COLLEGE OF ENGINEERING

Leo Kempel, DEAN

The College of Engineering prepares its students to solve technical, as well as social, economic, and global problems while instilling the essence of engineering – the iterative process of designing, predicting performance, building, and testing. Our engineering programs provide future engineers with firm knowledge and understanding of the fundamental engineering sciences, of engineering methods for the application of this knowledge and the project management and communications skills to bring designs to fruition. Programs require a strong base in mathematics, computing, and the sciences as the tools of the engineer. An engineering education provides a teams-based, systems approach to societal problems and therefore prepares students for a wide range of career options, including those outside engineering.

UNDERGRADUATE PROGRAMS

Programs With a Major in the Engineering Professional Fields

The Bachelor of Science degree may be earned in programs designed to prepare students for work in biosystems engineering, chemical engineering, civil engineering, computer engineering, electrical engineering, environmental engineering, materials science and engineering, mechanical engineering and technology engineering.

Programs With a Major in the Engineering Sciences

The Bachelor of Science degree may also be earned in engineering sciences with a major in computer science, computational data science, or applied engineering sciences. A required cognate combines the Computer Science major with studies such as business management, the social and behavioral or physical sciences, or a foreign language. The Computational Data Science major combines computing, mathematics, and statistics to provide an in-depth understanding of complex data sets. The Applied Engineering Sciences major is an interdisciplinary program that combines a broad foundation in core engineering disciplines with a required concentration area in business law, computer science, packaging, supply chain management, technical sales, or media and information.

Engineering Education Abroad

The field of engineering increasingly requires global perspective. Education abroad provides unparalleled cultural learning experiences that can strengthen academic goals, fit degree requirements, while providing opportunities for students to study in a variety of countries. Students interested in education abroad should contact their Engineering academic advisor as soon as possible.

Minors

Students who are enrolled in bachelor's degree programs in the college may elect the Minor in Environmental and Sustainability Studies. For additional information, refer to the statement on *Minor in Environmental and Sustainability Studies* in the *College of Natural Science* section of this catalog.

Students who are enrolled in bachelor's degree programs in The Eli Broad College of Business, the College of Communication Arts and Sciences, and the College of Engineering may elect a Minor in Information Technology. For additional information, refer to the statement on *Minor in Information Technology* in *The Eli Broad College of Business* section of this catalog or contact The Eli Broad College of Business.

Students who are enrolled in the Bachelor of Science degree in Computer Science in the College of Engineering may elect a Minor in Game Design and Development. For additional information, refer to the statement on *Minor in Game Design and Development* in the *Department of Media and Information* section of this catalog.

Experiential Education - The Center for Spartan Engineering

The College of Engineering offers a variety of opportunities for students to gain real-world experience in the field of engineering. These programs prepare students for work in industry or to enter graduate programs in engineering, medicine, law, or business. They include cooperative education, engineering internships, and undergraduate research. Cooperative Engineering Education is a program of alternating full-time employment in industry and full-time study on campus. Employment provides practical on-the-job experience by exposing students to types of work done by engineers. Locations of jobs are nationwide and students are given the opportunity to explore other regions of the country.

Engineering internships are usually one time-only, career based experiences usually completed during the summer semester. Internships provide practical on-the-job experience in the field of engineering. Undergraduate research opportunities are also available at Michigan State University and throughout the United States. Students who are considering graduate school are encouraged to participate in an undergraduate research program for exposure to research opportunities and protocol at the graduate level.

Each of these options can be eligible for engineering credit through a series of low cost, pass-fail experiential education courses. Any student who completes a combination of three full-time registered experiences in a pre-professional position that have been approved and assessed by the College of Engineering will receive a Certificate of Experiential Education. Students interested in any of these programs should contact The Center for Spartan Engineering in Room C108 Wilson Hall.

Honors Study

The College of Engineering encourages honors students to develop distinctive programs of study in engineering or computer science to satisfy their Honors College requirements. Honors advisors will help students tailor a program to suit a student's individual interests and abilities. This often includes the Honors Option by which students may earn Honors credits in courses approved by departments both within and outside the college

Accreditation

Currently, the Biosystems Engineering, Chemical Engineering, Civil Engineering, Computer Engineering, Electrical Engineering, Environmental Engineering, Materials Science and Engineering, and Mechanical Engineering undergraduate programs are accredited by the Engineering Accreditation Commission of ABET, *https://www.abet.org*. The Computer Science undergraduate program is accredited by the Computing Accreditation Commission of ABET, *https://www.abet.org*.

Licensure as a Professional Engineer

In Michigan, the Michigan Board of Professional Engineering provides an opportunity for students during their senior year to take the first half of a sixteen–hour, two–part examination as the first step toward licensure, provided the degree is to be awarded within six months and the degree program is one that has been accredited by the Engineering Accreditation Commission of ABET or determined as equivalent by the Michigan Board of Professional Engineering.

Freshmen

Students admitted to the university are enrolled in the Neighborhood Student Success Collaborative, but may declare a pre-engineering major preference in the College of Engineering. Such students are guided by a professional advisor from the college. All students are encouraged to review their progress with an advisor each semester. Students become eligible for admission to the college upon completion of the requirements listed below in the *Admission to the College* section of this catalog.

Students interested in engineering but not yet sure of a major may be an Engineering Exploratory major until attaining 56 credits, but students are encouraged to make their major selection as early as possible.

Students who elect a pre-engineering major preference should be strongly prepared in mathematics and sciences. Additional work in these areas is highly desirable and may make advanced placement in courses possible. Students entering with less than the minimum mathematics prerequisites may take some of the necessary courses after entering the University. However, such students will need additional time to complete the work for the degree.

The Engineering CoRe Experience

The CoRe Experience integrates first year engineering academics and co-curricular/residential activities to support the academic, professional, and personal growth of engineering students during their first year at Michigan State University. CoRe seeks to demonstrate to students the importance of engineering and the positive impact that engineers make on society and the world around them. Along with community and corporate partners, we bring real-world expertise and challenges into the classroom and residential environment, reinforcing the relevance of engineering to solving global challenges.

CoRe's academic program is based on the principle that engagement in meaningful engineering experiences early in students' undergraduate careers supports their success and persistence to graduation. Through our courses, EGR 100: Introduction to Engineering Design and EGR 102: Introduction to Engineering Modeling, we strive to engage students across the disciplines in team-based projects that pique their interest and give them a window into what professional engineering really is. CoRe co-curricular activities connect students to each other, to the College of Engineering, and to corporate partners, helping students persist and succeed as engineering students and campus citizens.

Supportive Services

The college provides a full range of supportive services including professional academic advising, tutoring, services for underrepresented and female students, career guidance and employment assistance, faculty connections, and peer mentors.

Admission to the College

Admission to the College of Engineering and a specific major provides access to enroll in certain courses required for the major. Enrollments in the College of Engineering are limited. Admission is based on the cumulative grade–point average of all courses taken and a grade–point average calculated on mathematics, physical and biological sciences, and engineering courses.

For additional information, students should contact the Undergraduate Studies Office in the College of Engineering.

Minimum criteria for admission to all programs except Technology Engineering are:

1. Completion of at least 28 credits earned after matriculation to Michigan State University.
2. Completion of Mathematics 132 and 133 with a minimum grade of 2.0 in each course.
3. A minimum grade-point average of 2.0 in all mathematics courses.
4. Completion of Chemistry 141 or 151 or approved substitution or waiver. Computational Data Science and Computer Science majors are not required to fulfill this requirement.
5. Completion of Physics 183.
6. Completion of Engineering 102 or Computer Science and Engineering 231 or Computer Science and Engineering 220 Computational Mathematics, Science and Engineering 202 or approved substitution or waiver.
7. Completion of Engineering 100.

Minimum criteria for admission to the Technology Engineering program:

1. Completion of at least 28 credits earned after matriculation to Michigan State University.
2. Completion of Mathematics 116 and 132 with a minimum grade of 2.0 in each course.
3. A minimum grade-point average of 2.0 in all mathematics courses.
4. Completion of Chemistry 141 or 151 or approved substitution or waiver.

5. Completion of Physics 183 or 231.
6. Completion of Engineering 102 or Computer Science 231.
7. Completion of Engineering 100.

Students interested in applying for a degree granting major in the College of Engineering may apply for admission during each semester, and applications will be reviewed after the end of each semester. Students must be admitted to a degree-granting college at the time they have completed 56 credits. Students must be admitted to a degree-granting college at the time they have completed 56 credits.

Admission to a Second Bachelor's Degree Program

Students seeking admission to a second bachelor's degree program must meet the same requirements as for admission to the college.

Graduation Requirements for All Majors

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of the catalog; 120 credits, including general elective credits, are required for the Bachelor of Science degree in Computational Data Science, Bachelor of Science degree in Computer Science and the Bachelor of Science degree in Applied Engineering Sciences; and 128 credits, including general elective credits, are required for the Bachelor of Science degree in the other Engineering majors.

   Students who are enrolled in majors leading to the Bachelor of Science degree in the College of Engineering may complete an alternative track to Integrative Studies in Biological and Physical Sciences that consists of the following courses:
   a. One of the following courses: Biological Science 161; Plant Biology 105; Entomology 205; Integrative Biology 150; Microbiology and Molecular Genetics 141, 201, 301; Physiology 250.
   b. Two of the following courses: Chemistry 141, Chemistry 151, Physics 183 or 183B, Physics 184 or 184B. Technology Engineering majors may use Physics 231 or 232.
   c. One of the following laboratory courses: Plant Biology 106; Chemistry 161; Physics 191. Technology Engineering majors may use Physics 251.

   Credits earned in the alternative track may also be counted toward college and major requirements for the Bachelor of Science degree.
2. The requirements of the College of Engineering for the Bachelor of Science degree in all majors other than Technology Engineering that are listed below:
   a. Mathematics 132, 133, 234, and 235. Computational Data Science and Computer Science majors are not required to complete Mathematics 235.
   b. Chemistry 141 or 151. Computational Data Science and Computer Science majors are not required to complete Chemistry 141 or 151.
   c. Physics 183 or 183B and 184 or 184B.
   d. Engineering 100.
   e. One technical computing course depending on intended major: CMSE 202 (Computational Data Science), CSE 220 (Electrical Engineering), CSE 231 (Computer Science, Computer Engineering, Mechanical Engineering) or EGR 102 (all other Engineering majors).
3. The requirements of the College of Engineering for the Bachelor of Science degree in Technology Engineering that are listed below:
   a. Mathematics 116 and 132.
   b. Chemistry 141 or 151.
   c. Physics 183 or 183B or 231 and 184 or 184B or 232.
   d. Engineering 100.
   e. Engineering 102.
   f. Computer Science and Engineering 231.

Students who are enrolled in bachelor's degree programs in the College of Engineering may elect a Minor in Environmental and Sustainability Studies. For additional information, refer to the *Minor in Environmental and Sustainability Studies* statement in the *College of Natural Science* section of this catalog.

Students who are enrolled in the Bachelor of Science Degree in Computer Science in the College of Engineering may elect a Minor in Game Design and Development. For additional information, refer to the *Minor in Game Design and Development* statement in the *Department of Media and Information* section of this catalog.

Students who are enrolled in bachelor's degree programs in the College of Engineering may elect a Minor in Information Technology. For additional information, refer to the *Minor in Information Technology* statement in *The Eli Broad College of Business* section of this catalog.

APPLIED ENGINEERING SCIENCES

The Applied Engineering Sciences major provides undergraduate opportunities leading to the Bachelor of Science degree. The core goal of applied engineering sciences is to prepare technically competent, broad-based engineering graduates who have acquired a systems perspective for problem-solving and business expertise. The program provides a broad foundation in science and mathematics, engineering, and business management and is designed to develop graduates who can apply the rigor of their technical education to diverse problems and settings. The program is structured to establish skills in areas such as effective management, contemporary technical issues, deployment of new technologies, resolving ethical dilemmas, effective communication across technical disciplines both in oral and written communication, and lifelong learning.

Requirements for the Bachelor of Science Degree in Applied Engineering Sciences

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 120 credits, including general elective credits, are required for the Bachelor of Science degree in Applied Engineering Sciences.

   Students who select the Business Analytics concentration will be required to complete 133 credits for the degree.

   The University's Tier II writing requirement for the Applied Engineering Sciences major is met by completing Applied Engineering Sciences 410. That course is referenced in item 3. a. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

			CREDITS
a. All of the following courses (41 credits):			
ACC	230	Survey of Accounting Concepts	3
AESC	110	AES as a Profession	1
AESC	210	Global Systems: Economics, Engineering, Environment	3
AESC	310	Sustainable Systems Analysis	3
AESC	410	Capstone Project in Applied Engineering Sciences	3
CE	221	Statics	3
CEM	161	Chemistry Laboratory I	1
EC	201	Introduction to Microeconomics	3
EC	202	Introduction to Macroeconomics	3
ECE	345	Electronic Instrumentation and Systems	3
ENE	371	Sustainable Civil and Environmental Engineering Systems	3
ME	201	Thermodynamics	3
ME	280	Graphic Communications	2
MKT	317	Marketing Analytics	3
MSE	250	Materials Science and Engineering	3
PHY	191	Physics Laboratory for Scientists, I	1
b. One of the following courses (3 credits):			
COM	225	An Introduction to Interpersonal Communication	3
MGT	325	Management Skills and Processes	3
c. One of the following courses (3 or 4 credits):			
STT	351	Probability and Statistics for Engineering	3
STT	380	Probability and Statistics for Data Science	4
d. **Concentration**:			15 to 38

In consultation with their academic advisor, students must select one of the following concentrations: business law, computer science, packaging, supply chain management, or technical sales. For students interested in computer science, the minimum criteria for acceptance is the completion of Computer Science and Engineering 231 and 260 with a combined grade-point average in those two courses of 3.0. The concentration will be noted on the student's academic record.

Business Analytics (38 credits)

1. All of the following courses (15 credits):			
EC	301	Intermediate Microeconomics	3
FI	320	Introduction to Finance	3
GBL	385	Business Law and Ethical Leadership	3
MKT	327	Introduction to Marketing	3
SCM	303	Introduction to Supply Chain Management	3
2. Completion of the Minor in Data Science			23

Business Law (16 or 17 credits)

1. All of the following courses (13 credits):			
EC	301	Intermediate Microeconomics	3
EC	425	Law and Economics (W)	3
GBL	385	Business Law and Ethical Leadership	3
GBL	480	Environmental Law and Sustainability for Business: From Local to Global	3
PHY	192	Physics Laboratory for Scientists, II	1
2. One of the following courses (3 or 4 credits):			
PHL	345	Business Ethics	4
PHL	354	Philosophy of Law	3
PLS	320	Judicial Politics	3
PLS	321	Constitutional Law	3
PLS	322	Comparative Legal Systems	3

Computer Science (18 or 19 credits)

1. All of the following courses (12 credits):			
CSE	231	Introduction to Programming I	4
CSE	232	Introduction to Programming II	4
CSE	260	Discrete Structures in Computer Science	4
2. Two of the following courses (6 or 7 credits):			
CSE	320	Computer Organization and Architecture	3
CSE	325	Computer Systems	3
CSE	331	Algorithms and Data Structures	3
CSE	335	Object-oriented Software Design	4
CSE	404	Introduction to Machine Learning	3
CSE	420	Computer Architecture	3
CSE	429	Interdisciplinary Topics in CyberSecurity	3
CSE	431	Algorithm Engineering	3
CSE	440	Introduction to Artificial Intelligence	3
CSE	471	Media Processing and Multimedia Computing	3
CSE	472	Computer Graphics	3
CSE	476	Mobile Application Development	3
CSE	477	Web Application Architecture and Development	3
CSE	480	Database Systems	3
CSE	482	Big Data Analysis	3

Packaging (17 credits);
All of the following courses:

CEM	143	Survey of Organic Chemistry	4
PKG	101	Principles of Packaging	3
PKG	221	Packaging with Glass and Metal	2
PKG	322	Packaging with Paper and Paperboard	4
PKG	323	Packaging with Plastics	4

Supply Chain Management (15 credits)
All of the following courses:

FI	320	Introduction to Finance	3
MKT	327	Introduction to Marketing	3
SCM	303	Introduction to Supply Chain Management	3
SCM	371	Procurement and Supply Management	3
SCM	372	Manufacturing Planning and Control	3

Technical Sales (18 credits)
All of the following courses:

COM	360	Advanced Sales Communication	3
COM	483	Practicum in Sales Communication	1
FI	320	Introduction to Finance	3
MGT	474	Negotiations	2
MKT	313	Consultative Selling	3
MKT	327	Introduction to Marketing	3
MKT	383	Sales Management	3

TECHNOLOGY ENGINEERING

Bachelor of Science

The Bachelor of Science degree in Technology Engineering is an innovative program which prepares students for modern engineering challenges in the multidisciplinary, interconnected world. The degree is designed to develop engineering and technology foundational skills including, but not limited to, embedded electronic systems, computer aided design, product prototyping, data science, project management, and computer programming in Python and C++. Students will choose a concentration in Mechatronics or Embedded Cybersecurity, to further advance their engineering and technology interests. The program utilizes hands-on, real-world projects to integrate modern technologies with the engineering mindset.

Requirements for the Bachelor of Science Degree in Technology Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Technology Engineering.

   The University's Tier II writing requirement for the Technology Engineering major is met by completing Technology Engineering 480. That course is referenced in item 3. b. below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the College statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of

Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

			CREDITS
a.	All of the following courses (29 credits):		
	CEM 161	General Chemistry Laboratory I	1
	CSE 232	Introduction to Programming II	4
	ECE 230	Digital Logic Fundamentals	3
	ME 280	Graphic Communications	2
	MGT 325	Management Skills and Processes	3
	Or		
	SCM 304	Survey of Supply Chain Management	3
	MSE 250	Materials Science and Engineering	3
	PHY 251	Introductory Physics Laboratory I	1
	Or		
	PHY 191	Physics Laboratory for Scientists I	1
	PHY 252	Introductory Physics Laboratory II	1
	STT 180	Introduction to Data Science	4
	STT 201	Statistical Methods	4
	A basic math or science elective from a define course pool		3
b.	All of the following courses (25 credits):		
	TNG 210	Manufacturing Processes and Prototyping	2
	TNG 220	Electrical Circuits	4
	TNG 310	Advanced Graphics Communications	3
	TNG 320	Sensors and Signal Processing	3
	TNG 322	Electronics and Embedded Systems Lab	1
	TNG 330	Quality and Continuous Improvement	3
	TNG 335	Computer Security Fundamentals	3
	TNG 430	Engineering Project Management	3
	TNG 480	Technology Engineering Capstone (W)	3
c.	One of the following concentrations (16 credits):		
	Mechatronics		
	TNG 340	Engineering Statics and Mechanics of Materials	3
	TNG 345	Mechanical Machine Dynamics	3
	TNG 440	Robotics, Automation, and Controls	3
	TNG 445	Troubleshooting Mechatronic Systems	4
	TNG 447	Topics in Mechatronics	3
	Embedded Cybersecurity		
	TNG 350	Operating System Fundamentals	3
	TNG 355	Networks and Network Security	3
	TNG 450	Hardware Cybersecurity	3
	TNG 455	Engineering Secure Hardware and Software	4
	TNG 457	Topics in Embedded Cybersecurity	3
	The concentration will be noted on the student's academic record.		

MINOR IN ENERGY

The Minor in Energy, administered by the College of Engineering, provides students with a foundation in energy science that focuses on topics of fundamental physical principles guiding energy generation, utilization, conservation, engineering applications and the impact of energy within a societal and geological context. Students gain a perspective in energy science that is applicable to many disciplines and highly interdisciplinary. It offers opportunities for students to prepare to work in industry, research, or government, as well as preparation for graduate studies in energy science.

The minor is available as an elective to students who are enrolled in bachelor's degree programs in the College of Engineering. With the approval of the department and college that administer the student's degree program, the courses that are used to satisfy the minor may also be used to satisfy the requirements for the bachelor's degree. At least 9 credits counted towards the requirements for this minor must be unique. Unique credits must not be used to fulfill another university, college, or major requirement in the student's program.

Students who plan to complete the requirements of the minor should consult the undergraduate advisor in the College of Engineering. Students accepted into the minor must be admitted to the College of Engineering and have completed items 1. and 2. of the requirements stated below. Enrollment for some courses may not be available and may be limited. Application forms are available at *https://www.egr.msu.edu/form/application-form-minor-energy*.

Requirements for the Minor in Energy

Complete a minimum of 21 credits from the following.

			CREDITS
1.	One of the following courses (3 credits):		
	BE 230	Engineering Analysis of Biological Systems	3
	CHE 201	Material and Energy Balances	3
	MSE 250	Materials Science and Engineering	3
2.	One of the following courses (3 or 4 credits):		
	BE 351	Thermodynamics for Biological Engineering	3
	CHE 321	Thermodynamics for Chemical Engineering	4
	ECE 320	Energy Conversion and Power Electronics	3
	ME 201	Thermodynamics	3
	MSE 310	Phase Equilibria in Materials	3
3.	One of the following courses (3 credits):		
	BE 456	Electric Power and Control	3
	ECE 302	Electronic Circuits	3
	ECE 345	Electronic Instrumentation and Systems	3
4.	One of the following courses (3 credits):		
	CE 473	Smart and Sustainable Building Design and Operations	3
	ENE 472	Life Cycle Assessment of Energy Technologies	3
	ME 417	Design of Alternative Energy Systems	3
	MSE 410	Materials Foundations for Energy Applications	3
5.	One of the following courses (3 credits):		
	AESC 310	Sustainable Systems Analysis	3
	CE 371	Sustainable Civil and Environmental Engineering Systems	3
	CSUS 200	Introduction to Sustainability	3
	EEM 255	Ecological Economics	3
6.	Two of the following courses (6 to 8 credits):		
	AFRE 829	Economics of Environmental Resources	3
	BE 469	Sustainable Bioenergy Systems	3
	CE 473	Smart and Sustainable Building Design and Operations	3
	CEM 485	Modern Nuclear Chemistry	3
	CHE 468	Biomass Conversion Engineering	3
	CSS 467	BioEnergy Feedstock Production	3
	CSUS 200	Introduction Sustainability	3
	CSUS 259	Sustainable Energy and Society	3
	CSUS 491	Special Topics in Community Sustainability	1 to 3
	ECE 423	Power System Analysis	3
	ECE 425	Solid State Power Conversion	3
	ECE 476	Electro-Optics	4
	ECE 821	Advanced Power Electronics and Applications	3
	EEM 320	Environmental Economics	3
	ENE 472	Life Cycle Assessment of Energy Technologies	3
	ENE 489	Air Pollution: Science and Engineering	3
	FOR 414	Renewable Wood Products	3
	GLG 201	The Dynamic Earth	4
	GLG 301	Geology of the Great Lakes Region	3
	GLG 471	Applied Geophysics	4
	MC 450	International Environmental Law and Policy	3
	ME 417	Design of Alternative Energy Systems	3
	ME 422	Introduction to Combustion	3
	ME 442	Turbomachinery	3
	ME 444	Automotive Engines	3
	MSE 410	Materials Foundations for Energy Applications	3
	MSE 460	Electronic Structure and Bonding in Materials and Devices	3
	TSM 130	Energy Efficiency and Conservation in Agricultural Systems	3

A course used to fulfill requirement 4. or 5. above may not be used to fulfill requirement 6. Not all courses will be available to all majors and students must meet all course prerequisites and restrictions.

GRADUATE STUDY

The College of Engineering offers programs leading to the Master of Science and Doctor of Philosophy degrees in the following fields:

biomedical engineering
chemical engineering
civil engineering
computational mathematics, science and engineering
computer science
electrical engineering
engineering mechanics
environmental engineering
materials science and engineering
mechanical engineering

Programs leading to the Master of Science and Doctor of Philosophy degrees in biosystems engineering are offered through the College of Agriculture and Natural Resources.

All programs are designed to provide a fundamental approach to basic engineering principles with emphasis on scientific methods, and to lead to careers in engineering research and development or teaching. Advanced work in the major field of specialization is combined with supporting courses in one or more other fields to develop individuals capable of creative work in engineering science and areas of application.

Master of Science

In addition to meeting the requirements of the University as described in the Graduate Education section of this catalog, students must meet the requirements specified below.

Admission

Regular Status. Admission to a master's degree program with regular status may be granted by the department, subject to the availability of resources and to the approval of the dean, upon consideration of the likelihood that the applicant will be able to pursue a master's program successfully without taking collateral courses. As evidence of eligibility for admission, the student may offer any of the following:

a. The possession of a bachelor's degree in an accredited program in engineering with a grade–point average not lower than 3.00 for the final two years of the undergraduate program, or with standing in the upper quarter of the graduating class in the student's major.
b. The possession of a bachelor's degree in engineering or a related field where the applicant has shown very high academic achievement, as certified by the department.
c. Evidence of ability and resolution to complete a master's program, as attested by the department upon review of the applicant's academic record, test scores, experience, reference statements, professional qualifications, proposed studies, and other relevant information.

Provisional Status. Admission to a master's degree program with provisional status may be granted by the department, subject to the approval of the dean:

a. To an applicant qualified for regular admission except that collateral courses are deemed necessary, or
b. To an applicant whose record is incomplete.

If collateral courses are required, the minimum acceptable grades and the semesters by which those courses must be completed will be specified on the admission form. The provisional status will be changed to regular status when the conditions specified on the admission form have been met, as certified by the department and approved by the dean.

Program Filing

The student's program of study must be approved before the student completes 6 credits of graduate work in order for the student to continue to enroll in the master's degree program. For any independent study or selected topics course that is included in the student's approved program of study, the subject material and the instructor must be specified.

Modification of Program

With reference to the student's approved program of study, none of the following types of changes will be approved:

1. Adding or deleting a course for which a grade has already been assigned under any of the three grading systems (numerical, Pass–No Grade, or Credit–No Credit).
2. Adding or deleting a course for which grading was postponed by the use of the DF–Deferred marker.
3. Adding or deleting a course which the student dropped after the middle of the semester and for which “W” or “N” or “0.0" was designated.
4. Adding or deleting a course during the final semester of enrollment in the master's degree program.

Requirements for the Master of Science Degree

The student must:

1. Complete a minimum of 30 credits in 400–, 800–, and 900–level courses under either Plan A (with thesis) or Plan B (without thesis). Courses below the 400 level may not be counted toward the requirements for the degree.
   a. ***Requirements for Plan A***: The student must:
      (1) Complete a minimum of 20 credits in courses at the 800–900 level.
      (2) Complete at least 4, but not more than 8, credits in Master's Thesis Research (course number 899 in the department of the student's major).
      (3) Provide to the major professor and to the department a hard–bound copy of the thesis made from the original unbound manuscript submitted to the Office of The Graduate School. Arrangements for delivery of the copies shall be made when the original manuscript is submitted to the Office of The Graduate School.
   b. ***Requirements for Plan B***: The student must:
      (1) Complete a minimum of 18 credits in courses at the 800–900 level.
2. Pass the final certifying examination administered by the student's department. It is the student's responsibility to obtain detailed information about this examination from the department.

Academic Standards

1. **Grades**. The student must earn a grade of 2.0 or higher in each course in the approved program of study. The student must repeat any course for which the grade earned was below 2.0.
2. **Cumulative Grade–Point Average**. The student must maintain a cumulative grade–point average of at least 3.00 in the courses in the approved program of study.
3. **Probational Status**. A student is placed on probational status if the student's cumulative grade–point average for the courses in the approved program of study is below 3.00. A student in probational status is not allowed to carry more than 7 credits per semester or to enroll in any course the primary focus of which is independent study.
4. **Retention In and Dismissal From the Program**.
   a. *Cumulative Grade–Point Average*. Should a student's cumulative grade–point average fall below 3.00 after having completed 16 or more credits in courses in the approved program of study, the student may be enrolled in probational status in the master's degree program for one additional semester. If at the end of the additional semester the student's cumulative grade–point average is 3.00 or higher, the student may continue to enroll in the master's degree program. If at the end of the additional semester the student's cumulative grade–point average is still below 3.00, the student will be dismissed from the program.
   b. *Academic Progress and Professional Potential*. Each student's academic progress and professional potential are evaluated by March 15 of each year. A student who in the judgment of the faculty is making satisfactory academic progress and has professional potential may continue to enroll in the master's degree program. A student who in the judgment of the faculty is not making satisfactory academic progress or lacks professional potential will be dismissed from the program.

Transfer Credits

As a member of the Michigan Coalition for Engineering Education (MCEE), Michigan State University will accept up to one less than half of the course credits required for the Master of Science degree program in the College of Engineering in transfer from other MCEE member institutions provided that (1) the student earned a grade of at least 3.0, or the equivalent, in the related courses; (2) the credits were not earned in research or thesis courses; and (3) the total number of credits accepted in transfer from MCEE member institutions and from other institutions does not exceed one less than half of the credits required.

Doctor of Philosophy

In addition to meeting the requirements of the university as described in the Graduate Education section of this catalog, students must meet the requirements specified below.

Admission

Regular Status. Admission to a doctoral degree program with regular status may be granted by the department, subject to the availability of resources and to the approval of the dean, upon consideration of the likelihood that the applicant will be able to pursue a doctoral program successfully without taking collateral courses. As evidence of eligibility for admission, the student may offer any of the following:

a. The possession of a master's degree in engineering or a related field.
b. The completion of the equivalent of a master's degree program in the major field.
c. Evidence of ability and resolution to complete a doctoral program, as attested by the department upon review of the applicant's academic record, test scores, experience, reference statements, professional qualifications, proposed studies, and other relevant information.

Admission to the doctoral program without a master's degree, or the equivalent thereof, will require special consideration by the department and the dean.

Provisional Status. Admission to a doctoral degree program with provisional status may be granted by the department, subject to the approval of the dean:

a. To an applicant qualified for regular admission except that collateral courses are deemed necessary, or
b. To an applicant whose record is incomplete.

If collateral courses are required, the minimum acceptable grades and the semesters by which those courses must be completed will be specified on the admission form. The provisional status will be changed to regular status when the conditions specified on the admission form have been met, as determined by the department and approved by the dean.

Guidance Committee

The student's guidance committee is appointed by the department chairperson in consultation with the student and the appropriate faculty members, and with the approval of the dean. At least two members of the guidance committee shall be from the major department and at least one member shall be from a department outside of the major department. The chairperson of the guidance committee will be appointed by the department chairperson after consultation with the student and the person recommended to chair the committee.

Guidance Committee Report

The student's program of study shall be submitted for approval to the department and to the Dean by no later than the end of the student's second semester of enrollment in the doctoral program. For any independent study or selected topics course that is included in the student's program of study, the subject material and the instructor must be specified.

The student's program of study must be approved in order for the student to continue to enroll in the doctoral degree program beyond the second semester.

Modification of Program

With reference to the student's approved guidance committee report, none of the following types of changes will be approved:

1. Adding or deleting a course for which a grade has already been assigned under any of the three grading systems (numerical, Pass–No Grade, or Credit–No Credit).
2. Adding or deleting a course for which grading was postponed by the use of the DF–Deferred marker.
3. Adding or deleting a course which the student dropped after the middle of the semester and for which "W" or "N" or "0.0" was designated.
4. Adding or deleting a course during the final semester of enrollment in the doctoral degree program.

Requirements for the Doctor of Philosophy Degree

The student must:

1. Pass the qualifying examination administered by the student's department. It is the student's responsibility to obtain detailed information about this examination from the department.
2. Pass the doctoral comprehensive examination at least six months prior to the final oral examination in defense of the dissertation. The examination may be retaken no more than twice. It is the student's responsibility to obtain detailed information about this examination from the department.
3. Provide to the major professor and to the department a hard–bound copy of the dissertation made from the original unbound manuscript submitted to the Office of the Graduate School. Arrangements for delivery of the copies shall be made when the original manuscript is submitted to the Office of The Graduate School.

Academic Standards

1. **Grades**. The student must earn a grade of 2.0 or higher in each course in the approved guidance committee report, including collateral courses and courses accepted in transfer. The student must repeat any course for which the grade earned was below 2.0.
2. **Cumulative Grade–Point Average**. The student must maintain a cumulative grade–point average of at least 3.00 in courses in the approved guidance committee report, with the exception of collateral courses and courses accepted in transfer.
3. **Deferred Grades**. A student may accumulate no more than 3 deferred grades (identified by the DF–Deferred marker) in courses other than those courses the primary focus of which is independent study.
4. **Probational Status**. A student is placed on probational status if either or both of the following conditions apply:
   a. The student's cumulative grade–point average for the courses in the approved guidance committee report is below 3.00.
   b. The student has accumulated more than three deferred grades (identified by the DF–Deferred marker) in courses other than those courses the primary focus of which is independent study.

   A student in probational status is not allowed to carry more than 7 credits per semester or to enroll in any course the primary focus of which is independent study.
5. **Retention In and Dismissal From the Program**.
   a. **Cumulative Grade–point Average**. Should a student's cumulative grade–point average fall below 3.00 after having completed half of the courses in the approved guidance committee report, the student may be enrolled in probational status in the doctoral degree program for one additional semester. If at the end of the additional semester the student's cumulative grade–point average is 3.00 or higher, the student may continue to enroll in the doctoral degree program. If at the end of the additional semester the student's cumulative grade–point average is still below 3.00, the student will be dismissed from the program.
   b. **Deferred Grades**. Should a student accumulate more than 3 deferred grades (identified by the DF–Deferred marker) in courses other than those courses the primary focus of which is independent study, the student may be enrolled on probational status in the doctoral degree program for one additional semester. If at the end of the additional semester the student has no more than 3 deferred grades, the student may continue to enroll in the doctoral degree program. If at the end of the additional semester the student still has more than 3 deferred grades, the student will be dismissed from the program.
   c. **Academic Progress and Professional Potential**. Each student's academic progress and professional potential are evaluated by March 15 of each year. A student who in the judgment of the faculty is making satisfactory academic progress and has professional potential may continue to enroll in the doctoral degree program. A student who in the judgment of the faculty is not making satisfactory academic progress or lacks professional potential will be dismissed from the program.

GRADUATE SPECIALIZATION IN ENVIRONMENTAL TOXICOLOGY

The College of Engineering, the College of Agriculture and Natural Resources, the College of Natural Science, and the College of Veterinary Medicine administer the Graduate Specialization in Environmental Toxicology. The College of Agriculture and Natural Resources is the primary administrative unit. For additional information, refer to the *Graduate Specialization in Environmental Toxicology* statement in the *College of Agriculture and Natural Resources* section of this catalog.

DEPARTMENT of BIOMEDICAL ENGINEERING

Adam Alessio, Chairperson

The mission of the Department of Biomedical Engineering is to train young investigators in quantitative analyses, engineering principles and innovative design concepts for the purpose of using these approaches to create novel solutions to the most pressing healthcare needs. These approaches are used to drive the principles of precision health by enabling predictive analytics, real time monitoring, early diagnosis, rapid intervention, and quantitative measures of outcome from basic science to practical application with an overarching goal to improve human health.

GRADUATE STUDY

BIOMEDICAL ENGINEERING

The Master of Science Degree in Biomedical Engineering prepares graduates to review technical literature related to a biomedical engineering research problem and communicate those results through oral presentations and written publications.

Master of Science

In addition to meeting the requirements of the university, and of the College of Engineering, students must meet the requirements specified below.

Admission

For admission to the master's degree in biomedical engineering on regular status, the student must:

1. have a bachelor's degree in biomedical engineering or related field;
2. have a grade-point average that would indicate success in graduate study.

Applicants who are admitted without a bachelor's degree in biomedical engineering may be required to complete collateral course work to make up deficiencies. Collateral course work will not count towards the fulfillment of degree requirements. International applicants are required to submit their scores on the Graduate Record Examination (GRE).

Requirements for the Master of Science Degree in Biomedical Engineering

The master's degree program in biomedical engineering is available under either Plan A (with thesis) or Plan B (without thesis). A total of 30 credits is required for the degree. The student's program of study is selected in consultation with a faculty advisor and the graduate program director. No more than 6 credits of 400-level courses may be counted towards the degree requirements.

CREDITS

Student's must complete the following core course:

BME 803	Research Methods	3

Additional Requirements for Plan A

1. Completion of the following course:

BME 892	Biomedical Engineering Seminar	1

2. Complete of at least 4, but not more than 8, credits of BME 899 Master's Thesis Research.
3. Pass a final oral examination in defense of the thesis.

Additional Requirements for Plan B

1. Pass a final examination or evaluation.

Doctor of Philosophy

The Doctor of Philosophy degree in Biomedical Engineering prepares graduates to review technical literature related to a biomedical engineering research problem and communicate those results through oral presentations and written publications.

In addition to meeting the requirements of the university, and of the College of Engineering, students must meet the requirements specified below.

Admission

For admission to the doctoral degree in biomedical engineering on regular status, the student must:

1. have a bachelor's degree in biomedical engineering or related field;
2. have a grade-point average that would indicate success in graduate study.

Applicants who are admitted without a bachelor's degree in biomedical engineering may be required to complete collateral course work to make up deficiencies. Collateral course work will not count towards the fulfillment of degree requirements. International applicants are required to submit their scores on the Graduate Record Examination (GRE).

Requirements for the Doctor of Philosophy Degree in Biomedical Engineering

The doctoral degree program in biomedical engineering program of study is selected in consultation with a faculty advisor and the graduate program director. A minimum of 22 credits of course work beyond the bachelor's degree is required in addition to doctoral dissertation research. No more than 6 credits of 400-level courses may be counted towards the degree requirements.

CREDITS

Student's must complete the following:

1. All of the following core courses:

BME 803	Research Methods	3
BME 840	BioDesignIQ I	3
BME 841	BioDesignIQ II	3
BME 892	Biomedical Engineering Seminar	1

2. Complete at least 12 credits in thematic elective courses at the 800-level or above. Must include an engineering science course, a life science course, a mathematics/statistics/computational course, and another elective course chosen from a list of approved courses maintained by the department.
3. Successful completion of the written and oral portions of the comprehensive examination by the end of the 4th semester in the program.
4. Complete 24 credits of BME 999 Doctoral Dissertation Research.
5. Successful completion of a dissertation and final oral examination in defense of the dissertation.

DEPARTMENT of BIOSYSTEMS and AGRICULTURAL ENGINEERING

Bradley P. Marks, Chairperson

The mission of the Department of Biosystems and Agricultural Engineering is to improve quality of life by integrating and applying principles of engineering and biology to systems involving food, environment, energy, and health. The Department of Biosystems and Agricultural Engineering is administered jointly by the College of Agriculture and Natural Resources and the College of Engineering.

UNDERGRADUATE PROGRAM

The department offers a Bachelor of Science degree program with a major in biosystems engineering through the College of Engineering. A Minor in Smart Agricultural Systems is also available. That program is described below.

The department also offers a Minor in Technology Systems Management through the College of Agriculture and Natural Resources. For information about that program, refer to the statement on the *Department of Biosystems and Agricultural Engineering* in the *College of Agriculture and Natural Resources* section of this catalog.

Students who are enrolled in the Bachelor of Science degree program with a major in biosystems engineering may elect a Minor in Plant, Animal and Microbial Biotechnology. For additional information, refer to the *Minor in Plant, Animal and Microbial Biotechnology* statement in the *College of Agriculture and Natural Resources* section of this catalog.

BIOSYSTEMS ENGINEERING

Bachelor of Science

Biosystems engineers design solutions to technical problems that involve a critical biological component. They apply quantitative skills to create products, processes, and systems that improve human existence. Working at the interface of engineering and biology, biosystems engineers are engaged in the most important challenges of our time.

Biosystems engineers may, for example, design pathogen control processes to protect the safety of our food supply, constructed wetlands to improve water quality and quantity, biomass conversion processes to sustainably supply renewable energy and products, and/or diagnostic and risk modeling systems to protect and enhance human and animal health. Biosystems engineers are sought after by a wide variety of employers that need creative individuals to integrate principles of engineering and biology, including food manufacturers, environmental consulting firms, health industries, and government agencies.

The Bachelor of Science Degree program in Biosystems Engineering is accredited by the Engineering Accreditation Commission of ABET, *www.abet.org*.

Requirements for the Bachelor of Science Degree in Biosystems Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Biosystems Engineering.

   The University's Tier II writing requirement for the Biosystems Engineering major is met by completing Biosystems Engineering 334 or 485. Those courses are referenced in item 3. a below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.
2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.
3. The following requirements for the major:

			CREDITS
a.	All of the following courses:		
	BE 101	Introduction to Biosystems Engineering	1
	BE 201	Drafting in Biosystems Engineering	1
	BE 230	Engineering Analysis of Biological Systems	3
	BE 332	Engineering Properties of Biological Materials	3
	BE 334	Biosystems Engineering Laboratory Practice (W)	3
	BE 350	Heat and Mass Transfer in Biosystems	3
	BE 351	Thermodynamics for Biological Engineering	3
	BE 360	Microbial Systems Engineering	3
	BE 385	Engineering Design and Optimization for Biological Systems	3
	BE 485	Biosystems Design Techniques (W)	3
	BE 487	Biosystems Design Project	3
	BS 161	Cell and Molecular Biology	3
	BS 162	Organismal and Population Biology	3
	CE 221	Statics	3
	CE 321	Introduction to Fluid Mechanics	4
	CEM 143	Survey of Organic Chemistry	4
	CEM 151	General and Descriptive Chemistry	4
	CEM 161	Chemistry Laboratory I	1
b.	One of the following courses (2 credits):		
	BS 171	Cell and Molecular Biology Laboratory	2
	BS 172	Organismal and Population Biology Laboratory	2
c.	One of the following courses (3 or 4 credits):		
	IBIO 341	Fundamental Genetics	4
	IBIO 355	Ecology	3
	MMG 301	Introductory Microbiology	3
	PLB 301	Introductory Plant Physiology	3
	PSL 250	Introductory Physiology	4
d.	One of the following courses (3 or 4 credits):		
	CSS 442	Agricultural Ecology	3
	CSS 451	Biotechnology Applications for Plant Breeding and Genetics	3
	FOR 406	Applied Forest Ecology: Silviculture	3
	FSC 440	Food Microbiology	3
	MMG 365	Medical Microbiology	3
	MMG 404	Human Genetics	3
	MMG 425	Microbial Ecology	3
	MMG 445	Microbial Biotechnology (W)	3
	PLB 402	Biology of Fungi	4
	PSL 425	Physiological Biophysics	3
e.	Four of the following courses (12 credits):		
	BE 444	Biosensors for Medical Diagnostics	3
	BE 449	Human Health Risk Analysis for Engineering Controls	3
	BE 456	Electric Power and Control	3
	BE 469	Sustainable Bioenergy Systems	3
	BE 477	Food Engineering: Fluids	3
	BE 478	Food Engineering: Solids	3
	BE 481	Water Resources Systems Analysis and Modeling	3
	BE 482	Engineering Ecological Treatment Systems	3

BE	484	Water Resource Recovery Engineering	3
CHE	468	Biomass Conversion Engineering	3

Concentrations in Biosystems Engineering

The department offers concentrations for students who wish to focus on a specific application area in the discipline. The concentrations are available to, but not required of, any student enrolled in the Bachelor of Science degree program in Biosystems Engineering. Courses completed to satisfy requirement 3. above may also be used to satisfy the requirements of a concentration. The concentration will be noted on the students transcript.

Bioenergy and Bioproduct Engineering
To earn a Bachelor of Science degree in Biosystems Engineering with a bioenergy and bioproduct engineering concentration, students must complete degree requirements 1., 2., and 3. above and the following:

1. All of the following courses (9 credits): — CREDITS

BE	469	Sustainable Bioenergy Systems	3
CHE	468	Biomass Conversion Engineering	3
CSS	467	Bioenergy Feedstock Production	3

2. Two of the following courses (6 to 8 credits):

CHE	481	Biochemical Engineering	3
CSS	442	Agricultural Ecology	3
CSS	451	Biotechnology Applications for Plant Breeding and Genetics	3
FOR	406	Applied Forest Ecology: Silviculture	3
FOR	427	Biomass and Bioproducts Chemistry	3
FOR	465	Natural Resource Policy	3
FW	444	Conservation Biology	3
GLG	435	Geomicrobiology	4
MC	450	International Environmental Law and Policy	3
ME	417	Design of Alternative Energy Systems	3
ME	422	Introduction to Combustion	3
MMG	425	Microbial Ecology	3
MMG	445	Microbial Biotechnology (W)	3
PLB	402	Biology of Fungi	4

Biomedical Engineering
To earn a Bachelor of Science degree in Biosystems Engineering with a biomedical engineering concentration, students must complete degree requirements 1., 2., and 3. above and the following:

1. Both of the following courses (6 credits): — CREDITS

BE	444	Biosensors for Medical Diagnostics	3
BE	449	Human Health Risk Analysis for Engineering Controls	3

2. One of the following courses (3 credits):

MMG	365	Medical Microbiology	3
MMG	404	Human Genetics	3
PSL	425	Physiological Biophysics	3

3. Two of the following courses (5 or 6 credits):

BE	440	Entrepreneurial Engineering for Innovation in Health and Safety	3
BLD	204	Mechanisms of Disease	3
BLD	313	Quality in Clinical Laboratory Practice	3
BLD	430	Molecular Diagnostics	2
BLD	434	Clinical Immunology	3
ECE	445	Biomedical Instrumentation	3
ME	494	Biofluid Mechanics and Heat Transfer	3
MMG	365	Medical Microbiology	3
MMG	404	Human Genetics	3
MSE	425	Biomaterials and Biocompatibility	3
PLB	400	Introduction to Bioinformatics	3
PSL	425	Physiological Biophysics	3

Courses used to fulfill requirement 2. in this concentration may not be used to fulfill this requirement.

Ecosystems Engineering
To earn a Bachelor of Science degree in Biosystems Engineering with a ecosystems engineering concentration, students must complete degree requirements 1., 2., and 3. above and the following:

1. All of the following courses (9 credits): — CREDITS

BE	481	Water Resources Systems Analysis and Modeling	3
BE	482	Engineering Ecological Treatment Systems	3
BE	484	Water Resource Recovery Engineering	3

2. One of the following courses (3 credits):

CSS	442	Agricultural Ecology	3
MMG	425	Microbial Ecology	3

3. Two of the following courses (5 or 6 credits):

CSS	210	Fundamentals of Soil Science	3
CSS	330	Soil Chemistry	2
CSS	360	Soil Biology	3
CSS	442	Agricultural Ecology	3
CSS	455	Environmental Pollutants in Soil and Water	3
ENE	422	Applied Hydraulics	3
FOR	340	Forest Ecology	3
FW	417	Wetland Ecology and Management	3
FW	420	Stream Ecology	3
FW	444	Conservation Biology	3
GEO	402	Agricultural Climatology	3
MC	450	International Environmental Law and Policy	3
MMG	425	Microbial Ecology	3
PLB	418	Plant Systematics	3
PLB	443	Restoration Ecology	3

Courses used to fulfill requirement 2. in this concentration may not be used to fulfill this requirement.

Food Engineering
To earn a Bachelor of Science degree in Biosystems Engineering with a food engineering concentration, students must complete degree requirements 1., 2., and 3. above and the following:

1. All of the following courses (9 credits): — CREDITS

BE	477	Food Engineering: Fluids	3
BE	478	Food Engineering: Solids	3
FSC	440	Food Microbiology	3

2. Two of the following courses, one of which must be at the 400-level (6 or 7 credits):

BMB	200	Introduction to Biochemistry	4
FSC	211	Principles of Food Science	3
FSC	401	Food Chemistry	3
FSC	430	Food Processing: Fruits and Vegetables	3
FSC	431	Food Processing: Cereals	3
FSC	432	Food Processing: Dairy Foods	3
FSC	433	Food Processing: Muscle Foods	3

MINOR IN SMART AGRICULTURAL SYSTEMS

The Minor in Smart Agricultural Systems, which is administered by the Department of Biosystems and Agricultural Engineering, is available for students with majors in Applied Engineering Sciences, Biosystems Engineering, Computational Data Science, Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering, and Lyman Briggs Computer Science who are interested in smart technology for management decision support and who plan to pursue careers in agriculture or natural resources. The minor will provide an opportunity for students to gain a working knowledge of digital technologies necessary to monitor and manage aspects of agriculture, food, natural resources, and bioenergy systems.

With the approval of the department and college that administer the student's degree program, the courses that are used to satisfy the minor may also be used to satisfy the requirements for the bachelor's degree. At least 10 unique credits counted towards the requirements for a student's minor must not be used to fulfill the requirements for that student's major.

Students who plan to complete the requirements of the minor should consult the Smart Agricultural Systems minor program coordinator in the Department of Biosystems

Engineering and have their program of study approved in advance and in writing.

Requirements for the Minor in Smart Agricultural Systems

Students must complete a minimum of 16 credits from the following:

			CREDITS
1. All of the following courses (10 credits):			
BE`	221	Introduction to Smart Agriculture	1
BE	321	Principles of Precision Agriculture	3
BE	421	Sensors and Robotics for Agricultural Systems	3
BE	422	Crop Modeling and Optimization	3
2. Two of the following courses (6 or 7 credits):			
BE	449	Human Health Risk Analysis for Engineering Controls	3
BE	456	Electric Power and Control	3
BE	481	Water Resources Systems Analysis and Modeling	3
BE	482	Engineering Ecological Treatment Systems	3
CSE	404	Introduction to Machine Learning	3
CSE	440	Introduction to Artificial Intelligence	3
CSE	480	Database Systems	3
CSE	482	Big Data Analysis	3
CSS	467	Bioenergy Feedstock Production	3
ECE	416	Digital Control	3
ECE	417	Robotics	3
ECE	431	Smart Sensor Systems	3
ECE	434	Autonomous Vehicles	3
ECE	477	Microelectronic Fabrication	3
ME	417	Design of Alternative Energy Systems	3
ME	451	Control Systems	4
ME	456	Mechatronic System Design	3

LINKED BACHELOR'S-MASTER'S DEGREE IN BIOSYSTEMS ENGINEERING

Bachelor of Science Degree in Biosystems Engineering
Master of Science Degree in Biosystems Engineering

The department welcomes applications from Michigan State University Biosystems Engineering undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Biosystems Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Biosystems Engineering at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or another postsecondary accredited institution of comparable academic quality. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

GRADUATE STUDY

The department offers Master of Science and Doctor of Philosophy programs in biosystems engineering through the College of Agriculture and Natural Resources. For information about those programs, refer to the statement on the *Department of Biosystems and Agricultural Engineering* in the *College of Agriculture and Natural Resources* section of this catalog.

DEPARTMENT of CHEMICAL ENGINEERING and MATERIALS SCIENCE

Christina Chan, Chairperson

The undergraduate and graduate programs of the Department of Chemical Engineering and Materials Science have been training top-quality graduates for over 75 years. Graduates from the Department of Chemical Engineering and Materials Science are highly sought after to create solutions for important technological and societal problems. The faculty is dedicated to strong classroom instruction and world-class research focused in the areas of energy and sustainability, advanced materials and nanotechnology, and biotechnology and bioengineering.

UNDERGRADUATE PROGRAMS

The Department of Chemical Engineering and Materials Science offers two Bachelor of Science degree programs, one in chemical engineering and one in materials science and engineering. Students learn to convert low-value raw materials into high-value products. Students learn how to analyze and understand different processes and how, at the macroscopic, microstructural, and atomistic/molecular levels, these processes result in different properties in the final product. Emphasis is placed on developing students who understand the technical aspects of production, the environmental, economic, and societal impact of engineering, and who possess a desire for lifelong learning and growth. Optional concentrations are available for students to focus their programs of study on areas of particular interest.
Graduates are trained to succeed in multidisciplinary teams that interface between disciplines. They work across a broad spectrum of fields including industrial chemicals, automotive, metals, plastics, petroleum processing, pharmaceuticals, textiles, food, electronics, energy related materials, sensors, and biomedical technology. Within these fields, our graduates are involved in research and development of products and processes, in the design and operation of manufacturing facilities, and in management and product quality control.

CHEMICAL ENGINEERING

Chemical engineers convert raw materials to finished products via pathways involving chemical and physical changes. The principles of mass, energy, and momentum conservation, chemical reactions, thermodynamics, and economics are applied to develop new products and to design and operate manufacturing facilities to produce products that benefit society. Chemical engineering principles are, in turn, based on

the sciences of chemistry, biology, mathematics, and physics, which form the underlying foundation of the discipline.

Students in this degree program will study the application of chemical engineering principles to biochemical and biomedical systems, nanoscale devices, polymer processing, and novel energy systems. Principles of sustainability, environmentally-friendly "green" processing, entrepreneurship, and other emerging topics are also addressed in courses and concentrations.

The Bachelor of Science Degree program in Chemical Engineering is accredited by the Engineering Accreditation Commission of ABET, *www.abet.org* under the General Criteria and the Program Criteria for Chemical, Biochemical, Biomolecular and Similarly Named Engineering Programs.

Requirements for the Bachelor of Science Degree in Chemical Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Chemical Engineering.

   The University's Tier II writing requirement for the Chemical Engineering major is met by completing Chemical Engineering 316 and 433. Those courses are referenced in item 3. a. below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. The alternative track requirement for Integrative Studies in Biological Sciences in Chemical Engineering is Biological Science 161. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.
2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.
3. The following requirements for the major:

			CREDITS
a. All of the following courses (58 credits):			
	BS 161	Cell and Molecular Biology	3
	CEM 151	General and Descriptive Chemistry	4
	CEM 152	Principles of Chemistry	3
	CEM 161	Chemistry Laboratory I	1
	CEM 162	Chemistry Laboratory II	1
	CEM 351	Organic Chemistry I	3
	CEM 352	Organic Chemistry II	3
	CEM 355	Organic Laboratory I	2
	CHE 201	Material and Energy Balances	3
	CHE 210	Modeling and Analysis of Transport Phenomena	3
	CHE 301	Chemical Engineering as a Profession	1
	CHE 311	Fluid Flow and Heat Transfer	3
	CHE 312	Mass Transfer and Separations	4
	CHE 316	Laboratory Practice and Statistical Analysis	4
	CHE 321	Thermodynamics for Chemical Engineering	4
	CHE 431	Chemical Reaction Engineering	4
	CHE 432	Process Analysis and Control	3
	CHE 433	Process Design and Optimization I	4
	CHE 434	Process Design and Optimization II	2
	CHE 473	Chemical Engineering Principles in Polymers and Material Systems	3
b. One of the following (4 or 6 credits):			
	(1) BMB 401	Comprehensive Biochemistry	4
	(2) BMB 461	Advanced Biochemistry I	3
	BMB 462	Advanced Biochemistry II	3
Note: If BMB 462 is taken to fulfill requirements 3. b., it will also count as a technical elective in item 3. e.			
c. One of the following courses (3 credits):			
	CHE 472	Polymeric Composite Materials Processing	3
	CHE 481	Biochemical Engineering	3
d. One of the following courses (3 credits):			
	CEM 483	Quantum Chemistry	3
	CEM 484	Molecular Thermodynamics	3
e. **Technical Electives**.			

Students must complete at least 6 credits in courses selected from a list of approved technical electives available from the Department of Chemical Engineering and Materials Science.

Concentrations in Chemical Engineering

In response to increasing interest in the application of chemical engineering principles to related fields, the Department of Chemical Engineering and Materials Science offers concentrations in biochemical engineering, bioenergy, biomedical engineering, environmental engineering, food science, and polymer science and engineering to students wishing an area of concentration in the degree. Concentrations are available to, but not required of, any student enrolled in the Bachelor of Science degree program in chemical engineering. The concentration will be noted on the student's transcript.

NOTE: Completing the Bachelor of Science degree in chemical engineering with a concentration may require more than 128 credits. For any concentration, up to 3 credits of Independent Study (CHE 490) related to the subject area may be applied with approval of the Department of Chemical Engineering and Materials Science.

Biochemical Engineering

To earn a Bachelor of Science degree in Chemical Engineering with a biochemical engineering concentration, students must complete requirements 1., 2., 3. a., and 3.d. above and the following:

Both of the following courses (6 credits):			
	CHE 481	Biochemical Engineering	3
	MMG 301	Introductory Microbiology	3
One of the following tracks (11 to 13 credits):			
Track 1 (12 or 13 credits):			
The following course (4 credits):			
	BMB 401	Comprehensive Biochemistry	4
Three of the following courses (8 or 9 credits):			
	BMB 805	Protein Structure, Design, and Mechanism	3
	BMB 829	Special Problems in Macromolecular Analysis and Synthesis	2
	CHE 882	Advanced Biochemical Engineering	3
	CHE 883	Multidisciplinary Bioprocessing Laboratory	3
	MMG 409	Eukaryotic Cell Biology	3
	MMG 421	Prokaryotic Cell Physiology	3
	MMG 431	Microbial Genetics	3
Track 2 (11 or 12 credits):			
Both of the following courses (6 credits):			
	BMB 461	Advanced Biochemistry I	3
	BMB 462	Advanced Biochemistry II	3
Two of the following courses (5 or 6 credits):			
	BMB 805	Protein Structure, Design, and Mechanism	3
	BMB 829	Special Problems in Macromolecular Analysis and Synthesis	2
	CHE 882	Advanced Biochemical Engineering	3
	CHE 883	Multidisciplinary Bioprocessing Laboratory	3
	MMG 409	Eukaryotic Cell Biology	3
	MMG 421	Prokaryotic Cell Physiology	3
	MMG 431	Microbial Genetics	3

Bioenergy and Bioproducts

To earn a Bachelor of Science degree in Chemical Engineering with a bioenergy and bioproducts concentration, students must complete requirements 1., 2., 3.a., 3.b., and 3.d. above and the following:

All of the following courses (9 credits):			
	CHE 468	Biomass Conversion Engineering	3
	CHE 481	Biochemical Engineering	3
	CSS 467	Bioenergy Feedstock Production	3
One of the following courses (3 credits):			
	BE 469	Sustainable Bioenergy Systems	3
	BE 869	Life Cycle Assessment for Bioenergy and Bioproduct Systems	3
One of the following courses (3 credits):			
	AFRE 829	Economics of Environmental Resources	3
	CHE 882	Advanced Biochemical Engineering	3

CHE	883	Multidisciplinary Bioprocessing Laboratory	3
FOR	466	Natural Resource Policy	3
MC	450	International Environmental Law and Policy	3

Biomedical Engineering

To earn a Bachelor of Science degree in Chemical Engineering with a biomedical engineering concentration, students must complete requirements 1., 2., 3.a., 3.b., and 3.d. above and the following:

All of the following courses (10 credits):

CHE	481	Biochemical Engineering	3
MMG	409	Eukaryotic Cell Biology	3
PSL	431	Human Physiology I	4

One of the following courses (3 credits):

CHE	883	Multidisciplinary Bioprocessing Laboratory	3
ME	494	Biofluid Mechanics and Heat Transfer	3
MSE	425	Biomaterials and Biocompatibility	3

One of the following courses not taken above (3 or 4 credits):

BMB	471	Advanced Biochemistry Laboratory	4
CHE	883	Multidisciplinary Bioprocessing Laboratory	3
IBIO	341	Fundamental Genetics	4
ME	494	Biofluid Mechanics and Heat Transfer	3
MSE	425	Biomaterials and Biocompatibility	3

Environmental

To earn a Bachelor of Science degree in Chemical Engineering with an environmental concentration, the student must complete requirements 1., 2., and 3. a., 3.b., and 3.d. above and the following:

Both of the following courses (6 credits):

CHE	481	Biochemical Engineering	3
ENE	280	Principles of Environmental Engineering and Science	3

Three of the following courses (9 credits):

AFRE	265	Ecological Economics	3
AFRE	360	Environmental Economics	3
AFRE	465	Corporate Environmental Management (W)	3
CSUS	465	Environmental and Natural Resource Law	3
ENE	481	Environmental Chemistry: Equilibrium Concepts	3
ENE	483	Water and Wastewater Engineering	3
ENE	489	Air Pollution: Science and Engineering	3
IBIO	446	Environmental Issues and Public Policy	3

Food Science

To earn a Bachelor of Science degree in Chemical Engineering with a food science concentration, students must complete requirements 1., 2., 3. a., 3. b., 3.c., and 3.d. above and all of the following:

All of the following courses (9 credits):

FSC	401	Food Chemistry	3
FSC	440	Food Microbiology	3
MMG	301	Introductory Microbiology	3

One of the following courses (3 credits):

BE	477	Food Engineering: Fluids	3
BE	478	Food Engineering: Solids	3
FSC	325	Food Processing: Unit Operations	3
FSC	455	Food and Nutrition Laboratory	3
FSC	470	Integrated Approaches to Food Product Development	3

Polymer Science and Engineering

To earn a Bachelor of Science degree in Chemical Engineering with a polymer science and engineering concentration, students must complete requirements 1., 2., 3. a., 3. b., and 3.d. above and all of the following:

All of the following courses (9 credits):

CE	221	Statics	3
CHE	472	Polymeric Composite Materials Processing	3
ME	222	Mechanics of Deformable Solids	3

Two of the following courses (6 or 7 credits):

CHE	871	Material Surfaces and Interfaces	3
CHE	872	Polymers and Composites: Manufacturing, Structure and Performance	3
MSE	370	Synthesis and Processing of Materials	3
MSE	426	Introduction to Composite Materials	3
PKG	323	Packaging with Plastics	4

MATERIALS SCIENCE and ENGINEERING

Materials Science and Engineering majors learn to select and create materials used to realize engineering designs in fields such as bioengineering, microelectronics and aerospace. They also learn how to manipulate the elements of matter into the atomic arrangements that ensure efficient and cost-effective materials performance, demanded by today's advanced applications.

Through the core course work, students gain the scientific and engineering foundation needed to design metallic, ceramic, polymeric, and composite materials and, in turn, components manufactured from these materials. Students may enhance the knowledge they gain in metals, ceramics, and polymers by completing a concentration in biomedical materials, manufacturing, polymers, or metallurgy. Students may also choose to enroll in electives of complementary fields such as business, electronic materials, or statistics. Honors students are encouraged to request an honors option with the instructors of MSE courses listed in item 3. a. below.

The Bachelor of Science Degree program in Materials Science and Engineering is accredited by the Engineering Accreditation Commission of ABET, *www.abet.org* under the General Criteria and the Program Criteria for Materials, Metallurgical, Ceramics and Similarly Named Engineering Programs.

Requirements for the Bachelor of Science Degree in Materials Science and Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Materials Science and Engineering.

   The University's Tier II writing requirement for the Materials Science and Engineering major is met by completing Materials Science and Engineering 466. That course is referenced in item 3. a. below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading Graduation Requirements for All Majors in the College statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.
2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.
3. The following requirements for the major:

   a. All of the following courses (41 credits):

			CREDITS
CE	221	Statics	3
CEM	152	Principles of Chemistry	3
CEM	161	Chemistry Laboratory I	1
ECE	345	Electronic Instrumentation and Systems	3
ME	222	Mechanics of Deformable Solids	3
MSE	250	Materials Science and Engineering	3
MSE	260	Electronic, Magnetic, Thermal and Optical Properties of Materials	3
MSE	310	Phase Equilibria in Materials	3
MSE	320	Mechanical Properties of Materials	3
MSE	331	Materials Characterization Methods I	2
MSE	360	Fundamentals of Microstructural Design	3
MSE	370	Synthesis and Processing of Materials	3
MSE	381	Materials Characterization Methods II	2
MSE	466	Design and Failure Analysis (W)	3
STT	351	Probability and Statistics for Engineering	3

   Electrical and Computer Engineering 302 and 303 may be substituted for Electrical and Computer Engineering 345.

   b. Four of the following courses (12 credits):

ME	477	Manufacturing Processes	3
MSE	425	Biomaterials and Biocompatibility	3

MSE 474	Ceramic and Refractory Materials	3
MSE 460	Electronic Structure and Bonding in Materials and Devices	3
MSE 465	Design and Application of Engineering Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3

c. Complete at least 6 credits from 400-level courses within the College of Engineering.
d. Complete at least 3 credits in courses selected from a list of approved technical electives available from the Department of Chemical Engineering and Materials Science.

Concentrations in Materials Science and Engineering

Students may elect to complete a more focused set of courses to enhance their ability to function at the interface with another scientific, engineering, or business discipline. Concentrations are available to, but not required of, any student enrolled in the Bachelor of Science degree in Materials Science and Engineering. Completing the Bachelor of Science degree in Materials Science and Engineering with a concentration may require more than 128 credits. The concentration will be noted on the student's transcript.

Biomedical Materials Engineering
To gain interdisciplinary skills in human biology and earn a Bachelor of Science degree in Materials Science and Engineering with a biomedical materials engineering concentration, students must complete requirement 3. a. above and the following (25 credits):

1. All of the following courses (12 credits):

ANTR350	Human Gross Anatomy for Pre-Health Professionals	3
CEM 251	Organic Chemistry I	3
Or		
CEM 351	Organic Chemistry I	3
ME 495	Tissue Mechanics	3
MSE 425	Biomaterials and Biocompatibility	3

2. One of the following courses (4 credits):

PSL 250	Introduction to Physiology	4
PSL 310	Physiology for Pre-Health Professionals	4

3.Two of the following courses (6 credits):

ME 477	Manufacturing Processes	3
MSE 474	Ceramics and Refractory Materials	3
MSE 460	Electronic Structure and Bonding in Materials and Devices	3
MSE 465	Design and Application of Engineering Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3

4. At least 3 credits from a list of approved technical electives 6

Manufacturing Engineering
To gain interdisciplinary skills with business and design engineers for manufacturing projects and earn a Bachelor of Science degree in Materials Science and Engineering with a manufacturing engineering concentration, students must complete requirement 3. a. above and the following (21 credits):

1. All of the following courses (12 credits):

ECE 415	Computer Aided Manufacturing	3
ME 477	Manufacturing Processes	3
ME 478	Product Development	3
MSE 465	Design and Application of Engineering Materials	3

2. Three of the following courses (9 credits):

GBL 323	Introduction to Business Law	3
MSE 426	Introduction to Composite Materials	3
MSE 474	Ceramic and Refractory Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3

Completion of this concentration fulfills requirement 2. of the admission requirements for the Master of Science degree in Manufacturing and Engineering Management offered by The Eli Broad College of Business.

Metallurgical Engineering
To enhance the student's ability to characterize, process, and design with metals in association with mechanical engineers and earn a Bachelor of Science degree in Materials Science and Engineering with a metallurgical engineering concentration, students must complete requirement 3. a. above and the following (21 credits):

1. All of the following courses (18 credits):

ME 423	Intermediate Mechanics of Deformable Solids	3
ME 475	Computer Aided Design of Structures	3
ME 477	Manufacturing Processes	3
MSE 481	Spectroscopic and Diffraction Analysis of Materials	3
MSE 465	Design and Application of Engineering Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3

2. One of the following courses (3 credits):

ME 425	Experimental Mechanics	3
MSE 426	Introduction to Composite Materials	3

Polymeric Engineering
To gain interdisciplinary skills to facilitate interactions with chemical engineers and earn a Bachelor of Science degree in Materials Science and Engineering with a polymeric engineering concentration, students must complete requirement 3. a. above and the following (22 credits):

1. All of the following courses (19 credits):

CE 321	Introduction to Fluid Mechanics	4
CEM 251	Organic Chemistry I	3
Or		
CEM 351	Organic Chemistry I	3
CEM 252	Organic Chemistry II	3
Or		
CEM 352	Organic Chemistry II	3
CHE 472	Composite Materials Processing	3
CHE 473	Chemical Engineering Principles in Polymers and Materials Systems	3
MSE 426	Introduction to Composite Materials	3

2. Complete at least 3 credits in courses selected from a list of approved technical electives available from the Department of Chemical Engineering and Materials Science.

MINOR IN MATERIALS SCIENCE AND ENGINEERING

The Minor in Materials Science and Engineering, which is administered by the Department of Chemical Engineering and Materials Science, provides students with a basic foundation in materials science that is applicable to many disciplines. The minor also offers opportunities for students to work in industry, research, or government, as well as to prepare for graduate study in materials science.

The minor is available as an elective to students in a bachelor's degree program in the College of Engineering, other than the Bachelor of Science Degree in Materials Science and Engineering. With the approval of the college, the courses that are used to satisfy the minor may also be used to satisfy the requirements for the bachelor's degree.

Students who plan to complete the requirements for the minor must apply to the Department of Chemical Engineering and Materials Science. To be accepted into the minor, the student must be admitted into the College of Engineering. Enrollment for some MSE courses may be limited. Application forms are available at *www.chems.msu.edu*.

Requirements for the Minor in Materials Science and Engineering

CREDITS

Complete 18 credits from the following:

1. Both of the following courses (6 credits):

MSE 250	Materials Science and Engineering	3
MSE 360	Fundamentals of Microstructural Design	3

2. One of the following courses (3 credits):

MSE 260	Electronic, Magnetic, Thermal and Optical Properties of Materials	3
MSE 310	Phase Equilibria in Materials	3
MSE 320	Mechanical Properties of Materials	3
MSE 370	Synthesis and Processing of Materials	3

3. Three of the following courses (9 credits):

MSE 310	Phase Equilibria in Materials	3
MSE 320	Mechanical Properties of Materials	3
MSE 370	Synthesis and Processing of Materials	3
MSE 410	Materials Foundations for Energy Applications	3
MSE 425	Biomaterials and Biocompatibility	3
MSE 460	Electronic Structure and Bonding in Materials and Devices	3
MSE 465	Design and Application of Engineering Materials	3
MSE 466	Design and Failure Analysis (W)	3
MSE 474	Ceramic and Refractory Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3
MSE 477	Manufacturing Processes	3
MSE 481	Spectroscopic and Diffraction Analysis of Materials	3

A course used to fulfill requirement 2. above may not be used to fulfill this requirement.

LINKED BACHELOR'S-MASTER'S DEGREE IN CHEMICAL ENGINEERING

Bachelor of Science Degree in Chemical Engineering
Master of Science Degree in Chemical Engineering

The department welcomes applications from Michigan State University Chemical Engineering undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Chemical Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Chemical Engineering at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or another postsecondary accredited institution of comparable academic quality. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

LINKED BACHELOR'S-MASTER'S DEGREE IN MATERIALS SCIENCE AND ENGINEERING

Bachelor of Science Degree in Materials Science and Engineering
Master of Science Degree in Materials Science and Engineering

The department welcomes applications from Michigan State University Materials Science and Engineering undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Materials Science and Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Materials Science and Engineering at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or another postsecondary accredited institution of comparable academic quality. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

GRADUATE STUDY

The Department of Chemical Engineering and Materials Science offers Master of Science and Doctor of Philosophy degree programs in chemical engineering and in materials science and engineering. A Graduate Certificate in Foundations in Chemical Engineering is also available. A wide range of course offerings and research activities allows an individual program to be designed to fit the background, capabilities, and aims of the student. Studies in the department may be supplemented with courses offered by other departments in the College of Engineering and in other colleges.

The graduate programs in chemical engineering and materials science and engineering are designed to develop research expertise needed for the graduate to serve as a principal investigator in industrial, government, or academic research. Course work is designed to expand the student's knowledge of engineering principles and applications. Each student conducts an extensive research project that significantly advances fundamental understanding of a chemical engineering or materials science system. Results of the research are documented in a thesis, dissertation, or research paper(s) for publication in a peer-reviewed journal.

CHEMICAL ENGINEERING

Emphasis in the graduate programs in chemical engineering is placed upon a fundamental approach to chemical engineering principles and the applications of chemistry and advanced mathematics. Selected topics in chemical engineering are developed from a fundamental viewpoint, with opportunity for study and research in such areas as process design; thermodynamics; chemical reaction engineering; mass, heat, and momentum transfer; separations; polymers and composite materials; nanomaterials; and biochemical and biomedical engineering. The department has three primary thematic areas: energy and sustainability, nanotechnology and materials, and biotechnology and medicine.

Master of Science

In addition to meeting the requirements of the University and of the College of Engineering, students must meet the requirements specified below.

Admission

An applicant for admission to the master's degree program in chemical engineering must hold a bachelor's degree in

chemical engineering or a related field and must have a grade–point average that would indicate success in graduate study.

International applicants must submit their scores on the Graduate Record Examination General Test.

Students who are admitted to the program with a bachelor's degree in a field related to chemical engineering will be required to complete the following collateral courses, in addition to the courses that are required for the master's degree:

		CREDITS
CHE 432	Process Systems Control	3
CHE 433	Process Design and Optimization I	3
CHE 804	Thermodynamics and Kinetics in Chemical Engineering	3
CHE 805	Transport and Separation Processes	3

Equivalent undergraduate–level chemical engineering courses may be substituted for Chemical Engineering 804 and 805.

Requirements for the Master of Science Degree in Chemical Engineering

The students must complete a total of 30 credits for the degree under Plan A (with thesis) or Plan B (without thesis), and meet the requirements specified below. Students in Plan A must complete a minimum of 20 credits at the 800-level or above. Students in Plan B must complete a minimum of 18 credits at the 800-level or above. Courses at the 400-level are acceptable as long as the minimum credit requirement is met at the 800-level. Courses below the 400-level are not acceptable.

Requirements for Both Plan A and Plan B:

1. **Core Courses**. All of the following courses (12 credits):

		CREDITS
CHE 801	Advanced Chemical Engineering Calculations	3
CHE 821	Advanced Chemical Engineering Thermodynamics	3
CHE 822	Advanced Transport Phenomena	3
CHE 831	Advanced Chemical Reaction Engineering	3

2. Supporting Courses. Six credits in courses outside the Department of Chemical Engineering and Materials Science approved by the student's academic advisor.
3. Complete 2 credits in CHE 892 Seminar.

Additional Requirements for Plan A

1. Complete 6 credits of CHE 899 Master's Thesis Research
2. Additional elective credits as approved by the student's academic advisor.

Additional Requirements for Plan B

1. Complete 6 to 9 credits in a coordinated technical minor as approved by the student's academic advisor.
2. Pass a final examination, oral or written, given by the student's academic advisor.

Doctor of Philosophy

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

An applicant for admission to the Ph.D. degree program in chemical engineering must hold a bachelor's or master's degree in chemical engineering or a related field and must have a grade–point average that would indicate success in graduate study.

Applicants must submit their scores on the Graduate Record Examination General Test.

Students may be required to complete additional collateral course work to fulfill deficiencies in their academic background. A grade of 3.0 or higher is required in each course. In some cases, students may be granted provisional status in the program until collateral course work has been satisfactorily completed. Collateral course work does not count towards fulfillment of degree requirements.

Requirements for the Doctor of Philosophy Degree in Chemical Engineering

The Doctor of Philosophy degree in Chemical Engineering is comprised of course work, research, selection of an advisor, a qualifying examination, formation of a guidance committee and doctoral degree program, comprehensive examination, and successful completion of a dissertation and final oral examination in defense of the dissertation.

Students must complete the requirements specified by their guidance committee and must include the requirements specified below:

1. All of the following courses (13 credits):

		CREDITS
CHE 801	Advanced Chemical Engineering Calculations	3
CHE 802	Research Methods	1
CHE 821	Advanced Chemical Engineering Thermodynamics	3
CHE 822	Advanced Transport Phenomena	3
CHE 831	Advanced Chemical Reaction Engineering	3

2. Complete 5 credits of CHE 992 Seminar.
3. Students entering the program with a master's degree must complete 12 additional credits in consultation with the guidance committee. Students may receive a waiver for some of the required courses. Students who have a bachelor's degree are required to complete a minimum of 16 additional credits chosen in consultation with the guidance committee.
4. Pass a qualifying examination consisting of a written component and an oral component.
5. Pass a comprehensive examination in the form of a research proposal defense containing a written proposal and an oral defense.
6. Complete a minimum of 24 credits and no more than 36 credits of CHE 999 Doctoral Dissertation Research and successfully defend the dissertation.
7. Present the results of the research in a public seminar during the final oral examination.

MATERIALS SCIENCE AND ENGINEERING

Master of Science

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

The department welcomes applications from students who possess a bachelor's degree in a related engineering or science discipline. Students entering the program with a bachelor degree in a field other than Materials Science and Engineering may be required to complete additional collateral courses to fulfill deficiencies in their academic background. Collateral course work does not count towards the requirements for the degree program.

Requirements for the Master of Science Degree in Materials Science and Engineering

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis) and meet the requirements specified below.

Requirements for Both Plan A and Plan B:

1. Core Courses. All of the following courses (12 credits):

MSE 851	Thermodynamics of Solids	3
MSE 855	Advanced Rate Theory and Diffusion	3
MSE 860	Advanced Theory of Solids	3
MSE 870	Electron Microscopy in Materials Science	3
	Or	
MSE 881	Advanced Spectroscopy and Diffraction Analysis of Materials	3

Additional Requirements for Plan A

1. Complete the following course:
   CHE 892 Seminar 2
2. Complete 6 credits of MSE 899 Master's Thesis Research.
3. One course at the 400-level or above in mathematics or statistics as approved by the student's academic advisor.
4. Submit a written thesis and oral presentation, administered by the student's advisory committee.
5. A minimum of 16 credits must be at the 800-level or above as approved by the student's academic advisor.

Additional Requirements for Plan B

1. Complete the following course:
   CHE 892 Seminar 2
2. One course at the 400-level or above in mathematics or statistics as approved by the student's academic advisor.
3. At least 6 to 9 credits completed in a coordinated technical minor as approved by the student's academic advisor.
4. Additional elective credits as approved by the student's academic advisor.
5. A minimum of 18 credits at the 800-level or above as approved by the student's academic advisor.
6. Pass a final examination or evaluation.

Doctor of Philosophy

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

An applicant for admission to the Ph.D. degree program in materials science and engineering must hold a bachelor's or master's degree in materials science and engineering or a related field and must have a grade-point average that would indicate success in graduate study. Applicants must submit their scores on the Graduate Record Examination General Test.

Students entering the program with a bachelor's degree in a field other than Materials Science and Engineering may be required to complete additional collateral courses to fulfill deficiencies in their academic background. Collateral course work will not count towards degree requirements.

Requirements for the Doctor of Philosophy Degree in Materials Science and Engineering

Students must meet the requirements specified by their guidance committee and must meet the requirements specified below. Students entering the program with a bachelor's degree are required to complete a minimum of 13 additional credits selected in conjunction with the advisor and committee. Students entering the program with a master's degree are required to complete a minimum of 12 additional credits, but may receive a waiver for some of the required courses with approval of the advisor and committee.

1. All of the following courses (13 credits):

		CREDITS
CHE 802	Research Methods	1
MSE 851	Thermodynamics of Solids	3
MSE 855	Advanced Rate Theory and Diffusion	3
MSE 860	Advanced Theory of Solids	3
MSE 870	Electron Microscopy in Materials Science	3
	Or	
MSE 881	Advanced Spectroscopy and Diffraction Analysis of Materials	3

2. Complete 5 credits of CHE 992 Seminar.
3. Complete one mathematics or statistics course at the 400-level or above. 3
4. Pass a qualifying examination consisting of a written component and an oral component.
5. Pass a comprehensive examination in the form of a research proposal defense containing a written proposal and an oral defense.
6. Complete a minimum of 24 credits of MSE 999 Doctoral Dissertation Research, with no more than 36 credits.
7. Successfully defend the dissertation and present the results of the research in a public seminar during the final oral examination.

GRADUATE CERTIFICATE IN FOUNDATIONS IN CHEMICAL ENGINEERING

The Graduate Certificate in Foundations in Chemical Engineering provides a broad base of the key concepts relevant to chemical and biochemical process industries, including thermodynamics; reactor design; fluid flow; heat transfer; separations; and process control, economics, and design. The certificate is appropriate for graduates from other programs who seek to pursue graduate work in chemical engineering and for practitioners trained in other fields who seek to understand and apply chemical-engineering principles. The certificate is available only online.

Admission

Students are generally expected, but not required, to have bachelor's-level or significant training in a math, science or engineering field. Prospective students are encouraged to contact the Director of Graduate Studies in the Department of Chemical Engineering and Materials Science to determine if their background is a good fit for the certificate.

Requirements for the Graduate Certificate in Foundations in Chemical Engineering

Complete all of the following courses with a minimum grade of 3.0 in each course:

		CREDITS
CHE 804	Foundations of Chemical Engineering I	3
CHE 805	Foundations of Chemical Engineering II	3
CHE 806	Foundations of Chemical Engineering III	3

DEPARTMENT of CIVIL and ENVIRONMENTAL ENGINEERING

Peter Savolainen, Chairperson

UNDERGRADUATE PROGRAMS

The Department of Civil and Environmental Engineering offers Bachelor of Science degrees in Civil Engineering and Environmental Engineering. Each program is described below.

CIVIL ENGINEERING

The civil engineering major is designed to provide graduates with a broad understanding of the physical factors involved in the planning, design, and operation of public and private facilities. The bachelor's degree program in civil engineering is oriented to the application of engineering principles to several areas of specialization, including transportation, structures, geotechnical engineering, environmental engineering, water resources, and pavements and materials.

The Bachelor of Science Degree program in Civil Engineering is accredited by the Engineering Accreditation Commission of ABET, *www.abet.org*.

Requirements for the Bachelor of Science Degree in Civil Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Civil Engineering.

   The University's Tier II writing requirement for the Civil Engineering major is met by completing Civil Engineering 321 and 341. Those courses are referenced in item 3. a. below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.
2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.
3. The following requirements for the major:

			CREDITS
a. All of the following courses (42 credits):			
CE	221	Statics	3
CE	273	Civil and Environmental Engineering Measurements	2
CE	274	Graphics for Civil and Environmental Engineers	1
CE	275	GIS for Civil and Environmental Engineers	1
CE	305	Introduction to Structural Analysis	3
CE	312	Soil Mechanics	4
CE	321	Introduction to Fluid Mechanics	4
CE	337	Civil Engineering Materials	4
CE	341	Transportation Engineering	3
CE	371	Sustainable Civil and Environmental Engineering Systems	3
CE	372	Risk Analysis in Civil and Environmental Engineering	3
CE	495	Senior Design in Civil and Environmental Engineering	4
CEM	161	Chemistry Laboratory I	1
ENE	280	Principles of Environmental Engineering and Science	3
ME	222	Mechanics of Deformable Solids	3
b. One of the following courses (3 or 4 credits):			
GLG	201	The Dynamic Earth	4
GLG	301	Geology of the Great Lakes Region	3
c. One of the following courses (3 credits):			
CE	461	Computational Methods in Civil Engineering	3
ME	361	Dynamics	3
d. One of the following courses (3 credits):			
BE	351	Thermodynamics for Biological Engineering	3
ECE	345	Electronic Instrumentation and Systems	3
ME	201	Thermodynamics	3
MSE	250	Materials Science and Engineering	3
e. **Design-intensive Electives**. Complete 12 or 13 credits of electives from the list below in at least four different areas (environmental, geotechnical, pavements, structures, transportation, and water resources).			
Environmental			
ENE	483	Water and Wastewater Engineering	4
ENE	489	Air Pollution: Science and Engineering	3
Geotechnical			
CE	418	Geotechnical Engineering	3
CE	485	Landfill Design	3
Pavements			
CE	431	Design and Analysis for New and Rehabilitated Pavements	4
Structures			
CE	405	Design of Steel Structures	3
CE	406	Design of Concrete Structures	3
Transportation			
CE	444	Principles of Traffic Engineering	3
CE	449	Highway Design	3
Water Resources			
ENE	421	Engineering Hydrology	3
ENE	422	Applied Hydraulics	3
f. **Technical Electives**. Complete 6 additional credits in courses not used to fulfill areas above or from the following:			
CE	400	Structural Mechanics	3
CE	407	Materials Engineering: Properties, Selection and Processing	3
CE	432	Pavement Rehabilitation	3
CE	448	Transportation Planning	3
CE	471	Construction Engineering – Equipment, Methods and Planning	3
CE	473	Smart and Sustainable Building Design and Operations	3
ENE	472	Life Cycle Assessment of Energy Technologies	3
ENE	481	Environmental Chemistry: Equilibrium Concepts	3
ENE	487	Microbiology for Environmental Science and Engineering	3

ENVIRONMENTAL ENGINEERING

The environmental engineering major is designed to provide graduates with the engineering and scientific principles to analyze, design, and manage environmental systems, including water supplies, wastewater treatment facilities, air pollution control systems, surface and groundwater resources, and landfills. The program offers a thorough background in engineering fundamentals, along with a broad understanding of mathematical, physical, chemical, and biological concepts as they relate to environmental engineering.

The Bachelor of Science Degree program in Environmental Engineering is accredited by the Engineering Accreditation Commission of ABET, *www.abet.org*.

Requirements for the Bachelor of Science Degree in Environmental Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Environmental Engineering.

The University's Tier II writing requirement for the Environmental Engineering major is met by completing Civil Engineering 321. That course is referenced in item 3. a. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major.

			CREDITS
a. All of the following courses (53 credits):			
BS	161	Cell and Molecular Biology	3
BS	162	Organismal and Population Biology	3
CE	221	Statics	3
CE	274	Graphics for Civil and Environmental Engineers	1
CE	275	GIS for Civil and Environmental Engineers	1
CE	321	Introduction to Fluid Mechanics	4
CE	371	Sustainable Civil Environmental Engineering Systems	3
CE	372	Risk Analysis in Civil and Environmental Engineering	3
CE	495	Senior Design in Civil and Environmental Engineering	4
CEM	161	Chemistry Laboratory I	1
CHE	201	Material and Energy Balances	3
ENE	280	Principles of Environmental Engineering and Science	3
ENE	421	Engineering Hydrology	3
ENE	422	Applied Hydraulics	3
ENE	480	Environmental Measurements Laboratory	2
ENE	481	Environmental Chemistry: Equilibrium Concepts	3
ENE	483	Water and Wastewater Engineering	4
ENE	487	Microbiology for Environmental Science and Engineering	3
ENE	489	Air Pollution: Science and Engineering	3
b. One of the following courses (3 credits):			
CEM	142	General and Inorganic Chemistry	3
CEM	152	Principles of Chemistry	3
c. One of the following courses (3 or 4 credits):			
CHE	321	Thermodynamics for Chemical Engineering	4
ME	201	Thermodynamics	3
d. One of the following courses (3 or 4 credits):			
GLG	201	The Dynamic Earth	4
GLG	301	Geology of The Great Lakes Region	3
e. **Engineering Electives**. Complete at least one course for a minimum of 3 credits of electives from the list below or by approval of the department. Students must contact the department for approval.			
BE	449	Human, Health Risk Analysis for Engineering Controls	3
BE	469	Sustainable Bioenergy Systems	3
BE	482	Engineering Ecological Treatment Systems	3
BE	484	Water Resource Recovery Engineering	3
CE	473	Smart and Sustainable Building Design and Operations	3
CE	485	Landfill Design	3
ENE	472	Life Cycle Assessment of Energy Technologies	3
f. **Technical Electives**. Complete at least two courses for a minimum of 6 credits of electives from the list below, list above (e), or by approval of the department. Students may substitute a 3-credit experiential education experience for one of the three courses. The experience is obtained in a minimum of three out-of-classroom experiences through engineering cooperative education. Students must contact the department for approval.			
ANS	427	Environmental Toxicology and Society	3
BE	469	Sustainable Bioenergy Systems	3
BE	482	Diffuse-Source Pollution Engineering	3
CSS	455	Environmental Pollutants in Soil and Water	3
CSUS	320	Environmental Planning and Management	3
FW	414	Aquatic Ecosystem Management	3
FW	417	Wetland Ecology and Management	3
FW	420	Stream Ecology	3
FW	472	Limnology	3
GLG	303	Oceanography	4
GLG	411	Hydrogeology	3
GLG	412	Glacial Geology and the Record of Climate Change	4
GLG	421	Environmental Geochemistry	4
IBIO	353	Marine Biology (W)	4
IBIO	355	Ecology	3
IBIO	446	Environmental Issues and Public Policy	3
ISS	310	People and Environment (I)	4
PLB	443	Restoration Ecology	3

LINKED BACHELOR'S-MASTER'S DEGREE IN CIVIL ENGINEERING

Bachelor of Science Degree in Civil Engineering
Master of Science Degree in Civil Engineering

The department welcomes applications from Michigan State University Civil Engineering undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Civil Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Civil Engineering at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or an external accredited institution. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

LINKED BACHELOR'S-MASTER'S DEGREE IN ENVIRONMENTAL ENGINEERING

Bachelor of Science Degree in Civil Engineering with a concentration in Environmental Engineering
Master of Science Degree in Environmental Engineering

The department welcomes applications from Michigan State University Civil Engineering undergraduate students in their junior and senior year, who are pursuing an environmental engineering concentration within the Bachelor of Science degree in Civil Engineering. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Civil Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Environmental Engineering at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or an external accredited institution. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the

Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

GRADUATE STUDY

The Department of Civil and Environmental Engineering offers the graduate degree programs that are listed below:

Master of Science
Civil Engineering
Environmental Engineering
Doctor of Philosophy
Civil Engineering
Environmental Engineering

The civil engineering degrees offer tracks in structural, materials, pavement, and geotechnical engineering, and hydrology and water resources. The environmental engineering degrees offer specializations in environmental chemistry and physical-chemical processes, environmental microbiology and biotechnology, and environmental hydrology and water resources.

The Master of Science degrees provide opportunities for students who seek to enter professional practice as specialists or to continue study in a doctoral program. The Doctor of Philosophy degrees are research focused, designed to prepare students for careers in teaching, research or advanced specialized practice.

CIVIL ENGINEERING

Students in the master's and doctoral degree programs in civil engineering may pursue advanced study in the areas of geotechnical and pavement engineering, structural engineering, mechanics and materials; water resources; ad transportation engineering.

Master of Science

Courses are selected in consultation with the academic advisor based upon the student's background. The courses in the final program of study are subject to the approval of the guidance committee.

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

An applicant for admission to the master's degree program in civil engineering should have a bachelor's degree in civil engineering or a related field and should have a grade–point average that would indicate success in graduate study.
Depending on their undergraduate programs and their specialties within civil engineering, students who are admitted to the master's degree program with bachelor's degrees in fields related to civil engineering may be required to complete collateral courses.

All applicants are encouraged to submit their scores from the Graduate Record Examination General Test.

Requirements for the Master of Science Degree in Civil Engineering

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis).
A student under Plan A must complete at least 20 credits at the 800-level or above, including 4 credits of Civil Engineering 899, but not more than 6 credits. Up to 10 credits of 400-level course work may be counted toward the degree. The student's program must be approved by the guidance committee.

A student under Plan B must complete at least 18 credits at the 800-level or above, including the completion of a research or design project through enrollment of at least 1 credit, but no more than 4 credits in Civil Engineering 892. Up to 12 credits of 400-level course work may be counted toward the degree. The student's program must be approved by the guidance committee.

Doctor of Philosophy

Admission

An applicant for admission to the Ph.D. degree program in civil engineering should have a bachelor's or master's degree in civil engineering or a related field and should have a grade-point average that would indicate success in graduate study.

All applicants are encouraged to submit their scores from the Graduate Record Examination General Test.

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified by their guidance committees.

Requirements for the Doctor of Philosophy Degree in Civil Engineering

These general criteria are the same for all students, the specific requirements for each student are developed in consultation with the advisor and the guidance committee.

1. Students with a Master of Science degree in Civil Engineering must complete 12 credits of course work at the 800-level or above in consultation with their advisor and guidance committee.
2. Students admitted directly to the Doctor of Philosophy degree in Civil Engineering must also complete the requirements for the Master of Science degree in Civil Engineering as part of the doctoral plan of study.
3. Students entering the program with a bachelor's or master's degree in a field other than civil engineering may be required to complete additional collateral course work to fulfil deficiencies in their academic background as specified by the guidance committee. This course work will not count towards the requirements for the doctoral degree program.
4. Complete the following course during the first year of study:
   CE 900 Research Strategies and Methods in Civil Engineering 1
5. Complete 24 to 36 credits of CE 999 Doctoral Dissertation Research.
6. Complete a qualifying examination comprised of a written examination and an oral examination.
7. Complete a comprehensive examination comprised of a written thesis proposal and oral presentation. This examination must be completed at least six months prior to the doctoral dissertation defense.
8. Complete and successfully defend the dissertation and present the results of the dissertation research in a public seminar.

ENVIRONMENTAL ENGINEERING

Students in the master's and doctoral degree programs in environmental engineering may pursue advanced study in the areas of environmental chemistry and physical-chemical processes, environmental microbiology and biotechnology, and environmental hydrology and water resources.

Master of Science

Courses are selected in consultation with the academic advisor based upon the student's background. The courses in the final program of study are subject to the approval of the guidance committee.

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

Applicants for admission are expected to have a level of competency equivalent to that achieved by earning an undergraduate degree in environmental engineering, or in civil engineering with an environmental engineering specialization. The undergraduate program should have included courses in mathematics through differential equations, chemistry, physics (mechanics), fluid mechanics, computer programming, and the design of water and wastewater treatment processes.

Depending on their undergraduate programs and their specialties within environmental engineering, students who are admitted to the master's degree program with bachelor's degrees in fields related to environmental engineering may be required to complete collateral courses.

All applicants are encouraged to provide their scores from the Graduate Record Examination General Test.

Requirements for the Master of Science Degree in Environmental Engineering

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis).

A student under Plan A must complete at least 20 credits at the 800-level or above, including 4 credits of Environmental Engineering 899. Up to 10 credits of 400-level course work may be counted toward the degree. The student's program must be approved by the guidance committee.

A student under Plan B must complete at least 18 credits at the 800-level or above, including the completion of a research or design project through enrollment of at least 1 credit, but no more than 4 credits in Environmental Engineering 892. Up to 12 credits of 400-level course work may be counted toward the degree. The student's program must be approved by the guidance committee.

Doctor of Philosophy

Admission

An applicant for admission to the Ph.D. degree program in environmental engineering should have a bachelor's or master's degree in environmental engineering or a related field and should have a grade-point average that would indicate success in graduate study.

All applicants are encouraged to submit their scores from the Graduate Record Examination General Test.

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified by their guidance committees.

Requirements for the Doctor of Philosophy Degree in Environmental Engineering

These general criteria are the same for all students, the specific requirements for each student are developed in consultation with the advisor and the guidance committee.

1. Students with a Master of Science degree in Environmental Engineering must complete 15 credits of coursework at the 800-level or above in consultation with their advisor and guidance committee.
2. Students admitted directly to the Doctor of Philosophy degree in Environmental Engineering must also complete the requirements for the Master of Science degree in Environmental Engineering as part of the doctoral plan of study.
3. Students entering the program with a bachelor's or master's degree in a field other than environmental engineering may be required to complete additional collateral course work to fulfil deficiencies in their academic background as specified by the guidance committee.
   This course work will not count towards the requirements for the doctoral degree program.
4. Complete the following course during the first year of study:
   ENE 900 Research Strategies and Methods in Environmental Engineering and Science 1
5. Complete 24 to 36 credits of ENE 999 Doctoral Dissertation Research.
6. Complete a qualifying examination comprised of a written examination and an oral examination.
7. Complete a comprehensive examination comprised of a written thesis proposal and oral presentation. This examination must be completed at least six months prior to the doctoral dissertation defense.
8. Complete and successfully defend the dissertation and present the results of the dissertation research in a public seminar.

DEPARTMENT of COMPUTATIONAL MATHEMATICS, SCIENCE and ENGINEERING

Computational Mathematics, Science and Engineering is the multidisciplinary field that is concerned with the use of advanced computing capabilities to solve complex problems pertaining to computational modeling and data science. Among the areas of interest include the development and analysis of algorithms, high performance computing, including both parallel computing and heterogeneous architectures, and the application of both algorithms and high-performance computing to modeling and data analysis, exploration, and visualization. The department offers a wide range of courses in computational and data science. Graduates will use their skills in large-scale computing and data science to address a wide variety of problems in science, engineering and other fields.

The Department of Computational Mathematics, Science and Engineering is administered jointly by the colleges of Natural Science, and Engineering.

UNDERGRADUATE PROGRAMS

The department offers a minor in Computational Mathematics, Science and Engineering. The minor is a minimum of 17 credits and builds up on the first two undergraduate CMSE courses, CMSE 201 and 202. The purpose of the minor is to teach students foundational concepts in computational modeling and data science, and to have them apply these to domain-specific challenges. Mastery of these subject areas are attained through a variety of courses offered by CMSE, augmented by discipline-specific courses and project-based work through other departments on campus. For additional information on the minor, see the *Department of Computational Mathematics, Science and Engineering* section in the *College of Natural Science* section of this catalog.

GRADUATE STUDY

The Department of Computational Mathematics, Science and Engineering offers the programs listed below:

Master of Science
Computational Mathematics, Science and Engineering
Doctor of Philosophy
Computational Mathematics, Science and Engineering
Graduate Certificate
Computational Modeling
High-Performance Computing

Study for the department's graduate degree programs is administered by the College of Engineering.

Master of Science

The Master of Science degree in Computational Mathematics, Science, and Engineering provides students broad and deep knowledge of the fundamental techniques used in computational modeling and data science, as well as significant exposure to at least one application domain.

Admission

Admission to graduate study in computational mathematics, science, and engineering is primarily to the doctoral program. Under certain circumstances, the program may consider application for admission to the master's degree program for students who wish to earn the master's degree in preparation for the doctoral program in computational mathematics, science, and engineering, or another doctoral program, or in pursuit of other professional goals.

To be considered for admission to the master's degree, a student must:

1. have a four-year bachelor's degree in any area.
2. have a strong interest in computational and/or data science.
3. have taken course work in calculus through differential equations, and have a working knowledge of linear algebra, basic statistics, and basic numerical methods.
4. be proficient in at least one programming language.

In addition to meeting the requirements of the university and of the College of Natural Science, students must meet the requirements specified below.

Requirements for the Master of Science Degree in Computational Mathematics, Science, and Engineering

A total of 30 credits is required for the degree under either Plan A (with thesis) or Plan B (without thesis). The student's program of study must be approved by the student's guidance committee and must meet the requirements specified below.

CREDITS

Requirements for Both Plan A and Plan B

1. Complete three of the following courses (9 credits):
   CMSE 820 Mathematical Foundations of Data Science 3
   CMSE 821 Numerical Methods for Differential Equations 3
   CMSE 822 Parallel Computing 3
   CMSE 823 Numerical Linear Algebra, I 3
   Additional details on applicable course work can be found in the CMSE graduate handbook at www.cmse.msu.edu.
2. Complete additional course work in one or more cognate areas chosen in consultation with the student's guidance committee as specified in the CMSE graduate handbook at www.cmse.msu.edu.
3. All students must complete Responsible Conduct of Research Training.

Additional Requirements for Plan A:

1. The following course:
   CMSE 899 Master's Thesis Research 4 to 8
2. Successful completion and defense of a thesis based on original research on a problem in computational and/or data science. The thesis research will culminate in a written thesis to be submitted to, and accepted by, a guidance committee. An oral examination of the student's work may be required.

Additional Requirements for Plan B:

1. Completion of additional course work determined in consultation with the student's guidance committee.
2. Completion of a final examination or evaluation.

Doctor of Philosophy

The Doctor of Philosophy degree in Computational Mathematics, Science, and Engineering provides students broad and deep knowledge of the fundamental techniques used in computational modeling and data science, as well as significant exposure to at least one application domain, and to conduct significant original research in algorithms and/or applications relating to computational and data science.

Admission

Admission to graduate study in computational mathematics, science, and engineering is primarily to the doctoral program.

To be considered for admission to the doctoral degree, a student must:

1. have a four-year bachelor's degree in any area.
2. have a strong interest in computational and/or data science.
3. have taken course work in calculus through differential equations, and have a working knowledge of linear algebra, basic statistics, and basic numerical methods.
4. be proficient in at least one programming language.

In addition to meeting the requirements of the university and of the College of Natural Science, students must meet the requirements specified below.

Requirements for the Doctor of Philosophy Degree in Computational Mathematics, Science, and Engineering

The student's program of study must be approved by the student's guidance committee and must meet the requirements specified below.

1. Complete the following courses (12 credits):

			CREDITS
CMSE	820	Mathematical Foundations of Data Science	3
CMSE	821	Numerical Methods for Differential Equations	3
CMSE	822	Parallel Computing	3
CMSE	823	Numerical Linear Algebra, I	3

   Additional details on applicable course work can be found in the CMSE graduate handbook at www.cmse.msu.edu.
2. Complete additional course work to total a minimum of 30 credits beyond the bachelor's degree in one or more cognate areas chosen in consultation with the student's guidance committee as specified in the CMSE graduate handbook at www.cmse.msu.edu.
3. Complete at least 24 credits and no more than 36 credits of CMSE 999 Doctoral Dissertation Research.
4. Pass a written or practical qualifying examination.
5. Pass an oral or written comprehensive examination no less than six months before the defense of the student's dissertation.
6. Successfully defend the doctoral dissertation based on original research in algorithms pertaining to, or applications of computational and data science.
7. All students must complete Responsible Conduct of Research Training.

GRADUATE CERTIFICATE IN COMPUTATIONAL MODELING

The Graduate Certificate in Computational Modeling is intended for students with interest in applying computational and data science approaches to their research problems, or who generally desire broad training in computational modeling and methodology.

Requirements for the Graduate Certificate in Computational Modeling

Students must complete a minimum of 9 credits from the following:

1. Two of the following core courses (6 credits):

			CREDITS
CMSE	801	Introduction to Computational Modeling	3
CMSE	802	Methods in Computational Modeling	3
CMSE	820	Mathematical Foundations of Data Science	3
CMSE	821	Numerical Methods for Differential Equations	3
CMSE	822	Parallel Computing	3
CMSE	823	Numerical Linear Algebra I	3

2. One or more additional courses selected from the following:

AST	911	Numerical Techniques in Astronomy	2
CEM	883	Computational Quantum Chemistry	3
CEM	888	Computational Chemistry	3
CMSE	801	Introduction to Computational Modeling	3
CMSE	802	Methods in Computational Modeling	3
CMSE	820	Mathematical Foundations of Data Science	3
CMSE	821	Numerical Methods for Differential Equations	3
CMSE	822	Parallel Computing	3
CMSE	823	Numerical Linear Algebra I	3
CSE	836	Probabilistic Models and Algorithms in Computational Biology	3
CSE	845	Multi-disciplinary Research Methods for the Study of Evolution	3
CSE	881	Data Mining	3
ECE	837	Computational Methods in Electromagnetics	3
ME	835	Turbulence Modeling and Simulation	3
ME	840	Computational Fluid Dynamics and Heat Transfer	3
ME	872	Finite Element Method	3
MTH	451	Numerical Analysis I	3
MTH	452	Numerical Analysis II	3
MTH	850	Numerical Analysis I	3
MTH	851	Numerical Analysis II	3
MTH	852	Numerical Methods for Ordinary Differential Equations	3
MTH	950	Numerical Methods for Partial Differential Equations I	3
MTH	951	Numerical Methods for Partial Differential Equations II	3
MTH	995	Special Topics in Numerical Analysis and Operations Research	3 to 6
PHY	480	Computational Physics	3
PHY	915	Computational Condensed Matter Physics	2
PHY	919	Modern Electronic Structure Theory	2
PHY	950	Data Analysis Methods for High-Energy and Nuclear Physics	2
PHY	998	High Performance Computing and Computational Tools for Nuclear Physics	2
PLB	810	Theories and Practices in Bioinformatics	3
QB	826	Introduction to Quantitative Biology Techniques	1
STT	461	Computations in Probability and Statistics	3
STT	465	Bayesian Statistical Methods	3
STT	802	Statistical Computation	3
STT	874	Introduction to Bayesian Analysis	3

   Courses used to fulfill requirement 1. may not be used to fulfill this requirement. Additional courses at the 400-level or above may be used to fulfill this requirement if approved by the CMSE graduate advisor. Students must have a minimum 3.0 grade-point average in courses applied to the certificate in order for it to be awarded.

GRADUATE CERTIFICATE IN HIGH-PERFORMANCE COMPUTING

The Graduate Certificate in High-Performance Computing is intended for students with interest in applying computational and data science approaches that require parallel and/or high-performance computing to their research problems, or who generally desire broad training in parallel computational methodology.

Requirements for the Graduate Certificate in High-Performance Computing

Students must complete a minimum of 9 credits from the following:

		CREDITS
1. The following core course (3 credits):		
CMSE 822	Parallel Computing	3
2. Two or more additional courses selected from the following:		
AST 911	Numerical Techniques in Astronomy	2
CEM 883	Computational Quantum Chemistry	3
CEM 888	Computational Chemistry	3
CSE 836	Probabilistic Models and Algorithms in Computational Biology	3
CSE 845	Multi-disciplinary Research Methods for the Study of Evolution	3
CSE 881	Data Mining	3
ECE 837	Computational Methods in Electromagnetics	3
ME 835	Turbulence Modeling and Simulation	3
ME 840	Computational Fluid Dynamics and Heat Transfer	3
ME 872	Finite Element Method	3
MTH 850	Numerical Analysis I	3
MTH 851	Numerical Analysis II	3
MTH 852	Numerical Methods for Ordinary Differential Equations	3
MTH 950	Numerical Methods for Partial Differential Equations I	3
MTH 951	Numerical Methods for Partial Differential Equations II	3
MTH 995	Special Topics in Numerical Analysis and Operations Research	3 to 6
PHY 915	Computational Condensed Matter Physics	2
PHY 919	Modern Electronic Structure Theory	2
PHY 950	Data Analysis Methods for High-Energy and Nuclear Physics	2
PHY 998	High Performance Computing and Computational Tools for Nuclear Physics	2
PLB 810	Theories and Practices in Bioinformatics	3
QB 826	Introduction to Quantitative Biology Techniques	1
STT 802	Statistical Computation	3
STT 874	Introduction to Bayesian Analysis	3

Additional courses at the 800-level or above may be used to fulfill this requirement if approved by the CMSE graduate advisor. Students must have a minimum 3.0 grade-point average in courses applied to the certificate in order for it to be awarded.

DEPARTMENT of COMPUTER SCIENCE and ENGINEERING

Wolfgang Banzhaf, Chairperson

Computer science encompasses the broad areas of problem-solving and information processing using digital computers. Students learn to analyze, design and build integrated software and hardware systems that process, transmit, and reason about information to solve problems. Graduates of the Computer Science and Computational Data Science programs are employed in essentially all areas of industry, government, and education. They serve as project managers, designers, analysts, and developers involved with problems in commercial software development, data analysis, business and research, process and production control software systems, and computer components and systems.

UNDERGRADUATE PROGRAMS

The Department of Computer Science and Engineering offers two Bachelor of Science degree programs, one in Computer Science and one in Computational Data Science. Students in both programs are provided with a theoretical foundation in computer science, required for continued success in these rapidly changing fields, as well as practical experience with current tools and techniques. To achieve these goals, students take courses that span a spectrum of knowledge ranging from theoretical foundations, which enable a rigorous analysis of data and computational problems and solutions, to applied design and engineering methods. At the upper level, students choose from a wide range of elective courses focusing on computer networks, big data, artificial intelligence, database systems, computer security, software engineering, and computer graphics. The senior year in both programs culminates with a team-oriented design course building on much of what one has learned throughout the undergraduate experience. Students with interests in other areas can consult and work with interested faculty from a wide range of academic disciplines.

The Bachelor of Science in Computer Science prepares students to be professionals in software design and development. The Bachelor of Science in Computational Data Science prepares students for careers where the central focus is manipulating and deriving understanding from large volumes of data.

COMPUTATIONAL DATA SCIENCE

The Bachelor of Science degree in Computational Data Science focuses on the computational foundations of data science, providing an in-depth understanding of the algorithms and data structures for storing, manipulating, visualizing, and learning from large data sets. Students in the program have unique access to a wide range of fundamental computer science courses in topics ranging from mobile application and web development to theory of computation and fundamental algorithms. Students can tailor their degree to their unique interests and requirements, with an emphasis on computational foundations.

Requirements for the Bachelor of Science Degree in Computational Data Science

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 120 credits, including general elective credits, are required for the Bachelor of Science degree in Computational Data Science.

   The University's Tier II writing requirement for the Computational Data Science major is met by completing Computational Mathematics, Science and Engineering 495, referenced in item 3. b. below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement.
2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.
3. The following requirements for the major:

		CREDITS

a. **Bioscience** (4 to 6 credits)
   (1) One of the following courses:

BS	161	Cell and Molecular Biology	3
ENT	205	Pests, Society and Environment	3
IBIO	150	Integrating Biology: From DNA to Populations	3
MMG	141	Introductory Human Genetics	3
MMG	201	Fundamentals of Microbiology	3
PLB	105	Plant Biology	3
PSL	250	Introductory Physiology	4

   (2) One of the following courses:

BS	171	Cell and Molecular Biology Laboratory	2
CEM	161	Chemistry Laboratory I	1
CEM	162	Chemistry Laboratory II	1
PHY	191	Physics Laboratory for Scientists, I	1
PHY	192	Physics Laboratory for Scientists, II	1
PLB	106	Plant Biology Laboratory	1

b. All of the following courses (47 credits):

CMSE	201	Computational Modeling and Data Analysis I	4
CMSE	381	Fundamentals of Data Science Methods	4
CMSE	382	Optimization Methods in Data Science	4
CMSE	495	Experiential Learning in Data Science (W)	4
CSE	232	Introduction to Programming II	4
CSE	300	Social, Ethical, and Professional Issues in Computing	1
CSE	331	Algorithms and Data Structures	3
CSE	380	Information Management and the Cloud	3
CSE	404	Introduction to Machine Learning	3
CSE	482	Big Data Analysis	3
CSE	480	Database Systems	3
MTH	314	Matrix Algebra with Computational Applications	3
STT	180	Introduction to Data Science	4
STT	380	Probability and Statistics for Data Science	4

c. Two courses selected from the following (6 credits):

CSE	402	Biometrics and Pattern Recognition	3
CSE	415	Introduction to Parallel Computing	3
CSE	431	Algorithm Engineering	3
CSE	440	Introduction to Artificial Intelligence	3

Computer Science and Engineering 415 and Computational Science, Mathematics and Engineering 401 may not be used to fulfill both requirements c. and d.

d. Two courses selected from the following (6 credits):

CMSE	401	Methods for Parallel Computing	4
CMSE	402	Data Visualization Principles and Techniques	3
CSE	402	Biometrics and Pattern Recognition	3
CSE	415	Introduction to Parallel Computing	3
CSE	431	Algorithm Engineering	3
CSE	440	Introduction to Artificial Intelligence	3
CSE	471	Media Processing and Multimedia Computing	3
CSE	472	Computer Graphics	3
MTH	451	Numerical Analysis I	3
MTH	468	Predictive Analytics	3
STT	464	Statistics for Biologists	3
STT	465	Bayesian Statistical Methods	3

Computer Science and Engineering 415 and Computational Science, Mathematics and Engineering 401 may not be used to fulfill both requirements c. and d.

COMPUTER SCIENCE

The Bachelor of Science degree in Computer Science focuses on the analysis, design, and development of software and hardware computer systems. Computer Science applies creativity, logic, and computational thinking to solve problems important to science, healthcare, education, business, entertainment, government, and all aspects of modern life. Students develop the fundamental programming skills for building software systems and are introduced to a wide range of algorithms, data structures, and patterns that can be applied to problem-solving. A range of elective courses allows a student to customize the degree in this expansive field to their interests. Complementing these major areas, the cognate provides an excellent opportunity to develop an individually selected area of interest.

Students who are enrolled in the Bachelor of Science degree program with a major in computer science may elect a Minor in Game Design and Development. For additional information, refer to the *Minor in Game Design and Development* statement in the *Department of Media and Information* section of this catalog.

The Bachelor of Science degree program in Computer Science is accredited by the Computing Accreditation Commission of ABET, *www.abet.org* under the General Criteria and the *Computer Science* and *Similarly Named Computing Programs Program Criteria*.

Requirements for the Bachelor of Science Degree in Computer Science

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 120 credits, including general elective credits, are required for the Bachelor of Science degree in Computer Science.

   The University's Tier II writing requirement for the Computer Science major is met by completing Computer Science and Engineering 498, referenced in item 3. b. below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement.
2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.
3. The following requirements for the major:

CREDITS

a. **Bioscience** - Courses may not be used to satisfy both (1) and (2) below — 4 to 6
   (1) One of the following courses:

BS	161	Cell and Molecular Biology	3
ENT	205	Pests, Society and Environment	3
IBIO	150	Integrating Biology: From DNA to Populations	3
MMG	141	Introductory Human Genetics	3
MMG	201	Fundamentals of Microbiology	3
PLB	105	Plant Biology	3
PSL	250	Introductory Physiology	4

   (2) One of the following courses:

BS	171	Cell and Molecular Biology Laboratory	2
CEM	161	Chemistry Laboratory I	1
CEM	162	Chemistry Laboratory II	1
PHY	191	Physics Laboratory for Scientists, I	1
PHY	192	Physics Laboratory for Scientists, II	1
PLB	106	Plant Biology Laboratory	1

b. All of the following courses (32 credits):

CSE	232	Introduction to Programming II	4
CSE	260	Discrete Structures in Computer Science	4
CSE	300	Social, Ethical, and Professional Issues in Computing	1
CSE	320	Computer Organization and Architecture	3
CSE	325	Computer Systems	3
CSE	331	Algorithms and Data Structures	3
CSE	335	Object-Oriented Software Design	4
CSE	380	Information Management and the Cloud	3
CSE	498	Collaborative Design (W)	4
STT	351	Probability and Statistics for Engineering	3

Students must have a minimum grade of 2.0 in each of the following courses: CSE 300, CSE 320, CSE 325, CSE 331, CSE 335, CSE 380.

c. One of the following courses (3 or 4 credits):

MTH	314	Matrix Algebra with Computational Applications	3
MTH	317H	Honors Linear Algebra	4

d. An additional five courses selected from the following (15 credits):

CSE	402	Biometrics and Pattern Recognition	3
CSE	404	Introduction to Machine Learning	3
CSE	410	Operating Systems	3
CSE	415	Introduction to Parallel Programming	3

CSE	420	Computer Architecture	3
CSE	422	Computer Networks	3
CSE	425	Introduction to Computer Security	3
CSE	431	Algorithm Engineering	3
CSE	434	Autonomous Vehicles	3
CSE	435	Software Engineering	3
CSE	440	Introduction to Artificial Intelligence	3
CSE	450	Translation of Programming Languages	3
CSE	460	Computability and Formal Language Theory	3
CSE	471	Media Processing and Multimedia Computing	3
CSE	472	Computer Graphics	3
CSE	476	Mobile Application Development	3
CSE	477	Web Application Architecture and Development	3
CSE	480	Database Systems	3
CSE	482	Big Data Analysis	3
CSE	491	Selected Topics in Computer Science	1 to 4
MTH	451	Numerical Analysis I	3

e. **Required Cognate** (12 credits):
Cognates in the following areas are available to students in Computer Science: business, communication arts and sciences, foreign language, mathematics, the natural sciences, philosophy, psychology, the social sciences, and telecommunication. Students may complete cognates in other areas with the approval of the Department of Computer Science and Engineering academic advisor. The cognate should enhance the student's ability to apply analytical procedures in a specific subject area.

The cognate requires a minimum of four courses totaling 12 or more credits outside the College of Engineering selected from (1) or (2) below. The academic advisor of the Department of Computer Science and Engineering must preapprove both the cognate and the cognate courses.

(1) A minimum of four courses totaling 12 or more credits. At least 6 of the 12 credits must be in courses at the 300-400 level.
(2) Cognate in The Eli Broad College of Business consisting of this specific set of courses: ACC 230, FI 320, GBL 323 and MKT 327.
(3) A sequence of at least three courses in a foreign language totaling at least 12 credits.

Concentrations in Computer Science

The Department offers the following concentrations to students wishing an area of specialization in their degree. The concentrations are available to, but not required of, any student enrolled in the Bachelor of Science degree program in Computer Science. NOTE: Completing the Bachelor of Science degree in Computer Science with a concentration may require more than 120 credits. Upon completion of the required courses for a concentration, certification will appear on the student's official transcript. Students may select no more than one concentration.

For any concentration, 3 credits of CSE 499 Undergraduate Research related to the subject area may be applied with approval of the Department of Computer Science and Engineering.

Artificial Intelligence
To complete a Bachelor of Science degree in Computer Science with an artificial intelligence concentration, students must complete the requirements for the bachelor's degree, including the following:
Two of the following courses (6 credits):

CSE	404	Introduction to Machine Learning	3
CSE	440	Introduction to Artificial Intelligence	3
CSE	482	Big Data Analysis	3

Three of the following courses not taken above (9 to 12 credits):

CSE	402	Biometrics and Pattern Recognition	3
CSE	404	Intro to Machine Learning	3
CSE	434	Autonomous Vehicles	3
CSE	440	Introduction to Artificial Intelligence	3
CSE	482	Big Data Analysis	3
CSE	803	Computer Vision	3
ADV	401	Neuromarketing and Consumer Decisions	3
LIN	401	Introduction to Linguistics	4
LIN	424	Introduction to Phonetics and Phonology	3
LIN	427	Laboratory Phonetics	3
LIN	431	Introduction to Morphology	3
LIN	434	Introduction to Syntax	3
LIN	437	Introduction to Semantics and Pragmatics	3
LIN	463	Introduction to Cognitive Science	3
LIN	471	Sociolinguistics	3
MI	484	Human Robot Interaction (W)	3
MTH	468	Predictive Analysis	3
NEU	301	Introduction to Neuroscience I	3
NEU	302	Introduction to Neuroscience II	3
PHL	330	Formal Deductive Reasoning	4
PHL	331	Formal Practical Reasoning	4
PHL	432	Logic and its Metatheory	4
PSY	301	Cognitive Neuroscience	3

Computer Systems
To complete a Bachelor of Science degree in Computer Science with a computer systems concentration, students must complete the requirements for the bachelor's degree, including the following:
All of the following courses (9 credits):

CSE	410	Operating Systems	3
CSE	422	Computer Networks	3
CSE	450	Translation of Programming Languages	3

Two of the following courses (6 credits):

CSE	415	Introduction to Parallel Programming	3
CSE	420	Computer Architecture	3
CSE	425	Introduction to Computer Security	3
CSE	434	Autonomous Vehicles	3
CSE	472	Computer Graphics	3
CSE	480	Database Systems	3

Cybersecurity
To complete a Bachelor of Science degree in Computer Science with a cybersecurity concentration, students must complete the requirements for the bachelor's degree, including the following:
All of the following courses (6 credits):

CSE	402	Biometrics and Pattern Recognition	3
CSE	425	Introduction to Computer Security	3

Three of the following courses (9 credits):

CSE	410	Operating Systems	3
CSE	422	Computer Networks	3
CSE	431	Algorithm Engineering	3
CSE	434	Autonomous Vehicles	3
CSE	480	Database Systems	3
CSE	482	Big Data Analysis	3
MI	239	Digital Footprints: Privacy and Online Behavior	3
MTH	416	Introduction to Algebraic Coding	3

Multimedia and Graphics
To complete a Bachelor of Science degree in Computer Science with a multimedia and graphics concentration, students must complete the requirements for the bachelor's degree, including the following:
Two of the following courses (6 credits):

CSE	471	Media Processing and Multimedia Computing	3
CSE	472	Computer Graphics	3
CSE	476	Mobile Application Development	3
CSE	477	Web Application Architecture and Development	3

Three of the following courses not taken above (8 or 9 credits):

CSE	471	Media Processing and Multimedia Computing	3
CSE	472	Computer Graphics	3
CSE	476	Mobile Application Development	3
CSE	477	Web Application Architecture and Development	3
CSE	803	Computer Vision	3
CMSE	402	Data Visualization Principles and Techniques	3
FLM	230	Introduction to Film	3
FLM	260	Introduction to Digital Film and Emergent Media	3
MI	231	Game and Interactive Media Development	3
MI	247	Three-Dimensional Graphics and Design	3
MI	337	Compositing and Special Effects	3
MI	347	Advanced Three-Dimensional Computer Animation	3
MI	350	Evaluating Human-Centered Technology	3
MI	377	Advanced 3D Modeling	3
MI	445	Game Design and Development I	3
MI	450	Creating Human-Centered Technology	3
MI	455	Game Design and Development II	3
MI	462	Social Media and Social Computing	3
MI	482	Building Virtual Worlds (W)	3
MI	497	Game Design Studio	3
STA	380	Electronic Art	3

STA	384	Experiments in Digital Video	3
THR	205	Media Acting I	2
THR	419	Projection Design for Live Performance	3

Software Engineering
To complete a Bachelor of Science degree in Computer Science with a software engineering concentration, students must complete the requirements for the bachelor's degree, including the following:
The following course (3 credits):

CSE	435	Software Engineering	3

Four of the following courses (12 credits):

CSE	431	Algorithm Engineering	3
CSE	476	Mobile Application Development	3
CSE	477	Web Application Architecture and Development	3
CSE	480	Database Systems	3
CSE	870	Advanced Software Engineering	3
MI	350	Evaluating Human-Centered Technology	3
MI	420	Interactive Prototyping	3
MI	450	Creating Human-Centered Technology (W)	3

Theory
To complete a Bachelor of Science degree in Computer Science with a theory concentration, students must complete the requirements for the bachelor's degree, including the following:
The following course (3 credits):

CSE	460	Computability and Formal Language Theory	3

One of the following courses (3 credits):

CSE	431	Algorithm Engineering	3
CSE	830	Design and Theory of Algorithms	3

Three of the following courses (9 or 10 credits):

CSE	835	Algorithmic Graph Theory	3
CSE	860	Foundations of Computing	3
MTH	299	Transitions 4	
MTH	416	Introduction to Algebraic Coding	3
MTH	417	Topics in Number Theory	3
MTH	880	Combinatorics I	3
MTH	882	Combinatorics II	3

MINOR IN COMPUTER SCIENCE

The Minor in Computer Science and Engineering is administered by the Department of Computer Science and Engineering. This minor will provide students with a foundation in computer science that applies to many disciplines. This will also provide opportunities for students in industry or government, as well as prepare students for graduate-level study in computer science.

The minor is available as an elective to students who are enrolled in bachelor's degree programs at Michigan State University other than the Bachelor of Science Degree in Computer Science or the Bachelor of Science Degree in Computer Engineering or the Bachelor of Science Degree in Computational Data Science, or the Bachelor of Science Degree in Data Science. With the approval of the department and college that administers the student's degree program, the courses that are used to satisfy the minor may also be used to satisfy the requirements for the bachelor's degree.

Students who plan to complete the requirements for the minor must apply to the Department of Computer Science and Engineering. The minimum criteria for acceptance are the completion of Computer Science and Engineering 231 and 260 with a combined grade-point average in those two courses of 3.0. Enrollment may be limited. Application forms are available at *www.cse.msu.edu*.

Requirements for the Minor in Computer Science

Complete a minimum of 18 credits in the Department of Computer Science and Engineering from the following:

			CREDITS
1. All of the following courses (13 credits):			
	CSE	231 Introduction to Programming I	4
	CSE	232 Introduction to Programming II	4
	CSE	260 Discrete Structures in Computer Science	4
	CSE	300 Social, Ethical, and Professional Issues in Computing	1
2. Two of the following courses (6 or 7 credits):			
	CSE	320 Computer Organization and Architecture	3
	CSE	325 Computer Systems	3
	CSE	331 Algorithms and Data Structures	3
	CSE	335 Object-Oriented Software Design	4
	CSE	380 Information Management and the Cloud	3
	CSE	402 Biometrics and Pattern Recognition	3
	CSE	404 Introduction to Machine Learning	3
	CSE	420 Computer Architecture	3
	CSE	431 Algorithm Engineering	3
	CSE	434 Autonomous Vehicles	3
	CSE	440 Introduction to Artificial Intelligence	3
	CSE	460 Computability and Format Language Theory	3
	CSE	471 Media Processing and Multimedia Computing	3
	CSE	472 Computer Graphics	3
	CSE	476 Mobile Application Development	3
	CSE	477 Web Application Architecture and Development	3
	CSE	480 Database Systems	3
	CSE	482 Big Data Analysis	3

LINKED BACHELOR'S-MASTER'S DEGREE IN COMPUTER SCIENCE

Bachelor of Science Degree in Computer Engineering Master of Science Degree in Computer Science

The department welcomes applications from Michigan State University Computer Engineering undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Computer Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Computer Science at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or an external accredited institution. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

LINKED BACHELOR'S-MASTER'S DEGREE IN COMPUTER SCIENCE

Bachelor of Science Degree in Computer Science
Master of Science Degree in Computer Science

The department welcomes applications from Michigan State University Computer Science undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Computer Science undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Computer Science at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or an external accredited institution. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

GRADUATE STUDY

The Department of Computer Science and Engineering offers programs leading to the Master of Science and Doctor of Philosophy degrees. Advanced study is available in a variety of computer science research areas such as algorithms, computer security, databases, data mining, machine learning, natural language processing, networking, pattern recognition and image processing, and software engineering, as well as many interdisciplinary research areas such as bioinformatics, cognitive science, and digital evolution.

Students who are enrolled in master's or doctoral degree programs in the Department of Computer Science and Engineering may elect an Interdepartmental Specialization in Cognitive Science. For additional information, refer to the statement on *Interdepartmental Graduate Specializations in Cognitive Science* in the *College of Social Science* section of this catalog. For additional information, contact the Department of Computer Science and Engineering.

Master of Science

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

Applicants for admission should possess a bachelor's degree in computer science or a related field such as mathematics, physics, or electrical engineering. All applicants are encouraged to submit their scores from the Graduate Record Examination (GRE) General Test. Additional information is available on the Department's Web site at *http://cse.msu.edu*.

Requirements for the Master of Science Degree in Computer Science

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis) and meet the requirements specified below:

Requirements for Both Plan A and Plan B:
The student must complete a minimum of 18 credits in courses listed below with at least one course from each breadth area:

System Design and Analysis		
CSE 812	Distributed Systems	3
CSE 820	Advanced Computer Architecture	3
CSE 822	Parallel Computing	3
CSE 824	Advanced Computer Networks and Communications	3
CSE 825	Computer and Network Security	3
CSE 834	Advanced Topics in Automated Vehicles	3
CSE 893	Selected Topics in System Design and Analysis	3
CSE 870	Advanced Software Engineering	3
Theory and Algorithms		
CSE 814	Computer Aided Verification	3
CSE 830	Design and Theory of Algorithms	3
CSE 835	Algorithmic Graph Theory	3
CSE 860	Foundations of Computing	3
CSE 894	Selected Topics in Theory and Algorithms	3
Data Analysis and Applications		
CSE 802	Pattern Recognition and Analysis	3
CSE 803	Computer Vision	3
CSE 840	Computational Foundations in Artificial Intelligence	3
CSE 841	Artificial Intelligence	3
CSE 842	Natural Language Processing	3
CSE 845	Multidisciplinary Research Methods for the Study of Evolution	3
CSE 847	Machine Learning	3
CSE 849	Deep Learning	3
CSE 848	Evolutionary Computation	3
CSE 881	Data Mining	3

Additional Requirements for Plan A:
The student must complete:
1. A minimum of 21 credits in 800-900 level courses chosen in consultation with the student's advisor, excluding Computer Science and Engineering 801, 890, 898, and 899.
2. Complete 6 credits of CSE 899 Master's Thesis Research.

Additional Requirements for Plan B:
1. Complete a minimum of 24 credits in 800-900 level courses chosen in consultation with the student's advisor, excluding Computer Science 801, 890, 898, and 899.

Doctor of Philosophy

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

Applicants should be in the top 25 percent of their master's degree classes and should have a grade–point average of at least 3.50 on a scale of 4.0.

Applicants are encouraged to submit their scores on the Graduate Record Examination General Test.

Applicants who have a Bachelor of Science degree and who demonstrate exceptional potential for graduate study may be accepted for admission to the doctoral program.

Additional information is available on the Department's Web site at *http://cse.msu.edu*.

Requirements for the Doctor of Philosophy Degree in Computer Science

1. Students must complete a minimum of 30 credits beyond the research requirements in CSE 999. Students must maintain a cumulative grade-point average of at least 3.00 in all courses counted towards the 30 credits. The student's guidance committee reserves the right to require additional course work beyond the minimum. Students should contact the graduate director for approval of any courses outside the Department of Computer Science and Engineering.
2. Students may receive credit for 24 credits of course work taken during a prior completed Master of Science degree or equivalent. In the case where the master's degree was obtained from the Department of Computer Science and Engineering at Michigan State University, the Ph.D. student is only required to complete 24 to 36 credits of CSE 999 Doctoral Dissertation Research.
3. As part of the total credit requirements, students must complete a minimum of 18 credits in courses listed below with at least one course from each breadth area. If a student has completed a Master of Science degree and receives a waiver, then the corresponding breadth area requirement will also be waived.

System Design and Analysis

CSE 812	Distributed Systems	3
CSE 820	Advanced Computer Architecture	3
CSE 822	Parallel Computing	3
CSE 824	Advanced Computer Networks and Communications	3
CSE 825	Computer and Network Security	3
CSE 834	Advanced Topics in Automated Vehicles	3
CSE 870	Advanced Software Engineering	3
CSE 893	Selected Topics in System Design and Analysis	3

Theory and Algorithms

CSE 814	Computer Aided Verification	3
CSE 830	Design and Theory of Algorithms	3
CSE 835	Algorithmic Graph Theory	3
CSE 860	Foundations of Computing	3
CSE 894	Selected Topics in Theory and Algorithms	3

Data Analysis and Applications

CSE 802	Pattern Recognition and Analysis	3
CSE 803	Computer Vision	3
CSE 840	Computational Foundations in Artificial Intelligence	3
CSE 841	Artificial Intelligence	3
CSE 842	Natural Language Processing	3
CSE 845	Multidisciplinary Research Methods for the Study of Evolution	3
CSE 847	Machine Learning	3
CSE 848	Evolutionary Computation	3
CSE 849	Deep Learning	3
CSE 850	Advanced Topics in Adversarial Machine Learning	3
CSE 851	Genetic Programming	3
CSE 850	Advanced Topics in Adversarial Machine Learning	3
CSE 851	Genetic Programming	3
CSE 881	Data Mining	3
CSE 895	Selected Topics in Data Analysis and Applications	3

4. Complete a minimum of 24 credits in 800-900 level courses chosen in consultation with the student's advisor, excluding Computer Science 801, 890, 898, and 899.
5. Pass a qualifying examination consisting of a written and an oral part, generally within two years of beginning the Ph.D. program.
6. Pass the comprehensive examination that includes a program statement presenting the student's learning and professional background and goals, and provides a rationale for the students declared focus areas.
7. Complete 24 credits of CSE 999 Doctoral Dissertation Research and successfully defend the dissertation. Present the results of the research in a public seminar during the final oral examination.

DEPARTMENT of ELECTRICAL and COMPUTER ENGINEERING

John Papapolymerou, Chairperson

The Department of Electrical and Computer Engineering offers two undergraduate programs and a concentration leading to a Bachelor of Science degree. The computer engineering program provides students the opportunity to customize their program through core electives in computer architecture, computer networks, and VLSI design and focus electives in hardware or software tracks. The program in electrical engineering allows students to choose their major electives from seven areas: electromagnetics, power, integrated circuits/VLSI, solid-state electronics/electro-optics, communications/signal processing, control/robotics, and biomedical engineering. In addition, a student in either program can choose a biomedical engineering concentration that is noted on the student's transcript.

UNDERGRADUATE PROGRAMS

COMPUTER ENGINEERING

Computer engineering is concerned with the organization and design of computers and computer systems. The study of computer hardware and software, and their integration and application, is emphasized. The undergraduate program in computer engineering integrates studies in mathematics, basic sciences, engineering sciences, and engineering design. The program is structured to establish analytical and design skills in areas such as computer architecture, digital logic design, analog and mixed-signal circuits, computer communication networks, digital computer control, integrated circuit engineering, software engineering, operating systems, data structures and algorithms, computer–aided engineering, and electronic design automation. Complementing these fundamentals, the program also provides opportunities for specialization in individually selected areas of interest.

The Bachelor of Science Degree program in Computer Engineering is accredited by the Engineering Accreditation Commission of ABET, *www.abet.org*.

Requirements for the Bachelor of Science Degree in Computer Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Computer Engineering.

   The University's Tier II writing requirement for the Computer Engineering major is met by completing Electrical and Computer Engineering 480. That course is referenced in item 3. c. below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.
2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

		CREDITS
a. One of the following courses (1 credit):		
CEM 161	Chemistry Laboratory I	1
PHY 191	Physics Laboratory for Scientists, I	1
b. All of the following courses (39 credits):		
CSE 232	Introduction to Programming II	4
CSE 260	Discrete Structures in Computer Science	4
CSE 325	Computer Systems	3
CSE 331	Algorithms and Data Structures	3
ECE 201	Circuits and Systems I	3
ECE 202	Circuits and Systems II	3
ECE 203	Electric Circuits and Systems Laboratory	1
ECE 230	Digital Logic Fundamentals	3
ECE 280	Electrical Engineering Analysis	3
ECE 302	Electronic Circuits	3
ECE 303	Electronics Laboratory	1
ECE 331	Microprocessors and Digital Systems	4
ECE 366	Introduction to Signal Processing	3
ECE 390	Ethics, Professionalism and Contemporary Issues	1
c. One of the following courses (4 credits):		
ECE 480	Senior Design	4
ECE 489	Independent Senior Design	4

d. **Electives**

Complete 21 credits of electives as specified below. At least 15 credits must be from the focus tracks below including at least 6 credits from the core, with at least one course with a laboratory. Additional credits to meet the 21 credit requirement may be taken from other courses listed below, any 400-level Computer Science and Engineering (CSE) or Electrical and Computer Engineering (ECE) courses, or by completing an approved 3 or 4 credit experiential, out-of-classroom education experience obtained through engineering cooperative education or independent study.

Focus Tracks

Core

At least 6 credits from the following:

CSE 335	Object-Oriented Software Design	4
CSE 420	Computer Architecture	3
CSE 422	Computer Networks	3
or		
ECE 442	Introduction to Communication Networks	3
CSE 425	Introduction to Computer Security	3
or		
ECE 456	Introduction to Communication and Network Security	3
ECE 430	Embedded Cyber-Physical Systems	4

Both CSE 422 and ECE 442 or CSE 425 and ECE 456 may not be used to fulfill this requirement.

Hardware

ECE 410	VLSI Design	4
ECE 411	Electronic Design Automation	4
ECE 431	Smart Sensor Systems	3
ECE 445	Biomedical Instrumentation	3

Software Systems

CSE 410	Operating Systems	3
CSE 415	Introduction to Parallel Programming	3
CSE 431	Algorithm Engineering	3
CSE 435	Software Engineering	3
CSE 450	Translation of Programming Languages	3
CSE 476	Mobile Application Development	3
CSE 480	Database Systems	3

Intelligent Systems

CSE 404	Introduction to Machine Learning	3
CSE 440	Introduction to Artificial Intelligence	3
CSE 482	Big Data Analysis	3
ECE 434	Autonomous Vehicles	3
ECE 446	Biomedical Signal Processing	3
ECE 466	Digital Signal Processing and Filter Design	3
MTH 314	Matrix Algebra with Computational Applications	3
STT 351	Probability and Statistics for Engineering	3

Electrical Systems

ECE 305	Electromagnetic Fields and Waves I	4
ECE 313	Control Systems	3
ECE 377	Principles of Electronic Devices	3
ECE 404	Radio Frequency Electronic Circuits	4
ECE 417	Robotics	4

Concentrations

The department offers the following concentrations to students wishing an area of specialization in their degree. Concentrations are available to, but not required of, any student enrolled in the Bachelor of Science Degree in Computer Engineering. Courses completed to satisfy requirement 3 above may also be used to satisfy the requirements of a concentrations. NOTE: Completing the Bachelor of Science degree in Computer Engineering with a concentration may require more than 128 credits. Upon completion of the required courses for a concentration, certification will appear on the student's official transcript.

Biomedical Engineering

This concentration is for students who plan to pursue graduate work in biomedical areas or seek employment in selected medical-related areas.

To earn a Bachelor of Science degree in Computer Engineering with a biomedical engineering concentration, students must complete requirements 1., 2., and 3. above and the following:

		CREDITS
1. Complete 6 credits from the following courses:		
ANTR350	Human Gross Anatomy for Pre-Health Professionals	3
BS 161	Cell and Molecular Biology	3
PSL 250	Introductory Physiology	4
PSL 310	Physiology for Pre-Health Professionals	4
2. Complete 9 credits from the following courses:		
BE 444	Biosensors for Medical Diagnostics	3
ECE 445	Biomedical Instrumentation	3
ECE 446	Biomedical Signal Processing	3
ECE 447	Introduction to Biomedical Imaging	3
ECE 448	Modeling and Analysis of Bioelectrical Systems	3
ECE 449	Fundamentals of Acoustics	3

Students may enroll in 3 or 4 credits of ECE 490 or 491 with biomedical engineering content as approved by the student's advisor for partial fulfillment of this requirement.

Cybersecurity

This concentration is for students interested in the theory and practice of communication networks and security. To earn a Bachelor of Science degree in Computer Engineering with a cybersecurity concentration, students must complete requirements 1., 2., and 3. above and the following:

		CREDITS
1. All of the following courses (9 credits):		
ECE 442	Introduction to Communication Networks	3
ECE 456	Introduction to Communication and Network Security	3
ECE 457	Communication Systems	3
2. Two of the following courses (6 credits):		
CSE 402	Biometrics and Pattern Recognition	3
CSE 410	Operating Systems	3
CSE 425	Introduction to Computer Security	3
CSE 482	Big Data Analysis	3

Robotics and Automation

This concentration is for students interested in graduate work or employment in robotics or automation areas. To earn a Bachelor of Science degree in Computer Engineering with a robotics and automation concentration, students must complete requirements 1., 2., and 3. above and the following:

		CREDITS
1. The following course:		
ECE 417	Robotics	4
2. Complete 9 credits from the following:		
ECE 415	Computer Aided Manufacturing	3
ECE 416	Digital Control	3
ECE 430	Embedded Cyber-Physical Systems	4
ECE 431	Smart Sensors Systems	3
ECE 434	Autonomous Vehicles	3
ECE 466	Digital Signal Processing	3

Smart Systems
This concentration is for students interested in the design and implementation of smart devices and systems for graduate work or employment in consumer electronics, wearables, and internet of things (IoT) fields. To earn a Bachelor of Science degree in Computer Engineering with a smart systems concentration, students must complete requirements 1., 2., and 3. above and the following:

		CREDITS
1. Complete at least 13 credits from the following:		
CSE 404	Introduction to Machine Learning	3
CSE 420	Computer Architecture	3
CSE 440	Introduction Artificial Intelligence	3
CSE 476	Mobile Application Development	3
CSE 482	Big Data Analysis	3
ECE 410	VLSI Design	4
ECE 411	Electronic Design Automation	4
ECE 430	Embedded Cyber-Physical Systems	4
ECE 431	Smart Sensors Systems	3
ECE 445	Biomedical Instrumentation	3
ECE 466	Digital Signal Processing	3

Software Systems
This concentration is for students wishing to focus on software development for graduate work or employment in embedded systems, cloud services and other software intensive fields. To earn a Bachelor of Science degree in Computer Engineering with a software systems concentration, students must complete requirements 1., 2., and 3. above and the following:

		CREDITS
1. Complete at least 13 credits from the following:		
CSE 410	Operating Systems	3
CSE 415	Introduction to Parallel Programming	3
CSE 435	Software Engineering	3
CSE 450	Translation of Programming Languages	3
CSE 476	Mobile Application Development	3
ECE 430	Embedded Cyber-Physical Systems	4

ELECTRICAL ENGINEERING

The program provides both required and elective studies in communications, computers, control systems, electromagnetics, electronics, materials processing, power, signals, solid state, and biomedical engineering. It places emphasis on the fundamentals of science and mathematics and their application to the solution of contemporary problems that are within the purview of professional electrical engineers. The program is designed to establish a sound scientific basis for continuous growth in professional competence.

The Bachelor of Science Degree program in Electrical Engineering is accredited by the Engineering Accreditation Commission of ABET, *www.abet.org*.

Requirements for the Bachelor of Science Degree in Electrical Engineering

1. The University requirements for bachelor's degrees as described in the Undergraduate *Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Electrical Engineering.

   The University's Tier II writing requirement for the Electrical Engineering major is met by completing Electrical and Computer Engineering 480. That course is referenced in item 3. c. below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.
2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.
3. The following requirements for the major:

		CREDITS
a. One of the following courses (1 credit):		
CEM 161	Chemistry Laboratory I	1
PHY 191	Physics Laboratory for Scientists, I	1
b. All of the following courses (38 credits):		
ECE 201	Circuits and Systems I	3
ECE 202	Circuits and Systems II	3
ECE 203	Electric Circuits and Systems Laboratory	1
ECE 230	Digital Logic Fundamentals	3
ECE 280	Electrical Engineering Analysis	3
ECE 302	Electronic Circuits	3
ECE 303	Electronics Laboratory	1
ECE 305	Electromagnetic Fields and Waves I	4
ECE 313	Control Systems	3
ECE 320	Energy Conversion and Power Electronics	3
ECE 331	Microprocessors and Digital Systems	4
ECE 366	Introduction to Signal Processing	3
ECE 377	Principles of Electronic Devices	3
ECE 390	Ethics, Professionalism and Contemporary Issues	1
c. One of the following courses (4 credits):		
ECE 480	Senior Design	4
ECE 489	Independent Senior Design	4

d. Complete a minimum of 18 credits including at least 12 credits from the focus areas below. The 12 credits must include at least one laboratory course (ECE 402, 404, 405, 407, 410, 415, 417, 420, 430, 431, 445, 458, 476, 477) and at least one 3 or 4 credit course from two different focus areas. Additional credits to meet the 18 credit requirement may be taken from MTH 314, any 400-level engineering course or by completing an approved 3 or 4 credit experiential education experience obtained in a minimum of three out-of-classroom experiences through engineering cooperative education or independent study. Students interested in the experiential education experience must contact the department for approval. Courses at the 400-level outside of Electrical and Computer Engineering may have restrictions or require additional prerequisites not included within this degree program.

Computing and Electronics		
ECE 410	VLSI Design	4
ECE 430	Embedded Cyber-Physical Systems	4
ECE 431	Smart Sensor Systems	3
ECE 434	Autonomous Vehicles	3
ECE 442	Introduction to Communication Networks	3
ECE 445	Biomedical Instrumentation	3
ECE 456	Introduction to Communication and Network Security	3
Electrosciences		
ECE 404	Radio Frequency Electronic Circuits	4
ECE 405	Electromagnetic Fields and Waves II	4
ECE 407	Electromagnetic Compatibility	4
ECE 447	Introduction to Biomedical Imaging	3
ECE 449	Fundamentals of Acoustics	3
ECE 476	Electro-Optics	4
ECE 477	Microelectronic Fabrication	3
Systems		
ECE 415	Computer Aided Manufacturing	3
ECE 416	Digital Control	3
ECE 417	Robotics	4
ECE 420	Machines and Power Laboratory	1
ECE 423	Power System Analysis	3
ECE 424	Electrical Drives	3
ECE 425	Solid State Power Conversion	3
ECE 446	Biomedical Signal Processing	3
ECE 448	Modeling and Analysis of Bioelectrical Systems	3
ECE 457	Communication Systems	3
ECE 458	Communication Systems Laboratory	1
ECE 466	Digital Signal Processing	3

Concentrations

The department offers the following concentrations to students wishing an area of specialization in their degree. Concentrations are available to, but not required of, any student enrolled in the Bachelor of Science Degree in Electrical Engineering. Courses completed to satisfy requirement 3. above may also be used to satisfy the

requirements of a concentrations. NOTE: Completing the Bachelor of Science degree in Electrical Engineering with a concentration may require more than 128 credits. Upon completion of the required courses for a concentration, certification will appear on the student's official transcript.

Biomedical Engineering
This concentration is for students who plan to pursue graduate work in biomedical areas or seek employment in selected medical-related areas. To earn a Bachelor of Science degree in Electrical Engineering with a biomedical engineering concentration, students must complete requirements 1., 2., and 3. above and the following:

			CREDITS
1.	Complete 6 credits from the following courses:		
	ANTR350	Human Gross Anatomy for Pre-Health Professionals	3
	BS 161	Cell and Molecular Biology	3
	PSL 250	Introductory Physiology	4
	PSL 310	Physiology for Pre-Health Professionals	4
2.	Complete 9 credits from the following courses:		
	BE 444	Biosensors for Medical Diagnostics	3
	ECE 445	Biomedical Instrumentation	3
	ECE 446	Biomedical Signal Processing	3
	ECE 447	Introduction to Biomedical Imaging	3
	ECE 448	Modeling and Analysis of Bioelectrical Systems	3
	ECE 449	Fundamentals of Acoustics	3

Students may enroll in 3 or 4 credits of ECE 490 or 491 with biomedical engineering content as approved by the student's advisor for partial fulfillment of this requirement.

Digital Systems and Internet of Things
This concentration is for students interested in graduate work or employment in the world of digital hardware, software and systems within the internet of things (IoT) industry. To earn a Bachelor of Science degree in Electrical Engineering with a Digital Systems and IoT concentration, students must complete requirements 1., 2., and 3. above and the following:

			CREDITS
1.	Complete at least four courses from the following:		
	CSE 231	Introduction to Programming I	4
	ECE 411	Electronic Design Automation	4
	ECE 430	Embedded Cyber-Physical Systems	4
	ECE 431	Smart Sensors Systems	3
	ECE 442	Introduction to Communication Networks	3
	ECE 456	Introduction to Communication and Network Security	3
	ECE 466	Digital Signal Processing	3

Electromagnetics, Acoustics and Optics
This concentration is for students interested in graduate work or employment in areas related to electromagnetics, acoustics and optics. To earn a Bachelor of Science degree in Electrical Engineering with an EM, Acoustics and Optics concentration, students must complete requirements 1., 2., and 3. above and the following:

			CREDITS
1.	Complete at least four courses from the following:		
	ECE 405	Electromagnetic Fields and Waves II	4
	ECE 407	Electromagnetic Compatibility	4
	ECE 447	Introduction to Biomedical Imaging	3
	ECE 449	Fundamentals of Acoustics	3
	ECE 476	Electro-Optics	4

Radio Frequency and Wireless Technologies
This concentration is for students interested in radio frequency technologies and the theories and principles of electronic communication and networking for graduate work or employment in areas related to wireless communication. To earn a Bachelor of Science degree in Electrical Engineering with an RF and Wireless concentration, students must complete requirements 1., 2., and 3. above and the following:

			CREDITS
1.	Completion at least four courses from the following:		
	ECE 404	Radio Frequency Electronic Circuits	4
	ECE 405	Electromagnetic Fields and Waves II	4
	ECE 407	Electromagnetic Compatibility	4
	ECE 442	Introduction to Communication Networks	3
	ECE 457	Communication Systems	3

Robotics and Automation
This concentration is for students interested in graduate work or employment in robotics or automation areas. To earn a Bachelor of Science degree in Electrical Engineering with a robotics and automation concentration, students must complete requirements 1., 2., and 3. above and the following:

			CREDITS
1.	The following course:		
	ECE 417	Robotics	4
2.	Complete 9 credits from the following:		
	ECE 415	Computer Aided Manufacturing	3
	ECE 416	Digital Control	3
	ECE 430	Embedded Cyber-Physical Systems	4
	ECE 431	Smart Sensors Systems	3
	ECE 434	Autonomous Vehicles	3
	ECE 466	Digital Signal Processing	3

Microelectronics
This concentration is for students interested in graduate work in electronic materials, devices or circuits or employment in the semiconductor industry. To earn a Bachelor of Science degree in Electrical Engineering with a Microelectronics concentration, students must complete requirements 1., 2., and 3. above and the following:

			CREDITS
1.	Complete at least four courses from the following:		
	ECE 404	Radio Frequency Electronic Circuits	4
	ECE 410	VLSI Design	4
	ECE 425	Solid State Power Conversion	3
	ECE 476	Electro-Optics	4
	ECE 477	Microelectronic Fabrication	3

Smart Devices
This concentration is for students interested in the design and implementation of smart devices and systems for graduate work or employment in consumer electronics and wearables fields. To earn a Bachelor of Science degree in Electrical Engineering with a Smart Devices concentration, students must complete requirements 1., 2., and 3. above and the following:

			CREDITS
1.	Complete at least four courses from the following:		
	ECE 410	VLSI Design	4
	ECE 411	Electronic Design Automation	4
	ECE 416	Digital Control	3
	ECE 431	Smart Sensors Systems	3
	ECE 445	Biomedical Instrumentation	3
	ECE 477	Microelectronic Fabrication	3

LINKED BACHELOR'S-MASTER'S DEGREE IN COMPUTER SCIENCE

Bachelor of Science Degree in Computer Engineering
Master of Science Degree in Computer Science

The department welcomes applications from Michigan State University Computer Engineering undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Computer Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Computer Science at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or an external accredited institution. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

LINKED BACHELOR'S-MASTER'S DEGREE IN ELECTRICAL AND COMPUTER ENGINEERING

Bachelor of Science Degree in Computer Engineering
Master of Science Degree in Electrical and Computer Engineering

The department welcomes applications from Michigan State University Computer Engineering undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Computer Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Electrical and Computer Engineering at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or an external accredited institution. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

LINKED BACHELOR'S-MASTER'S DEGREE IN ELECTRICAL AND COMPUTER ENGINEERING

Bachelor of Science Degree in Electrical Engineering
Master of Science Degree in Electrical and Computer Engineering

The department welcomes applications from Michigan State University Electrical Engineering undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior Fall semester for an anticipated Fall graduation to allow admission before the final semester as a Electrical Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Electrical and Computer Engineering at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or an external accredited institution. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

GRADUATE STUDY

The Department of Electrical and Computer Engineering offers programs leading to the Master of Science and Doctor of Philosophy degrees. Graduate study is available in research areas such as: computer engineering including computer architecture, computer networks, and VLSI/microelectronics; electrosciences including electromagnetics, electronic materials and devices, and non-destructive evaluation; systems including control and robotics, and power as well as systems including signal processing, communications, and biomedical engineering. An interdisciplinary approach marks many of the research projects and helps prepare students for leadership roles in industrial or academic research. A Graduate Certificate in Secure and Connected Cyber-Physical Systems and a Graduate Certificate in Semiconductor Manufacturing, Processing, and Devices are also available..

Master of Science

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

Applicants for admission should possess a Bachelor of Science degree in electrical engineering or a related field such as physics, mathematics, or computer science, and should have a grade–point average that would indicate success in graduate study.

Students who are admitted without a Bachelor of Science degree in electrical engineering may be required to complete collateral courses.

International applicants are required to submit Graduate Record Examination General Test scores.

Requirements for the Master of Science Degree in Electrical and Computer Engineering

The student must complete a total of 30 credits under either Plan A (with thesis) or Plan B (without thesis) and meet the requirements specified below:

CREDITS

Requirements for Both Plan A and Plan B:

1. **Core Courses**. Complete a minimum of four Electrical and Computer Engineering courses at the 800 or 900-level totaling at least 12 credits. Two of the courses must be selected from the following:

ECE 820	Advanced Computer Architecture	3
ECE 821	Advanced Power Electronics and Applications	3
ECE 830	Embedded Cyber-Physical Systems	3
ECE 835	Advanced Electromagnetic Fields and Waves I	3
ECE 842	Performance Modeling of Communication Networks	3
ECE 851	Linear Systems and Control	3
ECE 863	Analysis of Stochastic Systems	3
ECE 874	Physical Electronics	3

   Electrical and Computer Engineering 801 cannot be used to fulfill this requirement
2. Completion of supporting course work outside the department and college at the 400-level and above chosen in consultation with the student's academic advisor. Plan A students must have at least 20 credits at the 800-level or above and Plan B students must have 18 credits at the 800-level or above.
3. **Seminar Requirement**. First-year graduate students are required to attend seven seminars from the graduate seminar series.

Additional Requirements for Plan A

1. Completion of at least 4 credits of ECE 899 Master's Thesis Research, and no more than 8 credits.
2. Pass an oral examination in defense of the thesis.

Additional Requirements for Plan B

1. Completion of a final examination or evaluation.

Doctor of Philosophy

Admission

International applicants are required to submit Graduate Record Examination General Test scores.

Requirements for the Doctor of Philosophy Degree in Electrical and Computer Engineering

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified by their guidance committees.

1. The doctoral program must include a minimum of 36 credits, in addition to 24 credits of Electrical and Computer Engineering 999.
2. No 800-900 level independent study credits taken beyond the bachelor's degree may be counted towards the doctoral degree.
3. A minimum of 3 credits must be taken outside of the College of Engineering in disciplinary areas such as mathematics, statistics, or physics.
4. All courses that are used to satisfy the requirements for the degree must have been completed under the numerical grading system.
5. Students may request up to 3 credits of master's thesis research be applied towards this requirement.
6. First year graduate students are required to attend seven seminars from the graduate seminar series.

GRADUATE CERTIFICATE IN SECURED AND CONNECTED CYBER-PHYSICAL SYSTEMS

The Graduate Certificate in Secured and Connected Cyber-Physical Systems is intended for students with interest in the modeling, design, and analysis of secure and networked cyber-physical systems (CPS). The certificate prepares students for both research work as well for jobs in government and industry in secure and connected CPS, which are growing rapidly.

Requirements for the Graduate Certificate in Secured and Connected Cyber-Physical Systems

Students must complete all of the following courses (9 credits):

		CREDITS
ECE 816	Cryptography and Network Security	3
ECE 830	Embedded Cyber-Physical Systems	3
ECE 842	Performance Modeling of Communication Networks	3

Students must have a minimum 3.00 grade-point average over the courses applied to the certificate for it to be awarded.

GRADUATE CERTIFICATE IN SEMICONDUCTOR MANUFACTURING, PROCESSING, AND DEVICES

The Graduate Certificate in Semiconductor Manufacturing, Processing, and Devices is designed to provide students with semiconductor research training that will make them more competitive in the field of semiconductor processing and manufacturing.

Requirements for the Graduate Certificate in Semiconductor Manufacturing, Processing, and Devices

Students must complete a minimum of 9 credits from the following courses:

		CREDITS
ECE 813	Advanced VLSI Design	3
ECE 832	Analog Integrated Circuit Design	3
ECE 850	Electrodynamics of Plasmas	3
ECE 870	Introduction to Micro-Electro-Mechanical Systems	3
ECE 871	Micro-electro-mechanical Systems Fabrication	3
ECE 874	Physical Electronics	3
ECE 875	Electronic Devices	3
ECE 877	Cleanroom Procedures	3
ECE 931C	Properties of Semiconductors	3
ECE 989	Advanced Topics in Plasma	3

DEPARTMENT of MECHANICAL ENGINEERING

Minami Yoda, Chairperson

UNDERGRADUATE PROGRAMS

Mechanical engineering is a diverse profession that relies on fundamental science principles to conceive, design, and manufacture everything from miniaturized individual parts (e.g. biosensors, printer nozzles, micro-reactors, electronic coolers) to large complex systems and devices (e.g., rocket propulsion, jet engines, robotic tools, wind turbines, automobiles, water purification, energy storage). Mechanical engineers concentrate/focus on devices and systems that alter, transfer, transform, and utilize energy forms that cause motion. The mechanical engineering practitioner requires a broad range of skills and knowledge. The Department of Mechanical Engineering provides a curriculum that intertwines a foundation in mathematics and engineering science with creativity and innovation in design and fabrication. Students learn the skills to develop ideas from concept to product. The program integrates individual mastery of these subjects with teamwork-based solutions to open-ended design problems and practical engineering experiences. Along with the required courses, optional concentrations are available for students to focus their program of study within a particular area of interest, as well as opportunities to study abroad.

MECHANICAL ENGINEERING

Mechanical engineering is a diverse profession that relies on fundamental science principles to conceive, design, and manufacture everything from miniaturized individual parts such as biosensors, printer nozzles, and micro-reactors to large complex systems and devices such as rocket propulsion, jet engines, robotic tools, wind turbines, and automobiles. Mechanical engineers are concerned with conceiving, designing, manufacturing, testing and marketing devices and systems that alter, transfer, transform and utilize energy forms that cause motion. In order to be accomplished in the

mechanical engineering profession, a broad range of skills and knowledge are required.

The Department of Mechanical Engineering provides a curriculum that intertwines a foundation in mathematics and engineering science with creativity and innovation in design. Students learn the skills to develop ideas from concept to product. The program integrates individual mastery of these subjects with teamwork-based solutions to open-ended design problems and practical engineering experiences. Along with the required courses, optional concentrations are available for students to focus their program of study within a particular area of interest.

The design program is a core pillar of the undergraduate curriculum that combines core instruction in design with hands-on experiences in design-build-test projects. A sequence of four design intensive courses culminates in a capstone course, underpinned by industrially-sponsored projects. Industrial sponsorship for the capstone design experience is strong. Over the last ten years, 130 companies, many from within the state, have sponsored over 325 capstone design projects. In addition to industrially-motivated projects, students have the option to participate in humanitarian projects. Students present their work on Design Day, the last day of classes in fall and spring.

The Department has a long-established study abroad program in Germany (RWTH in Aachen) and study abroad programs in France (École Catholique d'Arts et Métiers), the United Kingdom (University of Edinburgh), Korea (Korea University) and Denmark (Technical University of Denmark). The program also attracts a diverse group of international students to study with us. Included in the variety of activities open to students is the cooperative education program, in which a student may participate after his/her freshman year.

The Bachelor of Science Degree program in Mechanical Engineering is accredited by the Engineering Accreditation Commission of ABET, *www.abet.org*.

Requirements for the Bachelor of Science Degree in Mechanical Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Mechanical Engineering.

   The University's Tier II writing requirement for the Mechanical Engineering major is met by completing Mechanical Engineering 332, 412, and 481. Those courses are referenced in item 3. b. (1) below.

   Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.
2. The requirements of the College of Engineering for the Bachelor of Science degree.

   The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.
3. The following requirements for the major:

			CREDITS
a. All of the following courses outside the Department of Mechanical Engineering (13 credits):			
	CE 221	Statics	3
	CEM 161	Chemistry Laboratory I	1
	ECE 345	Electronic Instrumentation and Systems	3
	MSE 250	Materials Science and Engineering	3
	STT 351	Probability and Statistics for Engineering	3
b. All of the following courses in the Department of Mechanical Engineering (40 credits):			
	ME 222	Mechanics of Deformable Solids	3
	ME 280	Graphic Communications	2
	ME 201	Thermodynamics	3
	ME 300	Professional Issues in Mechanical Engineering	1
	ME 333	Fluid Mechanics	3
	ME 333L	Fluid Mechanics Laboratory	1
	ME 361	Dynamics	3
	ME 370	Mechanical Design and Manufacturing I	3
	ME 391	Mechanical Engineering Analysis	3
	ME 410	Heat Transfer	3
	ME 412	Heat Transfer Laboratory	2
	ME 452	Control Systems	3
	ME 452L	Vibrations and Controls Laboratory	1
	ME 461	Mechanical Vibrations	3
	ME 470	Mechanical Design and Manufacturing II	3
	ME 481	Mechanical Engineering Design Projects	3
c. **Senior Electives** (a minimum of 9 credits):			
	ME 413	Cryogenic-Thermal Systems	3
	ME 414	Mechanical Design of Cryogenic Systems	3
	ME 416	Computer Assisted Design of Thermal Systems	3
	ME 417	Design of Alternative Energy Systems	3
	ME 422	Introduction to Combustion	3
	ME 423	Intermediate Mechanics of Deformable Solids	3
	ME 425	Experimental Mechanics	3
	ME 426	Introduction to Composite Materials	3
	ME 433	Introduction to Computational Fluid Dynamics	3
	ME 440	Aerospace Propulsion	3
	ME 441	Aerodynamics and Aircraft Performance	3
	ME 442	Turbomachinery	3
	ME 444	Automotive Engines	3
	ME 445	Automotive Powertrain Design	3
	ME 456	Mechatronic System Design	3
	ME 464	Intermediate Dynamics	3
	ME 465	Computer Aided Optimal Design	3
	ME 475	Computer Aided Design of Structures	3
	ME 477	Manufacturing Processes	3
	ME 478	Product Development	3
	ME 490	Independent Study in Mechanical Engineering	1 to 3
	ME 491	Selected Topics in Mechanical Engineering	1 to 4
	ME 494	Biofluid Mechanics and Heat Transfer	3
	ME 495	Tissue Mechanics	3
	ME 496	Biomechanical Analysis of Human Movement	3
	ME 497	Biomechanical Design in Product Development	3
d. **Design-intensive Senior Electives** (a minimum of 3 credits):			
	ME 414	Mechanical Design of Cryogenic Systems	3
	ME 416	Computer Assisted Design of Thermal Systems	3
	ME 417	Design of Alternative Energy Systems	3
	ME 442	Turbomachinery	3
	ME 445	Automotive Powertrain Design	3
	ME 456	Mechatronic System Design	3
	ME 465	Computer Aided Optimal Design	3
	ME 475	Computer Aided Design of Structures	3
	ME 478	Product Development	3
	ME 497	Biomechanical Design in Product Development	3

Courses used to fulfill item 3. c. may not be used to fulfill item 3. d.

Concentration in Aerospace Engineering

A concentration in Aerospace Engineering is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in Aerospace Engineering may require more than 128 credits. The concentration will be noted on the student's transcript.

Aerospace Engineering

A mechanical engineering degree with the aerospace engineering concentration recognizes the expertise of students in subjects related to aerospace applications and to the aerospace industry, which provides many career opportunities for mechanical engineering graduates. Students who meet the requirements of this concentration will have expertise in aerodynamics,

propulsion and structures, supplemented by other strengths in the core Mechanical Engineering degree program. To complete a Bachelor of Science degree in mechanical engineering with an aerospace engineering concentration, students must complete the requirements for the B.S. degree, including the following:

			CREDITS
Both of the following courses (6 credits):			
ME	440	Aerospace Propulsion	3
ME	441	Aerodynamics and Aircraft Performance	3
One of the following courses (3 credits):			
ME	423	Intermediate Mechanics of Deformable Solids	3
ME	426	Introduction to Composite Materials	3
ME	456	Mechatronic System Design	3
ME	475	Computer Aided Design of Structures	3
One of the following courses (3 credits):			
ME	422	Introduction to Combustion	3
ME	433	Introduction to Computational Fluid Dynamics	3
ME	442	Turbomachinery	3

Concentration in Automotive Powertrain

A concentration in Automotive Powertrain is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in automotive powertrain may require more than 128 credits. The concentration will be noted on the student's transcript.

Automotive Powertrain
To earn a Bachelor of Science degree in Mechanical Engineering with an automotive powertrain concentration, students must complete the requirements for the B.S. degree, including the following:

			CREDITS
All of the following courses (9 credits):			
ME	422	Introduction to Combustion	3
ME	444	Automotive Engines	3
ME	445	Automotive Powertrain Design	3
One of the following courses (3 credits):			
ME	433	Introduction to Computational Fluid Dynamics	3
ME	442	Turbomachinery	3

Concentration in Biomedical Engineering

A concentration in Biomedical Engineering is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in biomedical engineering may require more than 128 credits. The concentration will be noted on the student's transcript.

Biomedical Engineering
To earn a Bachelor of Science degree in Mechanical Engineering with a biomedical engineering concentration, students must the requirements for the B.S. degree, including the following:

			CREDITS
Both of the following courses (7 credits):			
BS	161	Cell and Molecular Biology	3
PSL	250	Introductory Physiology	4
Nine credits from the following courses:			
BE	444	Biosensors for Medical Diagnostics	3
ECE	445	Biomedical Instrumentation	3
ME	494	Biofluid Mechanics and Heat Transfer	3
ME	495	Tissue Mechanics	3
ME	496	Biomechanical Analysis of Human Movement	3
ME	497	Biomechanical Design in Product Development	3
MSE	425	Biomaterials and Biocompatibility	3

Students who select BE 444, ECE 445, or MSE 425 may request to apply these course credits towards fulfillment of the Mechanical Engineering Major Senior-Elective requirement (item 3. c. above).

Concentration in Computational Design

A concentration in Computational Design is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in computational design may require more than 128 credits. The concentration will be noted on the student's transcript.

Computational Design
To earn a Bachelor of Science degree in Mechanical Engineering with a computational design concentration, students must the requirements for the B.S. degree, including the following:

			CREDITS
All of the following courses (9 credits):			
ME	416	Computer Assisted Design of Thermal Systems	3
ME	417	Design of Alternative Energy Systems	3
ME	433	Introduction to Computational Fluid Dynamics	3
ME	445	Automotive Powertrain Design	3
ME	456	Mechatronic System Design	3
ME	465	Computer Aided Optimal Design	3
ME	475	Computer Aided Design of Structures	3

Concentration in Cryogenic Engineering

A concentration in Cryogenic Engineering is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in Cryogenic Engineering may require more than 128 credits. The concentration will be noted on the student's transcript.

Cryogenic Engineering
A mechanical engineering degree with the cryogenic engineering concentration recognizes the expertise of students in thermal and mechanical analysis and design techniques as applied to cryogenic engineering applications. To complete a Bachelor of Science degree in mechanical engineering with a cryogenic engineering concentration, students must complete the requirements for the B.S. degree, including the following:

			CREDITS
All of the following courses (12 credits):			
ME	413	Cryogenic-Thermal Systems	3
ME	414	Mechanical Design of Cryogenic Systems	3
ME	416	Computer Assisted Design of Thermal Systems	3
ME	442	Turbomachinery	3

Concentration in Energy

A concentration in Energy is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in energy may require more than 128 credits. The concentration will be noted on the student's transcript.

Energy
To earn a Bachelor of Science degree in Mechanical Engineering with an energy concentration, students must complete the requirements for the B.S. degree, including the following:

			CREDITS
Both of the following courses (6 credits):			
ME	416	Computer Assisted Design of Thermal Systems	3
ME	417	Design of Alternative Energy Systems	3
Two of the following courses (6 credits):			
ME	422	Introduction to Combustion	3
ME	440	Aerospace Propulsion	3
ME	442	Turbomachinery	3
ME	444	Automotive Engines	3

Concentration in Engineering Mechanics

A concentration in Engineering Mechanics is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in engineering mechanics may require more than 128 credits. The concentration will be noted on the student's transcript.

Engineering Mechanics

To earn a Bachelor of Science degree in Mechanical Engineering with a engineering mechanics concentration, students must complete the requirements for the B.S. degree, including the following:

			CREDITS
The following courses (12 credits):			
ME	423	Intermediate Mechanics of Deformable Solids	3
ME	425	Experimental Mechanics	3
ME	464	Intermediate Dynamics	3
ME	475	Computer Aided Design of Structures	3

Concentration in Manufacturing Engineering

A concentration in Manufacturing Engineering is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in manufacturing engineering may require more than 128 credits. The concentration will be noted on the student's transcript.

Manufacturing Engineering

To earn a Bachelor of Science degree in Mechanical Engineering with a manufacturing engineering concentration, students must the requirements for the B.S. degree, including the following:

			CREDITS
All of the following courses (7 credits):			
ME	372	Machine Tool Laboratory	1
ME	477	Manufacturing Processes	3
ME	478	Product Development	3
One of the following courses (3 credits):			
CHE	472	Polymeric Composite Materials Processing	3
ECE	415	Computer Aided Manufacturing	3
MSE	426	Introduction to Composite Materials	3
One of the following courses (3 credits):			
ACC	230	Survey of Accounting Concepts	3
EC	201	Introduction to Microeconomics	3

Students who select CHE 472, ECE 415, or MSE 426 may request to apply these course credits towards fulfillment of the Mechanical Engineering Major Senior-Elective requirement (item 3. c. above).

LINKED BACHELOR'S-MASTER'S DEGREE IN ENGINEERING MECHANICS

Bachelor of Science Degree in Mechanical Engineering with a concentration in Engineering Mechanics
Master of Science Degree in Engineering Mechanics

The department welcomes applications from Michigan State University Mechanical Engineering undergraduate students in their junior and senior year, who are pursuing an engineering mechanics concentration within the Bachelor of Science degree in Mechanical Engineering. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Mechanical Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Engineering Mechanics at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or an external accredited institution. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

LINKED BACHELOR'S-MASTER'S DEGREE IN MECHANICAL ENGINEERING

Bachelor of Science Degree in Mechanical Engineering
Master of Science Degree in Mechanical Engineering

The department welcomes applications from Michigan State University Mechanical Engineering undergraduate students in their junior and senior year. Admission applications must be made during the prior spring semester for an anticipated spring graduation or the prior fall semester for an anticipated fall graduation to allow admission before the final semester as a Mechanical Engineering undergraduate. Admission to the program requires a minimum undergraduate grade-point average of 3.5 and an approved program of study for the Master of Science degree in Mechanical Engineering at the time of admission. Admission to the Linked Bachelor's-Master's program allows the application of up to 9 credits toward the master's program for qualifying 400-level and above course work taken at the undergraduate level at Michigan State University or an external accredited institution. The number of approved credits, not to exceed 9, are applied toward the credit requirement of the master's degree. Credits applied to the Linked Bachelor's-Master's program are not eligible to be applied to any other graduate degree program.

GRADUATE STUDY

The Department of Mechanical Engineering offers programs leading to Master of Science and Doctor of Philosophy degrees, both in mechanical engineering and engineering mechanics. An individualized plan of study can be designed from a wide range of courses and research experiences to suit the professional aspirations of graduate students. A plan of study typically includes courses within and external to the department. The department offers research experiences in four broad areas: Fluid Thermal Science and Engineering; Biomechanics; Dynamic Systems and Control; and Solid Mechanics, Design, and Manufacturing. The research opportunities are diverse and include working closely with an individual faculty member and/or as part of a team in a large interdisciplinary research center. Graduate students are expected to enroll in courses that promote rapid professional growth as well as engage in research that leads to new knowledge creation that pushes the boundaries of science and engineering.

ENGINEERING MECHANICS

Master of Science

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

The department welcomes applications from students who possess a bachelor's degree in a related engineering or science discipline.

Students who are admitted to the master's program with a degree in a discipline other than engineering mechanics and who have not completed Mechanical Engineering 221, 222, 361, and 423 or equivalent courses may be admitted with provisional status. Such students will be required to demonstrate proficiency in the material in the courses referenced above, either by completing each of those courses with a grade of at least 3.0 or by passing an examination on the material in those courses sanctioned by the department Graduate Studies Committee. Of the courses referenced above, only Mechanical Engineering 423 may be counted toward the requirements for the master's degree.

Requirements for the Master of Science Degree in Engineering Mechanics

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis) and must meet the requirements specified below:

Requirements for Both Plan A and Plan B:

1. The following core courses in engineering mechanics: Mechanical Engineering 825 or 861, 820, and 821.
2. At least one of the following core courses in mechanical engineering: Materials Science and Engineering 851, 855, 862, or 865.
3. At least one credit of Materials Science and Engineering 885.
4. At least one course in mathematics or statistics at the 400–level or above approved by the student's academic advisor.

Doctor of Philosophy

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

An applicant for admission must identify at least one prospective faculty advisor that they would like to direct their program of study. Admission to the Ph.D. program is contingent on a faculty advisor accepting the student as an advisee.

Requirements for the Doctor of Philosophy Degree in Engineering Mechanics

The student must complete:

1. At least one of the following core courses in materials science and engineering: Materials Science and Engineering 851, 855, 862, or 865.
2. At least one course in mathematics or statistics at the 400–level or above.

These requirements are waived for those students who completed equivalent courses prior to enrolling in the doctoral program.

MECHANICAL ENGINEERING

Master of Science

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

An applicant should possess a bachelor's degree in mechanical engineering or a related field.

The applicant must submit scores from the Graduate Record Examination General Test.

Requirements for the Master of Science Degree in Mechanical Engineering

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis) and meet the requirements specified below. A maximum of 9 credits may be at the 400-level. A maximum of 4 credits may be taken from ME 490 and ME 990 combined.

Requirements for Both Plan A and Plan B:

The student must:

1. Complete one course from each of the following areas:

Fluid-Thermal Science and Engineering			
ME	810	Advanced Classical Thermodynamics	3
ME	812	Conductive Heat Transfer	3
ME	814	Convective Heat Transfer	3
ME	819	Combustion	3
ME	830	Fluid Mechanics I	3
ME	840	Computational Fluid Dynamics and Heat Transfer	3
ME	842	Advanced Turbomachinery	3
ME	872	Finite Element Method	3
Dynamic Systems and Control			
ECE	851	Linear Systems and Control	3
ME	860	Theory of Vibrations	3
ME	861	Advanced Dynamics	3
ME	891	Selected Topics in Mechanical Engineering	1 to 4

The topic for ME 891 must be approved by the student's guidance committee.

Solid Mechanics, Design, and Manufacturing and Biomechanics			
ME	820	Continuum Mechanics	3
ME	821	Linear Elasticity	3
ME	826	Laminated Composite Materials	3
ME	872	Finite Element Method	3
ME	891	Selected Topics in Mechanical Engineering	1 to 4

The topic for ME 891 must be approved by the student's guidance committee.

Additional Requirements for Plan A:

The student must:

1. Complete 21 credits in courses at the 800–900 level including at least 6, but not more than 8, credits in Mechanical Engineering 899.
2. Submit a brief thesis proposal for approval by the student's academic advisor early in the student's program of study.
3. Pass an oral examination in defense of the thesis.

Additional Requirements for Plan B:

1. Complete 21 credits in courses at the 800–900 level.
2. Complete a final examination or evaluation.

Doctor of Philosophy

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

Admission

The applicant must submit scores from the Graduate Record Examination General Test.

Requirements for the Doctor of Philosophy Degree in Mechanical Engineering

In addition to meeting the requirements of the university and the College of Engineering, students must meet the requirements specified by their guidance committees.