.

The Bingham Student Workshop is a 2380 sq.ft. facility complete with machining, welding, metal fabrication, and woodworking equipment. This facility is available for the Case undergrads in Mechanical Engineering. Before gaining access to the shop all ME students are required to take the EMAE 160, Mechanical Manufacturing course. This course gives the student a foundation in basic machining, welding, sheet metal fabrication, and safety. Manual drafting, design, and computer-aided drafting is also included in the course. After completion, the student can use the shop for other Mechanical Engineering courses requiring prototypes. The BSW, is also, used for senior projects and student organizations, such as the SAE Baja and Formula and the Design-Build and Fly.

The Harry A. Metcalf Laboratory in Glennan Hall Room 458, which was made possible through the generous gift of Sylvia Lissa to honor her late husband and Mechanical Engineering graduate, Class of 1903, has recently been renovated and updated. The restructuring of the computational lab and adjacent experimental lab takes advantage of the Case School of Engineering’s Virtual Desktop Infrastructure built on Citrix XenDesktop via gigabit networking. This high-speed networking provides access to software packages including SolidWorks, PTC Creo, MasterCam, Abaqus, MatLab, Microsoft Office, Mathematica, LabView, and many others. The lab is set up to allow the students to use their laptops or ones provided in the lab by the Department for course and project work. As a result of using the Virtual Desktop Infrastructure, engineering students will also be able to access the engineering software listed above from anywhere on any device. Students’ home drives are automatically mapped as well when using the virtual applications so that they have access to their files at all times on any device.

The Reinberger Design Studio includes a total of 33 Wyse terminals for Undergraduate Student design use. The Studio is tied directly to the campus network allowing information to be shared with the HAMCL and other network resources. The Studio is used for the instruction of the SolidWorks 2005 CAD software, MasterCam 9.0 CAM software, Solidworks CAD/CAM/FEA software, and Algor 16.1 FEA software. The RDS also offers a 3D Systems SLA 250 and a Dimension machine for generating SLA models from CAD models.

The Reinberger Product and Process Development Laboratory is a 1600 square feet of laboratory and office space dedicated to computer-aided engineering activities. The computer numerical control (CNC) laboratory includes both two industrial sized machine tools with additional space for lecture and group project activities. The CNC machine tools located in the laboratory are; a HAAS VF3 4 axis-machining center, a HAAS 2 axis lathe. A Mitutoyo coordinate measuring machine (CMM) located in its own laboratory space completes the facilities. The CMM enables students to inspect their manufactured components to a very degree of precision. The laboratory is used to support both undergraduate and graduate manufacturing courses (EMAE 390, EMAE 490).

High Performance Computing- For high performance computing the department uses the CWRU high performance computing cluster (HPCC). The HPCC consists of 112 compute nodes with Intel Pentium 4 Xeon EM64T processors. All nodes are interconnected with Gigabit Ethernet for MPI message passing and all nodes are interconnected by a separate Ethernet for the purpose of out-of-band cluster management. The MAE Department also has a direct access to all the Ohio Supercomputing Center and all NSF supercomputing centers, primarily to the Pittsburgh Supercomputing Center. Computing-intensive research projects can obtain an account on those supercomputers through their advisers. Research projects carried on in cooperation with the NASA Glenn Research Center can have access to NASA computing facilities. Sophisticated, extensive, and updated general and graphics software are available for applications in research and classroom assignments.

Courses

EMAE 160. Mechanical Manufacturing. 3 Units.

The course is taught in two sections—Graphics and Manufacturing. Manufacturing To introduce manufacturing processes and materials and their relationships to mechanical design engineering. Course includes hands-on machining and metal fabrication lab. Also, each lab creates a ‘virtual’ field trip of a manufacturing facility to be shared with the class. Graphics Development of mechanical engineering drawings in orthographic, sectional, and pictorial views using manual drafting and computer-aided drafting (CAD software), dimensioning, tolerancing geometric dimensioning and tolerancing and assembly drawings will also be covered. All students are paired up to give a Manufacturing Design Presentation demonstrating the course material. The course has two (75) minute lectures and one (110) minute Machining Lab per week.
Studio activities are an integral part of the course, and enable the managing product data through all stages of the product life-cycle (PLM). This understanding of the complex processes associated with controlling and the student to the integration of engineering design, manufacturing, management, engineering economics, and design for manufacture as a creative process, decision-based design methodologies, project execution, and evaluation of students' devices that include both actuators and transmission mechanisms. Recommended preparation: MATH 122 and PHYS 121 and ENGR 200.

EMAE 250. Computers in Mechanical Engineering. 3 Units.

EMAE 251. Thermodynamics. 3 Units.
Thermodynamic concepts and definitions, properties of pure substances, work and heat, first and second laws, entropy, power and refrigeration cycles, thermodynamic relations, mixtures and solutions, chemical reactions, phase and chemical equilibrium. Prereq: CHEM 111, PHYS 121 and MATH 122.

EMAE 252. Fluid Mechanics. 3 Units.
Fluid properties, hydrostatics, fluid dynamics and kinematics, control volume analysis, differential analysis, dimensional analysis and similarity, viscous internal flows, external flows and boundary layers, lift and drag. Prereq: EMAE 251 and MATH 223.

EMAE 260. Design and Manufacturing I. 3 Units.
This is the second course of a 4-course sequence focusing on "Engineering Design and Manufacturing." This course develops students' competence and self-confidence as design engineers by exposing the students to design as a creative process and its relationship with modern manufacturing practices. The outcomes of the course focus on the student's ability to apply their knowledge of mathematics, science, and engineering to design a system, component, or process that meets desired needs within realistic, multi-dimensional constraints, such as: economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. Additionally, students will be given the opportunity to identify, formulate, and solve engineering problems, while applying professional and ethical practices. Professional communication skills are emphasized and expected during all stages of the design process. The course has five main areas of emphasis: design as a creative process, decision-based design methodologies, project management, engineering economics, and design for manufacture (CAD/CAM/CAE) using industrial software tools. The course exposes the student to the integration of engineering design, manufacturing, and management disciplines and includes activities to consider and understand the complex processes associated with controlling and managing product data through all stages of the product life-cycle (PLM). Topics include: engineering ethics, design as a creative process, design methodologies, project management, engineering economics, product life-cycle management (PLM), CAD/CAE/CAM, and the role of digital manufacturing within the design process. Design/Rapid Prototyping Studio activities are an integral part of the course, and enable the students to be part of a design and build team working on various project-based tasks. Prereq: EMAE 160.

EMAE 272. Actuators and Drive Trains. 3 Units.
Graphical, analytical, and computer techniques for analyzing displacements, velocities, and accelerations in mechanisms. Analysis and synthesis of linkages, cams, and gears. Analysis of actuators, including motors, linear actuators, solenoids, hydraulics, pneumatics, piezoelectrics. Laboratory projects include analysis, design, construction, and evaluation of students' devices that include both actuators and transmission mechanisms. Prereq: EMAE 181 and EMAE 250.

EMAE 285. Mechanical Engineering Measurements Laboratory. 4 Units.
Techniques and devices used for experimental work in mechanical and aerospace engineering. Lecture topics include elementary statistics, linear regression, propagation of uncertainty, digital data acquisition, characteristics of common measurement systems, background for measurement laboratories, and elements of report writing. Hands-on laboratory experiences may include measurements in solid mechanics, dynamics, and fluid and thermal sciences, which are summarized in group reports. At least one report will focus on design of a measurement. Recommended preparation: EMAE 181, ENGR 225 and ECIV 310.

EMAE 290. Computer-Aided Manufacturing. 3 Units.
An advanced design and manufacturing engineering course covering a wide range of topics associated with the 'design for manufacturability' concept. Students will be introduced to a number of advanced solid modeling assignments (CAD), rapid prototyping (RP), and computer-aided manufacturing (CAM). In addition students will be introduced to computer numerical control (CNC) manual part-programming for CNC milling and turning machine tools. All students will be given a design project requiring all detail and assembly drawings for a fully engineered design. The course has two (50) minute lectures and one (110) minute CAD/CAM Lab per week. Prereq: EMAE 160.

EMAE 350. Mechanical Engineering Analysis. 3 Units.

EMAE 352. Thermodynamics in Energy Processes. 3 Units.
Thermodynamic properties of liquids, vapors and real gases, thermodynamic relations, non-reactive mixtures, psychometrics, combustion, thermodynamic cycles, compressible flow. Prereq: ENGR 225.

EMAE 353. Heat Transfer. 3 Units.
Steady-state and transient conduction, principles of convection, empirical relations for forced convection, natural convection, boiling and condensation, radiation heat transfer, heat exchangers, mass transfer. Prereq: EMAE 251 and EMAE 252.

EMAE 355. Design of Fluid and Thermal Elements. 3 Units.

EMAE 356. Aerospace Design. 3 Units.
Interactive and interdisciplinary activities in areas of fluid mechanics, heat transfer, solid mechanics, thermodynamics, and systems analysis approach in design of aerospace vehicles. Projects involve developing (or improving) design of aerospace vehicles of current interest (e.g., hypersonic aircraft) starting from mission requirements to researching developments in relevant areas and using them to obtain conceptual design. Senior standing required.
EMAE 359. Aero/Gas Dynamics. 3 Units.

EMAE 360. Design and Manufacturing II. 3 Units.
This is the third course of a 4-course sequence focusing on "Engineering Design and Manufacturing," and is the senior capstone design course focused on a semester-long design/build/evaluate project. The course draws on a student's past and present academic and industrial experiences and exposes them to the design and manufacture of a product or device that solves an open-ended "real world" problem with multidimensional constraints. The course is structured and time-tabled within the Case School of Engineering (CSE) to give the EMAE 360 students the opportunity to team with students from other CSE departments (e.g., BME and EECS) to form multidisciplinary design teams to work on the solution to a common problem. The outcomes of the course continue to focus on the student's ability to function on multidisciplinary teams while applying their knowledge of mathematics, science and engineering to design a system, component, or process that meets desired needs within realistic, multidimensional constraints, such as: economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. Professional communication skills are emphasized and expected during all stages of the design process and will include formal and informal oral presentations, periodic peer-focused design reviews, and a development through its various evolutionary stages to completion. Counts as SAGES Senior Capstone. Prereq: EMAE 160 and EMAE 260.

EMAE 363. Mechanical Engineering Modern Analysis Methods. 3 Units.
This is a required mechanical engineering course to develop an in-depth fundamental understanding of current analysis software tools, as well as to develop an ability to perform practical analyses using current software tools to analyze assigned industrial case studies for the following topical areas: (1) mechanism synthesis, (2) finite element analyses for stress and deflection, (3) machinery vibration, and (4) computational fluid dynamics. It is comprised of three lectures and one software application laboratory period per week. Prereq: ENGR 225, EMAE 181, EMAE 250, and ECIV 310.

EMAE 370. Design of Mechanical Elements. 3 Units.

EMAE 371. Computational Fluid Dynamics. 3 Units.

EMAE 372. Structural Materials by Design. 4 Units.

EMAE 376. Aerostructures. 3 Units.

EMAE 377. Biorobotics Team Research. 3 Units.
Many exciting research opportunities cross disciplinary lines. To participate in such projects, researchers must operate in multidisciplinary teams. The Biorobotics Team Research course offers a unique capstone opportunity for undergraduate students to utilize skills they developed during their undergraduate experience while acquiring new teaming skills. A group of eight students form a research team under the direction of two faculty leaders. Team members are chosen from appropriate majors through interviews with the faculty. They will research a biological mechanism or principle and develop a robotic device that captures the actions of that mechanism. Although each student will cooperate on the team, they each have a specific role, and must develop a final paper that describes the research generated on their aspect of the project. Students meet for one class period per week and two 2-hour lab periods. Initially students brainstorm ideas and identify the project to be pursued. They then acquire biological data and generate robotic designs. Both are further developed during team meetings and reports. Final oral reports and a demonstration of the robotic device occur in week 15. Offered as BIOL 377, EMAE 377, BIOL 467, and EMAE 477. Counts as SAGES Senior Capstone.

EMAE 378. Mechanics of Machinery I. 3 Units.
Comprehensive treatment of design analysis methods and computational tools for machine components. Emphasis is on bearings, seals, gears, hydraulic drives and actuators, with applications to machine tools. Recommended preparation: EMAE 370. Offered as EMAE 378 and EMAE 478.

EMAE 382. Propulsion. 3 Units.

EMAE 383. Flight Mechanics. 3 Units.
EMAE 384. Orbital Dynamics. 3 Units.
Spacecraft orbital mechanics: the solar system, elements of celestial mechanics, orbit transfer under impulsive thrust, continuous thrust, orbit transfer, decay of orbits due to drag, elements of lift-off and re-entry. Rigid body dynamics, altitude dynamics and control, simulations.

EMAE 387. Vibration Problems in Engineering. 4 Units.

EMAE 390. Advanced Manufacturing Technology. 3 Units.
This course will focus on advanced manufacturing technologies and processes, with an emphasis on the fundamental understanding of the material behaviors and process in the manufacturing operations. Topics will include: materials in manufacturing, glass manufacturing, polymer composite manufacturing, metal casting, metal machining, metal forming, grinding, welding, heat treatment, and quality control. The course will be lecture-based, with lab-based class project in the machine shop and think[box] studios. Prereq: EMAE 290.

EMAE 396. Special Topics in Mechanical and Aerospace Engineering. 1 - 18 Units.
(Credit as arranged.)

EMAE 397. Independent Laboratory Research. 1 - 3 Units.
Independent research in a laboratory.

EMAE 398. Senior Project. 3 Units.
Individual or team design or experimental project under faculty supervisor. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Recommended preparation: Senior standing, EMAE 360, and consent of instructor. Counts as SAGES Senior Capstone.

EMAE 399. Advanced Independent Laboratory Research/Design. 1 - 3 Units.
Students perform advanced independent research or an extended design project under the direct mentorship of the instructor. Typically performed as an extension to EMAE 397 or EMAE 398. Prereq: EMAE 397.

EMAE 400T. Graduate Teaching 1. 0 Unit.
This course will engage the Ph.D. candidate in a variety of teaching experiences that will include direct contact (for example, teaching recitations and laboratories, guest lectures, office hours) as well non-contact preparation (exams, quizzes, demonstrations) and grading activities. The teaching experiences will be conducted under the supervision of the faculty member(s) responsible for coordinating student teaching activities. All Ph.D. candidates enrolled in this course sequence will be expected to perform direct contact teaching at some point in the sequence. Recommended preparation: Ph.D. student in Mechanical Engineering.

EMAE 401. Mechanics of Continuous Media. 3 Units.
Vector and tensor calculus. Stress and traction, finite strain and deformation tensors. Kinematics of continuous media, general conservation and balance laws. Material symmetry groups and observer transformation. Constitutive relations with applications to solid and fluid mechanics problems.

EMAE 414. Nanobiomechanics in Biology. 3 Units.
This course will elucidate the forces at play at the level of proteins including those associated with mass, stiffness, viscosity, thermal and chemical factors. Basic polymer mechanics within the context of biological molecules will be covered and structures of key proteins associated with mechanical functions, such as actin, myosin and the cell membrane will be explained. Generation of force by polymerization of filamentous proteins as well as motor proteins will be included. Interaction forces between proteins, DNA/RNA mechanics will also be elucidated. Besides lectures, there will be term long project assignments (outreach-based or detailed literature survey on a subject associated with nanomechanics of cells/proteins). Recommended Preparation: Mechanics of Materials, Thermodynamics, Statics, Introductory Level Differential Equations, Introductory Level Fluid Mechanics.

EMAE 415. Introduction to Musculo-skeletal Biomechanics. 3 Units.

EMAE 421. Multiscale Modeling of Bio- and Bio-inspired Systems. 3 Units.
Depending on who you ask, the topic of Multiscale Computational Modeling is either a hot topic or passé; multiscale modeling is either a key to deciphering cellular mechanisms, e.g., of organismal mechanobiology, or an impossibility due to the necessity of unlimited access to super computers and ultrahigh resolution imaging that allow for explicit definition of organ scale events at subcellular length and time scales (and that require access to data storage of greater than terabyte scale databases). If you ask me, we are already "doing multiscale modeling", but new computational and experimental approaches are presenting opportunities to reach the goal of tying organ scale mechanical loading (physiological loading events) to cellular mechanisms of e.g. tissue modeling and remodeling during development, growth, aging, as well as in health and disease. In this graduate level class we will address one particular mechanobiological system as a case study (Spring 2013: Bone as a Biosystem) and then extrapolate approaches to student-driven, relevant biological, bio-inspired and medical problems. Typically graduate students participating in the class are developing computational models as part of their graduate research; tying the in the class topics to the student's research modeling serves as the "lab" for this class and the student reports on these activities both in class as well as in the initial review paper, the multiscale model to be developed by the student, and the final class paper which should be prepared for submission to a relevant journal. Students will keep a lab/modeling notebook throughout the course to develop the ideas and concepts introduced in the course in context of their own bio- or bio-inspired system of interest. The biological system of interest and the problem to be addressed will be developed using typical engineering problem approach rubrics (problem statement/hypothesis, governing equations, idealizations/assumptions, initial & boundary conditions, knows/unknowns, in-/dependent variables) to predict system behavior using a comp model. Recommended Preparation: Senior undergraduates in engineering recommended to have completed ENGR 225 and ECIV 310 and an engineering GPA above 3.25. Prereq: Senior undergraduates in Engineering, GPA greater or equal to 3.25.
EMAE 424. Introduction to Nanotechnology. 3 Units.
An exploration of emerging nanotechnology research. Lectures and class discussion on 1) nanostructures: superlattices, nanowires, nanotubes, quantum dots, nanoparticles, nanocomposites, proteins, bacteria, DNA; 2) nanoscale physical phenomena: mechanical, electrical, chemical, thermal, biological, optical, magnetic; 3) nanofabrication: bottom up and top down methods; 4) characterization: microscopy, property measurement techniques; 5) devices/applications: electronics, sensors, actuators, biomedical, energy conversion. Topics will cover interdisciplinary aspects of the field. Offered as EECS 424 and EMAE 424.

EMAE 450. Advanced Mechanical Engineering Analysis. 3 Units.
This course is intended to equip students with tools for solving mathematical problems commonly encountered in mechanical, fluid and thermal systems. Specific goals are to: i) Enable the student to properly categorize the problem in a variety of ways ii) Enable the student to identify appropriate approaches to solving the problem iii) Provide the student experience in applying some common methods for obtaining numerical solutions iv) Provide the student with understanding of trade-offs and expectations for the methods used. The course covers topics related to analytical and computational approaches to problems categorized in a variety of ways including: 1. Linear versus nonlinear problems 2) finite degrees of freedom v. infinite degrees of freedom, 3) equilibrium v. propagation v. eigenvalue problems, 4) direct formulations v. indirect formulations 5) analytical v. numerical solutions. The course will be built around specific examples from solid mechanics, dynamics, vibrations, heat transfer and fluid mechanics. The significance of the various categorizations will be developed as an ongoing part of the approach to solving the problems. Prereq: EMAE 350 or Requisites Not Met permission.

EMAE 453. Advanced Fluid Dynamics I. 3 Units.
Derivation and discussion of the general equations for conservation of mass, momentum, and energy using tensors. Several exact solutions of the incompressible Newtonian viscous equations. Kinematics and dynamics of inviscid, incompressible flow including free streamline theory developed using vector, complex variable, and numerical techniques.

EMAE 454. Advanced Fluid Dynamics II. 3 Units.

EMAE 455. Advanced Thermodynamics. 3 Units.
Basic ideas of thermodynamics and dominant methods of their development: operational, postulational, and statistical. Entropy and information theory. Irreversible thermodynamics. Applications.

Microscale technologies have enabled advanced capabilities for researchers in unexplored territories of cells in biology and medicine. Biological (or Biomedical) Micro-Electro-Mechanical Systems (MEMS) and Biomimualufiing involve the fundamentals of mechanics, electronics and advanced microfabrication technologies with specific emphasis on biological applications. MEMS is an interdisciplinary research area which brings together multiple disciplines including, mechanical engineering, biomedical engineering, chemical engineering, materials science, electrical engineering, clinical sciences, medicine, and biology. MEMS based technologies have found real world applications in tissue engineering, implantable microdevices, proteomics, genomics, molecular biology, and point-of-care platforms. This course aims to: (1) introduce the need for miniaturized systems in biology and medicine and the fundamental design and microfabrication concepts, (2) introduce the basics of microscale manipulation of cells, biological agents, and biomanufacturing, employing the fundamentals of microscale behaviors of fluids and mechanical systems, (3) expose the students to applications of MEMS and on-chip technologies in biology and medicine.

EMAE 457. Combustion. 3 Units.
Chemical kinetics and thermodynamics; governing conservation equations for chemically reacting flows; laminar premixed and diffusion flames; turbulent flames; ignition; extinction and flame stabilization; detonation; liquid droplet and solid particle combustion; flame spread, combustion-generated air pollution; applications of combustion processes to engines, rockets, and fire research.

EMAE 459. Advanced Heat Transfer. 3 Units.
Analysis of engineering heat transfer from first principles including conduction, convection, radiation, and combined heat and mass transfer. Examples of significance and role of analytic solutions, approximate methods (including integral methods) and numerical methods in the solution of heat transfer problems. Recommended preparation: EMAE 453.

EMAE 460. Theory and Design of Fluid Power Machinery. 3 Units.
Fluid mechanic and thermodynamic aspects of the design of fluid power machinery such as axial and radial flow turbomachinery, positive displacement devices and their component characterizations. Recommended preparation: Consent of instructor.
EMAE 461. Chemistry of Fire Safe Polymers and Composites. 3 Units.
Chemistry of Fire Safe Polymers and Composites starts with the introduction of characterization techniques used for fire safe materials and combustion phenomena research. General discussion on how reduced flammability of polymers and composites are obtained, for example by additives and preparing intrinsically thermally stable chemical structure and some examples of smart approaches, will be discussed. It also discusses the synthetic methods of preparing high temperature stable polymers in addition to the raw materials used to prepare those materials. Special emphasis will be placed on the thermal stability data obtained by thermogravimetric analysis (TGA) and combustion calorimetry for those fire safe materials. Mechanistic aspects of the flammability of polymers will be explained with special emphasis on the molar contribution of chemical functionality to the heat release capacity. Theoretical derivation of thermokinetic parameters will be explained. In addition, a common sense build-up will be attempted by providing actual numbers associated with those thermokinetic parameters. Upon completion of background formation, a more advanced materials, composites and nanocomposites, will be discussed using the results recently reported. Preliminary attempts to explain flame retardation by nanocomposite structures will also be discussed. Offered as EMAE 461 and EMAE 461.

EMAE 463. Fire Dynamics. 3 Units.
This course introduces compartment fires and burning behavior of materials. Topics include: buoyant driven flow, fire plume, ceiling jet, vent flow, flashover and smoke movement as well as steady burning of liquids and solids; ignition, extinction and flame spread over solids. Recommended Preparation: Elementary knowledge in thermo-fluids is required. Offered as EMAE 463 and EMAC 463. Prereq: EMAE 325 or Requisites Not Met permission.

EMAE 464. Fire Protection Engineering. 3 Units.
This course introduces essentials of fire protection in industry and houses. Topics include: hazard identification (release of flammable gases and their dispersion), fire and explosion hazards, prevention and risk mitigation, fire detection systems, mechanisms of fire extinguishment, evaluation of fire extinguishing agents and systems. Offered as EMAE 464 and EMAE 464.

EMAE 466. Mechanics of Biological Fluids. 3 Units.
This is a senior/graduate level course which aims to provide a solid grasp of the role of mechanics in biological fluids and in the human circulatory system that will help in the research and design of new medical instruments, equipment, and procedures. The course will cover properties of Newtonian and non-Newtonian fluids, hydrostatic and dynamic forces, principles of continuity, conservation of mass, energy and momentum and their applications in biological fluids, laminar and turbulent flows and boundary layer, introduction to Navier Stokes, dimensional analysis and similarity, blood flow in the cardiovascular system, gas exchange in the pulmonary system, blood flow in microcirculation and vessels. Important concepts will be covered by case studies.

EMAE 471. Computational Fluid Dynamics. 3 Units.

EMAE 477. Biorobotics Team Research. 3 Units.
Many exciting research opportunities cross disciplinary lines. To participate in such projects, researchers must operate in multidisciplinary teams. The Biorobotics Team Research course offers a unique capstone opportunity for undergraduate students to utilize skills they developed during their undergraduate experience while acquiring new teaming skills. A group of eight students form a research team under the direction of two faculty leaders. Team members are chosen from appropriate majors through interviews with the faculty. They will research a biological mechanism or principle and develop a robotic device that captures the actions of that mechanism. Although each student will cooperate on the team, they each have a specific role, and must develop a final paper that describes the research generated on their aspect of the project. Students meet for one class period per week and two 2-hour lab periods. Initially students brainstorm ideas and identify the project to be pursued. They then acquire biological data and generate robotic designs. Both are further developed during team meetings and reports. Final oral reports and a demonstration of the robotic device occur in week 15. Offered as BIOL 377, EMAE 377, BIOL 467, and EMAE 477. Counts as SAGES Senior Capstone.

EMAE 478. Mechanics of Machinery I. 3 Units.
Comprehensive treatment of design analysis methods and computational tools for machine components. Emphasis is on bearings, seals, gears, hydraulic drives and actuators, with applications to machine tools. Recommended preparation: EMAE 370. Offered as EMAE 378 and EMAE 478.

EMAE 480. Fatigue of Materials. 3 Units.

EMAE 481. Advanced Dynamics I. 3 Units.

EMAE 487. Vibration Problems in Engineering. 3 Units.
EMAE 488. Advanced Robotics. 3 Units.
This course will focus on up-to-date knowledge and theories related to robotics and multi-agent systems. Related mathematics and theories including group theory (Lie groups), rigid-body motions (SO(3) and SE(3)), kinematics, dynamics, and control will be studied. In addition, the class will also discuss structural, computational and task complexity in robotic systems based on combinatorial analysis, information theory, and graph theory. Lecture and discussion topics: Kinematics; Introduction to Group Theory and Lie Groups; Rigid-body Motions (SO(3), SE(3)); Multi-body Dynamical Systems: Order-N computational methods; Complexity Analysis for Robotic Systems; Structural complexity, information-theoretic complexity, and task complexity; Special Discussion Topics; Special discussion topics may vary each year. Students enrolled in this class will be required to conduct a final project. Two or three students will work as a team. The topics for student teams may include: computer simulation of multi-body dynamical systems, art robot design, and complexity analysis for coupled complex systems. The detailed information will be provided in the first week of the class. The final presentations and demonstrations will be held during the last week of class and will be open to the public audience. Students are also required to submit a final report following a IEEE conference paper template.

EMAE 489. Robotics I. 3 Units.

EMAE 494. Energy Systems. 3 Units.
The overarching goal of this course is to introduce energy systems to graduate students, allowing the class to explore energy resource options and technologies. We will evaluate (from a scientific, mathematical and societal perspective) the trade-offs and uncertainties of various energy systems and explores a framework for assessing solutions. Topics will include resource estimation, environmental effects and economic evaluations of fossil fuels, nuclear power, hydropower, solar energy and more. Prereq: Junior or Senior Undergraduate Engineering major or Graduate Engineering major.

EMAE 500T. Graduate Teaching II. 0 Unit.
This course will engage the Ph.D. candidate in a variety of teaching experiences that will include direct contact (for example, teaching, recitations and laboratories, guest lectures, office hours) as well non-contact preparation (exams, quizzes, demonstration) and grading activities. The teaching experience will be conducted under the supervision of the faculty member(s) responsible for coordinating student teaching activities. All Ph.D. candidates enrolled in this course sequence will be expected to perform direct contact teaching at some point in the sequence. Recommended preparation: Ph.D. student in Mechanical Engineering.

EMAE 501. Constitutive Modeling of Solids. 3 Units.
Fundamentals of constitutive modeling of deformable solids. Hyperelastic, viscoelastic, plastic, and viscoplastic material responses and how microstructural mechanisms influence the macroscopic mechanical behavior in different materials. The course also aims at equipping students with necessary background to develop constitutive models that can be used in commercial/research finite element software for the analysis of complex structures and components. Prereq: EMAE 401.

EMAE 540. Advanced Dynamics II. 3 Units.

EMAE 552. Viscous Flow Theory. 3 Units.
Compressible boundary layer theory. Blowing and suction effects. Three-dimensional flows; unsteady flows. Introduction to real gas effects. Recommended preparation: EMAE 454.

EMAE 554. Turbulent Fluid Motion. 3 Units.

EMAE 557. Convection Heat Transfer. 3 Units.
Energy equation of viscous fluids. Dimensional analysis. Forced convection; heat transfer from non-isothermal and unsteady boundaries, free convection and combined free and forced convection; stability of free convection flow; thermal instabilities. Real gas effects, combined heat and mass transfer; ablation, condensation, boiling. Recommended preparation: EMAE 453 and EMAE 454.

EMAE 558. Conduction and Radiation. 3 Units.
Fundamental law, initial and boundary conditions, basic equations for isotropic and anisotropic media, related physical problems, steady and transient temperature distributions in solid structures. Analytical, graphical, numerical, and experimental methods for constant and variable material properties. Recommended preparation: Consent of instructor.

EMAE 560. Sustainable Manufacturing. 3 Units.
This course provides an in-depth presentation of a number of important topics related to sustainable manufacturing processes and systems. The topics cover contents ranging from conventional manufacturing to emerging nano-manufacturing techniques. Some of the important goals of this course are: a. Students learn to understand the fundamental methods and techniques of sustainable manufacturing. b. Students learn the cutting-edge theory and practices in sustainable manufacturing on improving the sustainability performance or developing sustainable processes from real industrial practices. c. Students learn state-of-the-art knowledge on environmental impact assessment methods of industrial pollutants. d. Students apply the learned knowledge and skills in class discussions and project implementation. Prereq: EMAE 390.

EMAE 600T. Graduate Teaching III. 0 Unit.
This course will engage the Ph.D. candidate in a variety of teaching experiences that will include direct (for example, teaching recitations and laboratories, guest lectures, office hours) as well non-contact preparation (exams, quizzes, demonstrations) and grading activities. The teaching experience will be conducted under the supervision of the faculty member(s) responsible for coordinating student teaching activities. All Ph.D. candidates enrolled in this course sequence will be expected to perform direct contact teaching at some point in the sequence. Recommended preparation: Ph.D. student in Mechanical Engineering.
Co-op is available to students who have completed 4-5 semesters of coursework, in good academic standing, registered as a full-time student, and pursuing a degree in engineering, engineering physics, or physics. Registration in this course will serve to maintain full-time student status for the period of time that the student is on a co-op assignment.

Graduate Cooperative Education is an academic program designed for graduate students to enhance their classroom, laboratory, and research learning through participation and experience in various organizational/industrial environments where theory is applied to practice. Co-op is a paid full-time work experience for one seven-month period. Students must obtain approval from their academic advisor prior to accepting a co-op position. Graduate cooperative education experiences may be integrated with the student's thesis or research project areas, or be solely for the purpose of gaining professional experience related to the student's major field of study. Registration in this course will serve to maintain full-time student status for the period of time the student is on a co-op assignment. A large variety of companies hire and train the co-op students providing quality and challenging experiences. For additional information, please contact Genine Apidone (genine.apidone@case.edu) or 216.368.5024.

Dual Degree (3+2) Engineering Program
The Dual Degree (3+2) (http://engineering.case.edu/academics/dual-degree-program) Engineering Program enables superior undergraduate students, enrolled at approximately forty participating liberal arts colleges in the continental United States and Puerto Rico, to combine a strong liberal arts foundation with the study of engineering. While enrolled at a cooperating liberal arts college, students complete courses in mathematics, chemistry, physics, and computer science in addition to studies in the humanities and social sciences. Students complete these courses during their first three years and must obtain the approval of the designated faculty liaison at the liberal arts college prior to admission to the Case School of Engineering.

Qualified candidates continue at the Case School of Engineering for an additional two years of concentrated coursework in an engineering field. At the conclusion of five years, two baccalaureate degrees are awarded: one from the liberal arts college and the other in the Bachelor of Science in Engineering degree program from Case Western Reserve University. For additional information, please contact Deborah Fatica (deborah.fatica@case.edu) or 216.368.4449.

Engineering Academic Community Engagement
The DELPP develops strategic and intentional programming designed to engage students and promote a strong and supportive campus community.

Joint activities with faculty, alumni, staff and corporate sponsors include, but are not limited to: leadership opportunities in Engineering student organizations including National Engineers Week and the Dean's Student Advisory Committee, hands-on industry-sponsored design competitions, and networking and mentoring with alumni and faculty.

Global Programs
Global Programs (http://engineering.case.edu/outside-classroom/global-opportunities) offer international opportunities for engineering students ranging from study abroad to short-term programs, internships and cooperative education experiences, and research opportunities.
Participation in global activities optimizes the student's educational experience as well as contributes to their societal awareness. Exposure to global activities is a valuable asset for leadership positions within multinational corporations.

The Division of Engineering Leadership and Professional Practice designs and implements programs tailored to students' interests. Currently, short-term cultural and language immersion programs are offered in the summer at various international universities, with more being established. At the University of Botswana, a three-week engineering core course is taught, which intertwines engineering content with regional issues specific to sub-Saharan Africa. Additional Engineering core courses are being taught abroad during the summer.

The Case School of Engineering hosts many students from various countries which enables students to learn about and interact with various cultures. New programs and opportunities continue to develop for students.

On the graduate level, the Case School of Engineering is establishing partnerships with top-ranked international universities to host 3+1+1 students. This program enables students to receive a bachelor's degree from their home university along with receiving a master's degree from the Case School of Engineering.

Approximately 80% of the Case School of Engineering faculty collaborate with over one hundred universities and organizations in over thirty countries spanning six continents. For additional information, please contact Deborah Fatica (deborah.fatica@case.edu) or 216.368.4449.

**PreK-12 Outreach**

PreK-12 outreach is managed through the Leonard Gelfand STEM Center (http://gelfand.case.edu), a collaboration between the Case School of Engineering and the College of Arts and Sciences. The goals of the STEM Center are to: (1) broaden participation in STEM fields by increasing the number and diversity of students in the STEM disciplines at Case Western Reserve University and elsewhere and (2) increase students' scientific literacy through a variety of innovative STEM programs. The Gelfand STEM Center leverages the resources of Case Western Reserve University to engage pre-college students, teachers, and families in activities that introduce them to scientific practices and concepts, intended to inspire a lasting interest in science and engineering. For additional information, please contact Me'iani Labat Joseph (melani.joseph@case.edu) or 216.368.1651.
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