MECHANICAL ENGINEERING

For the undergraduate curriculum in mechanical engineering leading to the degree bachelor of science. This curriculum is accredited under the General Criteria and Mechanical Engineering Program Criteria by the Engineering Accreditation Commission of ABET, http://www.abet.org/.

Mechanical engineers apply the principles of motion, energy, and force to create mechanical solutions to technological problems, thereby realizing devices and systems that make life better. About one-fifth of all engineers practicing today are mechanical engineers. Their skills are used in research, development, design, testing, production, technical sales, technical management, as well as medicine, law, and business. Mechanical engineers are characterized by personal creativity, breadth of knowledge, and versatility. For these reasons they are found to function and thrive as valuable members and leaders of multidisciplinary teams.

Mechanical engineers are employed in a wide range of industries; examples include agricultural/heavy equipment, biomedical, consulting, energy and power, manufacturing, product design and transportation.

The mechanical engineering curriculum at Iowa State University is dedicated to preparing students for productive careers in the state, nation, and the world and has the following objectives:

1. Graduates will have utilized a foundation in engineering and science to improve lives and livelihoods through a successful career in mechanical engineering or other fields.
2. Graduates will have become effective collaborators and innovators, leading or participating in efforts to address social, technical and business challenges.
3. Graduates will have engaged in life-long learning and professional development through self-study, continuing education or graduate and professional studies in engineering, business, law or medicine.

The mechanical engineering curriculum is organized to provide students with a broad foundation in mathematics, science, engineering, social science and humanities. The mechanical engineering disciplinary areas emphasized are design and optimization, dynamic systems and control, materials processing and mechanics, and thermo-fluid sciences. Elective courses provide additional emphasis in terms of the student’s unique educational goals, whether they include immediate entry into industry or further professional or graduate study.

A major focus throughout the mechanical engineering curriculum is a series of experiences that emphasize engineering design, culminating in a capstone design experience in the senior year. Students will develop engineering judgment through open-ended problems that require establishment of reasonable engineering assumptions and realistic constraints. Development of skills needed to be independent, creative thinkers, effective communicators, and contributing team members is emphasized throughout the curriculum. Students also develop an understanding of the societal context in which they will practice engineering, including environmental, legal, aesthetic, and human aspects.

Students are encouraged to participate in the cooperative education program or to obtain engineering internships, both domestically and abroad. Study abroad is encouraged, and the department has exchange programs with several universities around the world. These experiences help students to round out their education and to better prepare for careers in the increasingly global practice of engineering.

Curriculum in Mechanical Engineering

Administered by the Department of Mechanical Engineering. Leading to the degree bachelor of science.

Total credits required: 129 cr.
Any transfer credit courses applied to the degree program require a grade of C or better (but will not be calculated into the ISU cumulative GPA, Basic Program GPA or Core GPA). See also Basic Program and Special Programs.
International Perspectives: 3 cr. 1
U.S. Diversity: 3 cr. 1
Communication Proficiency/Library requirement:
ENGL 150 Critical Thinking and Communication (minimum grade of C) 3
ENGL 250 Written, Oral, Visual, and Electronic Composition (minimum grade of C) 3
LIB 160 Information Literacy 1
Choose one of the following communication courses (minimum grade of C) 3
ENGL 302 Business Communication
ENGL 309 Proposal and Report Writing
ENGL 314 Technical Communication
SP CM 212 Fundamentals of Public Speaking

General Education Electives: 15 cr.
Choose one course from the following: 3

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECON 101</td>
<td>Principles of Microeconomics</td>
<td>3</td>
</tr>
<tr>
<td>or ECON 102</td>
<td>Principles of Macroeconomics</td>
<td></td>
</tr>
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</table>

Social Science 2 3

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humanities</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Humanities or Social Science 2</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

Total Credits 15

Basic Program: 27 cr.
A minimum GPA of 2.00 is required for this set of courses, including any transfer courses (please note that transfer course grades will not be calculated into the Basic Program GPA). See Requirement for Entry into Professional Program in College of Engineering Overview section.

CHEM 167 General Chemistry for Engineering Students 4
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>or CHEM 177</td>
<td>General Chemistry I</td>
<td></td>
</tr>
<tr>
<td>ENGL 150</td>
<td>Critical Thinking and Communication</td>
<td>3</td>
</tr>
<tr>
<td>ENGL 250</td>
<td>Written, Oral, Visual, and Electronic Composition</td>
<td>3</td>
</tr>
<tr>
<td>ENGR 101</td>
<td>Engineering Orientation</td>
<td>R</td>
</tr>
<tr>
<td>M E 160</td>
<td>Mechanical Engineering Problem Solving with Computer Applications</td>
<td>3</td>
</tr>
<tr>
<td>LIB 160</td>
<td>Information Literacy</td>
<td>1</td>
</tr>
<tr>
<td>MATH 165</td>
<td>Calculus I</td>
<td>4</td>
</tr>
<tr>
<td>MATH 166</td>
<td>Calculus II</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 221</td>
<td>Introduction to Classical Physics I</td>
<td>5</td>
</tr>
<tr>
<td>Total Credits</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

**Mechanical Engineering Foundations: 25 cr.**

A minimum GPA of 2.00 for the complete group of Foundations courses is required before students are permitted to enroll in the following Mechanical Engineering Core courses (please note that transfer course grades will not be calculated into the ME Foundations GPA): ME 324, ME 325, ME 332, ME 335, ME 370 and ME 421.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 265</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>4 credits from the following:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MATH 267</td>
<td>Elementary Differential Equations and Laplace Transforms</td>
<td>4</td>
</tr>
<tr>
<td>MATH 266</td>
<td>Elementary Differential Equations and Laplace Transforms</td>
<td></td>
</tr>
<tr>
<td>PHYS 222</td>
<td>Introduction to Classical Physics II</td>
<td>5</td>
</tr>
<tr>
<td>E M 274</td>
<td>Engineering Statics</td>
<td>3</td>
</tr>
<tr>
<td>E M 324</td>
<td>Mechanics of Materials</td>
<td>3</td>
</tr>
<tr>
<td>MAT E 273</td>
<td>Principles of Materials Science and Engineering</td>
<td>3</td>
</tr>
<tr>
<td>M E 231</td>
<td>Engineering Thermodynamics I</td>
<td>3</td>
</tr>
<tr>
<td>Total Credits</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

**Mechanical Engineering Core: 38 cr.**

A minimum GPA of 2.00 is required for this set of courses, including any transfer courses (please note that transfer course grades will not be calculated into the Core GPA):

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>E M 345</td>
<td>Engineering Dynamics</td>
<td>3</td>
</tr>
<tr>
<td>E E 442</td>
<td>Introduction to Circuits and Instruments</td>
<td>2</td>
</tr>
<tr>
<td>E E 448</td>
<td>Introduction to AC Circuits and Motors</td>
<td>2</td>
</tr>
<tr>
<td>M E 270</td>
<td>Introduction to Mechanical Engineering Design</td>
<td>3</td>
</tr>
<tr>
<td>M E 324</td>
<td>Manufacturing Engineering</td>
<td>3</td>
</tr>
<tr>
<td>M E 324L</td>
<td>Manufacturing Engineering Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>M E 325</td>
<td>Mechanical Component Design</td>
<td>3</td>
</tr>
<tr>
<td>M E 332</td>
<td>Engineering Thermodynamics II</td>
<td>3</td>
</tr>
<tr>
<td>M E 335</td>
<td>Fluid Flow</td>
<td>4</td>
</tr>
<tr>
<td>Total Credits</td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>

**Other Remaining Courses: 24 cr.**

Complete 15 cr. Technical Electives

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>M E 170</td>
<td>Engineering Graphics and Introductory Design</td>
<td>3</td>
</tr>
<tr>
<td>STAT 305</td>
<td>Engineering Statistics</td>
<td>3</td>
</tr>
<tr>
<td>Complete one of the following communication courses with a minimum grade of C.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENGL 302</td>
<td>Business Communication</td>
<td>3</td>
</tr>
<tr>
<td>ENGL 309</td>
<td>Proposal and Report Writing</td>
<td>3</td>
</tr>
<tr>
<td>ENGL 314</td>
<td>Technical Communication</td>
<td>3</td>
</tr>
<tr>
<td>SP CM 212</td>
<td>Fundamentals of Public Speaking</td>
<td>3</td>
</tr>
<tr>
<td>Total Credits</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

**Seminar/Co-op/Internships:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>M E 202</td>
<td>Mechanical Engineering - Professional Planning</td>
<td>R</td>
</tr>
<tr>
<td>Co-op/Internship optional</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. These university requirements will add to the minimum credits of the program unless the university-approved courses are also approved by the department to meet other course requirements within the degree program. U.S. diversity and international perspectives courses may not be taken Pass/Not Pass.

2. Choose from department approved list of technical electives (http://www.me.iastate.edu/students/degrees-and-programs/bs-degree/degree-requirements/tech-electives) and general education electives (http://www.me.iastate.edu/students/degrees-and-programs/bs-degree/degree-requirements/general-education). Note: electives used to meet graduation requirements may not be taken Pass-Not Pass (P-NP).

3. See Basic Program for Professional Engineering Curricula for accepted substitutions for curriculum designated courses in the Basic Program.

**Transfer Credit Requirements**

The Mechanical Engineering Department requires a grade of a C or better for any transfer credit course that is applied to the degree program. The degree program must include a minimum of 15 credits taken from courses offered through the Mechanical Engineering Department at Iowa
State University. Of these 15 credits, 3 must be from one of the senior capstone design courses. The remaining 12 credits may be from the core curriculum program (if a student is deficient in these courses) or from 400-level M E technical electives. No more than 3 credits of independent study shall be applied to meet the 12 credit requirement.

See also: A 4-year plan of study grid showing course template by semester.

**Energy Systems Minor**
http://www.me.iastate.edu/energy-systems-minor/

The Energy Systems minor is administered by the mechanical engineering department and is open to all undergraduates in the College of Engineering. The minor may be earned by completing 15 credits from the following courses. The complete list of approved elective courses can be found here (http://www.me.iastate.edu/energy-systems-minor).

Required courses
- ECON 380 Energy, Environmental and Resource Economics 3
- E E 351 Analysis of Energy Systems 3
- Electives: Choose from a list of approved courses 9

Total Credits 15

The minor must include at least 9 credits that are not used to meet any other department, college, or university requirement.

**Nuclear Engineering Minor**
http://www.me.iastate.edu/students/degrees-and-programs/engineering-minors/

The nuclear engineering minor is administered by the mechanical engineering department and is open to all undergraduates. The minor may be earned by completing 15 credits from the following courses. A complete list of approved courses can be found here (http://www.me.iastate.edu/students/degrees-and-programs/engineering-minors).

Required courses
- NUC E 401 Nuclear Radiation Theory and Engineering 3
- Electives: Choose from a list of approved courses. 12

Total Credits 15

The minor must include at least 9 credits that are not used to meet any other department, college, or university requirement.

**First Year**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 167</td>
<td></td>
<td>4 ENGL 150</td>
<td></td>
</tr>
</tbody>
</table>

**Second Year**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>E M 274</td>
<td></td>
<td>3 E M 324</td>
<td>3</td>
</tr>
<tr>
<td>MAT E 273</td>
<td></td>
<td>3 MATH 267</td>
<td>4</td>
</tr>
<tr>
<td>MATH 265</td>
<td></td>
<td>4 M E 231</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 222</td>
<td></td>
<td>5 M E 270</td>
<td>3</td>
</tr>
<tr>
<td>ENGL 250</td>
<td></td>
<td>3 General Education Elective 3</td>
<td>0</td>
</tr>
<tr>
<td>M E 202</td>
<td></td>
<td></td>
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</table>

Total Credits 18

**Third Year**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>E E 442</td>
<td></td>
<td>2 M E 325</td>
<td>3</td>
</tr>
<tr>
<td>E E 448</td>
<td></td>
<td>2 M E 335</td>
<td>4</td>
</tr>
<tr>
<td>E M 345</td>
<td></td>
<td>3 M E 370</td>
<td>3</td>
</tr>
<tr>
<td>M E 332</td>
<td></td>
<td>3 M E 324</td>
<td>3</td>
</tr>
<tr>
<td>STAT 305</td>
<td></td>
<td>3 Communication Requirement</td>
<td>3</td>
</tr>
<tr>
<td>M E 324L</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>General Education Elective</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Credits 17

**Fourth Year**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen Ed Elective (Intl Perspective)</td>
<td>3</td>
<td>Gen Ed Elective (US Diversity)</td>
<td>3</td>
</tr>
<tr>
<td>M E 421</td>
<td></td>
<td>4 Technical Elective</td>
<td>3</td>
</tr>
<tr>
<td>M E 436</td>
<td></td>
<td>4 Technical Elective</td>
<td>3</td>
</tr>
<tr>
<td>Technical Elective</td>
<td>3</td>
<td>Technical Elective</td>
<td>3</td>
</tr>
<tr>
<td>Technical Elective</td>
<td>3</td>
<td>Capstone Design</td>
<td>3</td>
</tr>
</tbody>
</table>

Total Credits 17

**Graduate Study**

The department offers programs for the degrees Master of Engineering (M. Eng.), Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) with a major in mechanical engineering. The M.Eng. degree is a coursework-only degree designed to improve professional expertise in mechanical engineering. The M.S. and Ph.D. degrees are designed to improve the student's capability to conduct research as well as their professional expertise. Although co-major and formal minor programs are not offered...
in mechanical engineering, courses may be used for minor work by students taking major work in other departments.

Well-qualified juniors and seniors in mechanical engineering who are interested in graduate study may apply for concurrent enrollment in the Graduate College to simultaneously pursue both the Bachelor of Science and Master of Science, the Bachelor of Science and Master of Business Administration. Under concurrent enrollment, students are eligible for assistantships and simultaneously take undergraduate and graduate courses. Details are available in the Graduate Programs Office and on the department’s website (http://www.me.iastate.edu/).

The graduate program offers advanced study in a variety of thrust areas, including biological and nanoscale sciences, clean energy technologies, complex fluid systems, design and manufacturing innovation, and simulation and visualization.

The department offers students the opportunity to broaden their education by participating in minor programs in established departments, interdepartmental programs, or other experiences as approved by their program of study committees.

The requirements for advanced degrees are established by the student’s program of study committee within established guidelines of the Graduate College. Graduate students who have not completed an undergraduate program of study substantially equivalent to that required of undergraduate students in the department can expect that additional supporting coursework will be required.

Program requirements can be found on the department webpage (http://www.me.iastate.edu/) and in the Mechanical Engineering Graduate Student Handbook.

Courses primarily for undergraduates:

**M E 170: Engineering Graphics and Introductory Design**
(2-2) Cr. 3. F.S.
Prereq: Satisfactory scores on mathematics placement assessments; credit or enrollment in MATH 142 or MATH 143 or MATH 145
Integration of fundamental graphics, computer modeling, and engineering design. Applications of multiview drawings and dimensioning. Techniques for visualizing, analyzing, and communicating 3-D geometries. Application of the design process including written and oral reports. Freehand and computer methods.

**M E 190: Learning Communities**
(1-0) Cr. 1. Repeatable. F.S.
Enrollment in M E learning communities.

**M E 202: Mechanical Engineering - Professional Planning**
(1-0) Cr. R. F.S.
Prereq: Sophomore classification
Preparation for a career in mechanical engineering; discussion of opportunities for leadership, undergraduate research, experiential learning.

**M E 220: Globalization and Sustainability**
(Cross-listed with ANTHR, ENV S, GLOBE, MAT E, SOC, T SC). (3-0) Cr. 3. F.S.
An introduction to understanding the key global issues in sustainability. Focuses on interconnected roles of energy, materials, human resources, economics, and technology in building and maintaining sustainable systems. Applications discussed will include challenges in both the developed and developing world and will examine the role of technology in a resource-constrained world. Cannot be used for technical elective credit in any engineering department.
Meets International Perspectives Requirement.

**M E 231: Engineering Thermodynamics I**
(3-0) Cr. 3. F.S.S.
Prereq: MATH 166, CHEM 167, PHYS 221
Fundamental concepts based on zeroth, first and second laws of thermodynamics. Properties and processes for ideal gases and solid-liquid-vapor phases of pure substances. Applications to vapor power cycles. Credit for either M E 231 or 330, but not both, may be applied toward graduation.

**M E 270: Introduction to Mechanical Engineering Design**
(1-6) Cr. 3. F.S.
Prereq: M E 160 or equivalent, M E 170 or equivalent, PHYS 221
Overview of mechanical engineering design with applications to thermal and mechanical systems. Introduction to current design practices used in industry. Semester-long team project focused on addressing societal needs. Past projects include designing human powered charging systems and products for developing nations.
M E 324: Manufacturing Engineering
(3-0) Cr. 3. F.S.S.
Prereq: M E 270, E M 324, MAT E 273 and M E 324L
Fundamentals of manufacturing processes including forming, machining, casting and welding with emphasis on design considerations in manufacturing. Mechanical behavior of metallic materials. Modern manufacturing practices.

M E 324L: Manufacturing Engineering Laboratory
(0-2) Cr. 1. F.S.S.
Prereq: M E 270, MAT E 273
Laboratory exercises in metrology, mechanical testing (tensile/compression and hardness tests), computer aided design (CAD), machining operations, metal welding, metal casting, and bulk/sheet metal forming.

M E 325: Mechanical Component Design
(3-0) Cr. 3. F.S.S.
Prereq: M E 170, E M 324, and STAT 305
Philosophy of design and design methodology. Consideration of stresses and failure models useful for static and fatigue loading. Analysis, selection and synthesis of machine elements.

M E 332: Engineering Thermodynamics II
(3-0) Cr. 3. F.S.S.
Prereq: M E 231
Gas power cycles. Fundamentals of gas mixtures, psychrometry, and thermochemistry. Applications to one-dimensional compressible flow, refrigeration, air conditioning and combustion processes.

M E 335: Fluid Flow
(3-2) Cr. 4. F.S.S.
Prereq: E M 345, MATH 265, MATH 266 or MATH 267, credit or enrollment in M E 332.
Incompressible and compressible fluid flow fundamentals. Dimensional analysis and similitude. Internal and external flow applications. Lab experiments emphasizing concepts in thermodynamics and fluid flow. Written reports are required.

M E 370: Engineering Measurements
(2-3) Cr. 3. F.S.S.
Prereq: E E 442, STAT 305
Fundamentals of design, selection, and operation of components of measuring systems. Measurement processes, data acquisition systems, analysis of data, and propagation of measurement uncertainty.

M E 396: Summer Internship
Cr. R. Repeatable. SS.
Prereq: Permission of department and Engineering Career Services
Professional work period of at least 10 weeks during the summer. Students must register for this course prior to commencing work. Offered on a satisfactory-fail basis only.

M E 398: Cooperative Education (Co-op).
Cr. R. Repeatable. F.S.
Prereq: Permission of department and Engineering Career Services
Professional work period. One semester per academic or calendar year. Students must register for this course before commencing work. Offered on a satisfactory-fail basis only.

M E 410: Mechanical Engineering Applications of Mechatronics
(2-2) Cr. 3. Alt. S., offered irregularly.
Prereq: E E 442, E E 448, credit or enrollment in M E 421
Fundamentals of sensor characterization, signal conditioning and motion control, coupled with concepts of embedded computer control. Digital and analog components used for interfacing with computer controlled systems. Mechanical system analysis combined with various control approaches. Focus on automation of hydraulic actuation processes. Laboratory experiences provide hands-on development of mechanical systems.

M E 411: Automatic Controls
(2-2) Cr. 3. F.
Prereq: M E 421
Methods and principles of automatic control. Pneumatic, hydraulic, and electrical systems. Representative applications of automatic control systems. Mathematical analysis of control systems.

M E 412: Ethical Responsibilities of a Practicing Engineer
(3-0) Cr. 3. F.
Prereq: Credit or enrollment in M E 325
The study of ethics in engineering design and the engineering profession. A comprehensive look at when ethical decisions must be made and an approach to make them. The approach takes into account moral, legal, technical, experiential, and standards to aid in ethical decision making. Each area will be studied through lectures, debates, guest speakers, class discussion, and case studies.

M E 413: Fluid Power Engineering
(Cross-listed with A B E). (2-2) Cr. 3. F.
Prereq: Credit or enrollment in E M 378 or M E 335, A B E 216 or M E 270
M E 415: Mechanical Systems Design  
(0-6) Cr. 3. F.S.  
Prereq: M E 324, M E 325  
Mechanical Engineering Capstone Design course. Team approach to solving design problems involving mechanical systems. Teams will use current design practices they will encounter in industry. Document decisions concerning form and function, material specification, manufacturing methods, safety, cost, and conformance with codes and standards. Solution description includes oral and written reports. Projects often worked with industry sponsors.

M E 417: Advanced Machine Design  
(Dual-listed with M E 517). (3-0) Cr. 3. S.  
Prereq: M E 325, MAT E 273  
Stress life, strain life, and fracture mechanics approaches to fatigue life and design with metals, polymers and ceramics. Introduction to material selection in design of machine components. Thermal and structural considerations in design of machine components and hybrid materials. Course project and relevant literature review required for graduate credit.

M E 418: Mechanical Considerations in Robotics  
(Dual-listed with M E 518). (3-0) Cr. 3. S.  
Prereq: Credit or enrollment in M E 421  
Three dimensional kinematics, dynamics, and control of robot manipulators, hardware elements and sensors. Laboratory experiments using industrial robots.

M E 419: Computer-Aided Design  
(3-0) Cr. 3. F.  
Prereq: M E 325  
Theory and applications of computer-aided design. Computer graphics programming, solid modeling, assembly modeling, and finite element modeling. Mechanical simulation, process engineering, rapid prototyping and manufacturing integration.

M E 421: System Dynamics and Control  
(3-2) Cr. 4. F.S.SS.  
Prereq: E E 442, E E 448, E M 345, MATH 267  
Modeling and simulation of mechanical, electrical, fluid, and/or thermal systems. Development of equations of motion and dynamic response characteristics in time and frequency domains. Fundamentals of classical control applications, including mathematical analysis and design for closed loop control systems. Introduction to computer interfacing for simulation, data acquisition, and control. Laboratory exercises for hands-on system investigation and control implementation.

M E 423: Creativity and Imagination for Engineering and Design  
(Dual-listed with M E 523). (3-0) Cr. 3.  
Broad exposure to the study of creativity, both in scientific research and in engineering design practice. Exploration of the subject includes readings from a variety of fields; in-class discussion and activities; and individual and team projects that enable students to develop their creativity. Graduate students also will do independent research on creativity and develop a related teaching module.

M E 425: Optimization Methods for Complex Designs  
(Dual-listed with M E 525). (3-0) Cr. 3. F.  
Prereq: M E 160, MATH 265  
Optimization involves finding the 'best' according to specified criteria. Review of a range of optimization methods from traditional nonlinear to modern evolutionary methods such as Genetic algorithms. Examination of how these methods can be used to solve a wide variety of design problems across disciplines, including mechanical systems design, biomedical device design, biomedical imaging, and interaction with digital medical data. Students will gain knowledge of numerical optimization algorithms and sufficient understanding of the strengths and weaknesses of these algorithms to apply them appropriately in engineering design. Experience includes code writing and off-the-shelf routines. Numerous case-studies of real-world situations in which problems were modeled and solved using advanced optimization techniques.

M E 433: Alternative Energy  
(3-0) Cr. 3. F.  
Prereq: PHYS 221/PHYS 222 and CHEM 167  
Basic principles, performance, and cost analysis of alternative energy systems including biofuels, bioenergy, wind, solar, fuel cells, storage and other alternative energy systems. Performance analysis and operating principles of systems and components, and economic analysis for system design and operation will be taught. Emphasis is on alternative energy technologies needed to meet our future energy needs at various scales ranging from household to city to national levels.

M E 436: Heat Transfer  
(3-2) Cr. 4. F.S.SS.  
Prereq: M E 335  
M E 437: Introduction to Combustion Engineering (3-0) Cr. 3. S.
Prereq: Credit in M E 332 or equivalent and credit or enrollment in M E 335 or equivalent.
Introduction to the fundamentals of combustion and the analysis of combustion systems for gaseous, liquid, and solid fuels-including biomass fuels. Combustion fundamentals are applied to the analysis of engines; turbines; biomass cookstoves; suspension, fixed-bed, and fluidized-bed furnaces; and other combustion devices.

M E 441: Fundamentals of Heating, Ventilating, and Air Conditioning (3-0) Cr. 3. F.
Prereq: Credit or enrollment in M E 436
Space conditioning and moist air processes. Application of thermodynamics, heat transfer, and fluid flow principles to the analysis of heating, ventilating, and air conditioning components and systems. Performance and specification of components and systems.

M E 442: Heating and Air Conditioning Design (1-5) Cr. 3. S.
Prereq: M E 441
Design criteria and assessment of building environment and energy requirements. Design of heating, ventilating, and air conditioning systems. System control and economic analysis. Oral and written reports required.

M E 444: Elements and Performance of Power Plants (3-0) Cr. 3. S.
Prereq: M E 332, credit or enrollment in M E 335
Basic principles, thermodynamics, engineering analysis of power plant systems. Topics include existing power plant technologies, the advanced energyplex systems of the future, societal impacts of power production, and environmental and regulatory concerns.

M E 448: Fluid Dynamics of Turbomachinery (Cross-listed with AER E). (3-0) Cr. 3. S.
Prereq: AER E 311 or M E 335
Applications of principles of fluid mechanics and thermodynamics in performance analysis and design of turbomachines. Conceptual and preliminary design of axial and radial flow compressors and turbines using velocity triangles and through-flow approaches.

M E 449: Internal Combustion Engines (3-1) Cr. 3. F.
Prereq: M E 335
Basic principles, thermodynamics, combustion, and exhaust emissions of spark-ignition and compression-ignition engines. Laboratory determination of fuel properties and engine performance. Effects of engine components and operating conditions on performance. Written reports required.

M E 451: Engineering Acoustics (Cross-listed with E E, E M). (2-2) Cr. 3. Alt. S., offered even-numbered years.
Prereq: PHYS 221 and MATH 266 or MATH 267

Prereq: MATH 317, M E 421 or permission of instructor
Broad exposure to the study of creativity, both in scientific research and in engineering design practice. Exploration of the subject includes readings from a variety of fields; in-class discussion and activities; and individual and team projects that enable students to develop their creativity. Graduate students also will do independent research on creativity and develop a related teaching module.

M E 466: Multidisciplinary Engineering Design (Cross-listed with A B E, AER E, B M E, CPR E, E E, ENGR, I E, MAT E). (1-4) Cr. 3. Repeatable. F.S.
Prereq: Student must be within two semesters of graduation; permission of instructor.
Application of team design concepts to projects of a multidisciplinary nature. Concurrent treatment of design, manufacturing, and life cycle considerations. Application of design tools such as CAD, CAM, and FEM. Design methodologies, project scheduling, cost estimating, quality control, manufacturing processes. Development of a prototype and appropriate documentation in the form of written reports, oral presentations and computer models and engineering drawings.

Prereq: Student must be within two semesters of graduation or receive permission of instructor.
Build and test of a conceptual design. Detail design, manufacturability, test criteria and procedures. Application of design tools such as CAD and CAM and manufacturing techniques such as rapid prototyping. Development and testing of a full-scale prototype with appropriate documentation in the form of design journals, written reports, oral presentations and computer models and engineering drawings.
M E 475: Modeling and Simulation
(3-0) Cr. 3. S.
Prereq: M E 421, credit or enrollment in M E 436
Introduction to computer solution techniques required to simulate flow, thermal, and mechanical systems. Methods of solving ordinary and partial differential equations and systems of algebraic equations; interpolation, numerical integration; finite difference and finite element methods.

M E 479: Sustainability Science for Engineering Design
(3-0) Cr. 3. Alt. S., offered irregularly.
Prereq: Any engineering design course
Scientific principles and quantitative methods concerning sustainability. Analysis of environmental issues associated with engineering design and product manufacturing in an economic and social context. Heuristic and analytical methods for assessing the sustainability of existing or potential product/service designs. Application to a design problem in teams.

M E 484: Technology, Globalization and Culture
(Dual-listed with M E 584). (Cross-listed with WLC). (3-0) Cr. 3. F.
Prereq: junior or senior classification for M E 484; graduate classification for M E 584
Cross-disciplinary examination of the present and future impact of globalization with a focus on preparing students for leadership roles in diverse professional, social, and cultural contexts. Facilitate an understanding of the threats and opportunities inherent in the globalization process as they are perceived by practicing professionals and articulated in debates on globalization. Use of a digital forum for presenting and analyzing globalization issues by on-campus and off-campus specialists.
Meets International Perspectives Requirement.

M E 486: Appropriate Technology Design
(3-0) Cr. 3. Alt. F., offered irregularly.
Prereq: M E 231, M E 270, enrollment in M E 335; or permission of instructor.
Hands-on design experience utilizing knowledge acquired in core mechanical engineering courses. Emphasis with engineering problem formulation and solution, oral and written communication, team decision-making and ethical conduct. Design projects include engineering considerations in appropriate technology which have multidisciplinary components in economics and sociology.

M E 490: Independent Study
Cr. 1-6. Repeatable.
Prereq: Senior classification
Investigation of topics holding special interest of students and faculty. Election of course and topic must be approved in advance by supervising faculty.

M E 490H: Independent Study: Honors
Cr. 1-6. Repeatable.
Prereq: Senior classification
Investigation of topics holding special interest of students and faculty. Election of course and topic must be approved in advance by supervising faculty.

M E 490J: Independent Study: Thermodynamics and Energy Utilization
Cr. 1-6. Repeatable.
Prereq: Senior classification
Investigation of topics holding special interest of students and faculty. Election of course and topic must be approved in advance by supervising faculty.

M E 490M: Independent Study: Nuclear Engineering
Cr. 1-6. Repeatable.
Prereq: Senior classification
Investigation of topics holding special interest of students and faculty. Election of course and topic must be approved in advance by supervising faculty.

M E 490O: Independent Study: Design and Optimization
Cr. 1-6. Repeatable.
Prereq: Senior classification
Investigation of topics holding special interest of students and faculty. Election of course and topic must be approved in advance by supervising faculty.

M E 490P: Independent Study: Dynamic Systems and Controls
Cr. 1-6. Repeatable.
Prereq: Senior classification
Investigation of topics holding special interest of students and faculty. Election of course and topic must be approved in advance by supervising faculty.

M E 490Q: Independent Study: Materials Processing and Mechanics
Cr. 1-6. Repeatable.
Prereq: Senior classification
Investigation of topics holding special interest of students and faculty. Election of course and topic must be approved in advance by supervising faculty.

M E 490R: Independent Study: Thermo-fluids
Cr. 1-6. Repeatable.
Prereq: Senior classification
Investigation of topics holding special interest of students and faculty. Election of course and topic must be approved in advance by supervising faculty.
M E 490S: Independent Study: Emerging Areas
Cr. 1-6. Repeatable.
Prereq: Senior classification
Investigation of topics holding special interest of student and faculty.
Election of course and topic must be approved in advance by supervising faculty.

Courses primarily for graduate students, open to qualified undergraduates:

Cr. 3. S.
Prereq: Graduate standing.
Economics and policy for U.S. energy systems, with an emphasis on connections to engineering. Topics include: economic analysis of conventional energy commodity markets and technologies, deregulated electricity markets, and emerging energy technologies; demand forecasting; economic and environmental policy in energy; integrated assessment; and semester-specific contemporary issues. Economics majors may not apply this course towards graduation.

M E 511: Advanced Control Design
(3-0) Cr. 3. S.
Prereq: M E 411
Application of control design methods using continuous, discrete, and frequency-based models. Approaches include classical, pole assignment, model reference, internal model, and adaptive control methods. Mechanical design projects.

M E 517: Advanced Machine Design
(Dual-listed with M E 417). (3-0) Cr. 3. S.
Prereq: M E 325, MAT E 273
Stress life, strain life, and fracture mechanics approaches to fatigue life and design with metals, polymers and ceramics. Introduction to material selection in design of machine components. Thermal and structural considerations in design of machine components and hybrid materials. Course project and relevant literature review required for graduate credit.

M E 518: Mechanical Considerations in Robotics
(Dual-listed with M E 418). (3-0) Cr. 3. S.
Prereq: Credit or enrollment in M E 421
Three dimensional kinematics, dynamics, and control of robot manipulators, hardware elements and sensors. Laboratory experiments using industrial robots.

M E 520: Material and Manufacturing Considerations in Design
(3-0) Cr. 3. Alt. F., offered irregularly.
Prereq: M E 324, M E 325

M E 521: Mechanical Behavior and Manufacturing of Polymers and Composites
(Cross-listed with M S E). (3-0) Cr. 3. Alt. S., offered odd-numbered years.
Prereq: M E 324 or MAT E 272 and E M 324

M E 523: Creativity and Imagination for Engineering and Design
(Dual-listed with M E 423). (3-0) Cr. 3.
Broad exposure to the study of creativity, both in scientific research and in engineering design practice. Exploration of the subject includes readings from a variety of fields; in-class discussion and activities; and individual and team projects that enable students to develop their creativity. Graduate students also will do independent research on creativity and develop a related teaching module.

M E 525: Optimization Methods for Complex Designs
(Dual-listed with M E 425). (3-0) Cr. 3.
Prereq: M E 160, MATH 265
Optimization involves finding the 'best' according to specified criteria. Review of a range of optimization methods from traditional nonlinear to modern evolutionary methods such as Genetic algorithms. Examination of how these methods can be used to solve a wide variety of design problems across disciplines, including mechanical systems design, biomedical device design, biomedical imaging, and interaction with digital medical data. Students will gain knowledge of numerical optimization algorithms and sufficient understanding of the strengths and weaknesses of these algorithms to apply them appropriately in engineering design. Experience includes code writing and off-the-shelf routines. Numerous case-studies of real-world situations in which problems were modeled and solved using advanced optimization techniques.
M E 527: Mechanics of Machining and Finishing Processes
(3-0) Cr. 3. Alt. S., offered odd-numbered years.
Prereq: M E 324

M E 528: Micro/Nanomanufacturing
(3-0) Cr. 3. Alt. S., offered irregularly.
Prereq: M E 324
Concepts and applications of micro/nanotechnology appropriate to the manufacturing field. An overview of micro/nano-fabrication techniques including mechanical, EDM, laser and lithography. MEMS device fabrication. Scaling laws. Top down and bottom up approaches of nanomanufacturing. Experimental or theoretical project leading to potential submission of a manuscript for journal or conference.

M E 530: Advanced Thermodynamics
(3-0) Cr. 3. F.
Prereq: M E 332
Fundamentals of thermodynamics from the classical viewpoint with emphasis on the use of the first and second laws for analysis of thermal systems. Generalized thermodynamic relationships. Computer applications of thermodynamic properties and system analysis. Selected topics.

M E 531: Advanced Energy Systems and Analysis
Cr. 3. F.
Prereq: any undergraduate thermodynamics course; mathematics through differential equations
Introduction to energy systems including economic and thermodynamic principles. Various production systems will be analyzed. Application to transportation and building systems will be emphasized. Sustainability, climate change and other current energy system topics.

M E 532: Compressible Fluid Flow
(Cross-listed with AER E). (3-0) Cr. 3. S.
Prereq: AER E 310, 311 or equivalent

M E 535: Thermochemical Processing of Biomass
(Cross-listed with BRT). (3-0) Cr. 3. S.
Prereq: Undergraduate course work in thermodynamics and transport phenomena
Introduction to thermal and catalytic processes for the conversion of biomass to biofuels and other biobased products. Topics include gasification, fast pyrolysis, hydrothermal processing, syngas to synfuels, and bio-oil upgrading. Application of thermodynamics, heat transfer, and fluid dynamics to bioenergy and biofuels.

M E 536: Advanced Heat Transfer
(3-0) Cr. 3. S.
Prereq: M E 436
Advanced treatment of heat transmission by conduction, convection, and radiation.

M E 538: Advanced Fluid Flow
(3-0) Cr. 3. F.
Prereq: Credit or enrollment in M E 436
Detailed analysis of incompressible/compressible, viscous/inviscid, laminar/turbulent, and developing fluid flows on a particle/point control volume basis.

M E 539: Nanoscale Heat Transfer
Cr. 3. S.
Prereq: Any undergraduate course on thermodynamics or heat transfer or transport phenomena or solid state physics

M E 542: Advanced Combustion
(3-0) Cr. 3. S.
Prereq: M E 332 or CH E 381
**M E 543: Introduction to Random Vibrations and Nonlinear Dynamics**  
(Cross-listed with E M). (3-0) Cr. 3. Alt. S., offered odd-numbered years.  
Vibrations of continuous systems. Nonlinear vibration phenomena, perturbation expansions; methods of multiple time scales and slowly-varying amplitude and phase. Characteristics of random vibrations; random processes, probability distributions, spectral density and its significance, the normal or Gaussian random process. Transmission of random vibration, response of simple single and two-degree-of-freedom systems to stationary random excitation. Fatigue failure due to random excitation.

**M E 545: Thermal Systems Design**  
(3-0) Cr. 3. Alt. F., offered even-numbered years.  
Prereq: M E 436  
Integrating thermodynamics, fluid mechanics, and heat transfer to model thermal equipment and to simulate thermal systems. Second law and parametric analysis; cost estimation, life cycle analysis and optimization. Some computer programming required.

**M E 546: Computational Fluid Mechanics and Heat Transfer I**  
(Cross-listed with AER E). (3-0) Cr. 3. F.  
Prereq: AER E 310 or M E 335, and programming experience  

**M E 547: Computational Fluid Mechanics and Heat Transfer II**  
(Cross-listed with AER E). (3-0) Cr. 3. S.  
Prereq: AER E 546 or equivalent  
Application of computational methods to current problems in fluid mechanics and heat transfer. Methods for solving the Navier-Stokes and reduced equation sets such as the Euler, boundary layer, and parabolized forms of the conservation equations. Introduction to relevant aspects of grid generation and turbulence modeling.

**M E 552: Advanced Acoustics**  
(Cross-listed with E M). (3-0) Cr. 3. Alt. F., offered irregularly.  
Prereq: E M 451  
Theoretical acoustics: wave propagation in fluids; acoustic radiation, diffraction and scattering; nonlinear acoustics; radiation force; cavitation; and ray acoustics.

**M E 556: Machine Vision**  
(Dual-listed with M E 456). Cr. 3. Repeatable. Alt. S., offered irregularly.  
Prereq: MATH 317, M E 421 or permission of instructor  
Broad exposure to the study of creativity, both in scientific research and in engineering design practice. Exploration of the subject includes readings from a variety of fields; in-class discussion and activities; and individual and team projects that enable students to develop their creativity. Graduate students also will do independent research on creativity and develop a related teaching module.

**M E 557: Computer Graphics and Geometric Modeling**  
(Cross-listed with COM S, CPR E). (3-0) Cr. 3. F.  
Prereq: M E 421, programming experience in C  

**M E 561: Scanning Probe Microscopy**  
(2-2) Cr. 3. Alt. F., offered irregularly.  
Prereq: First year physics, chemistry  
Introduction to the scanning probe microscope (SPM, also known as atomic force microscope or AFM) and associated measurement techniques. Overview of instrumentation system, basic principles of operation, probe-sample interaction and various operational modes to obtain micro/nanoscale structure and force spectroscopy of material surfaces. Examples of SPM significance and applications in science and engineering research, nanotechnology and other industries. Laboratory work involving use of a scanning probe microscope system is an integral part of the course.

**M E 563: Micro and Nanoscale Mechanics**  
(3-0) Cr. 3. Alt. S., offered odd-numbered years.  
Prereq: E M 324 and M E 325  
Review of Fundamentals: (Elasticity, Electromagnetism, Mechanical response), Mechanics of thermally, electrostatically and magnetically actuated microsystems, Mechanics and design of nanostructured materials, mechanics of surface stress engineering and its implications to sensors and thin film structures.

**M E 564: Fracture and Fatigue**  
(Cross-listed with AER E, E M, M S E). (3-0) Cr. 3. Alt. F., offered even-numbered years.  
Prereq: E M 324 and either MAT E 216 or MAT E 273 or MAT E 392.  
Undergraduates: Permission of instructor  
Materials and mechanics approach to fracture and fatigue. Fracture mechanics, brittle and ductile fracture, fracture and fatigue characteristics, fracture of thin films and layered structures. Fracture and fatigue tests, mechanics and materials designed to avoid fracture or fatigue.
M E 566: Phase Transformation in Elastic Materials
(Cross-listed with E M). (3-0) Cr. 3. S.
Prereq: EM 510 or EM 516 or EM 514

M E 573: Random Signal Analysis and Kalman Filtering
(Cross-listed with AER E, E E). (3-0) Cr. 3. F.
Prereq: E E 324 or AER E 331 or M E 370 or M E 411 or MATH 341

M E 574: Optimal Control
(Cross-listed with AER E, E E). (3-0) Cr. 3. S.
Prereq: E E 577

M E 575: Introduction to Robust Control
(Cross-listed with AER E, E E). (3-0) Cr. 3.
Prereq: E E 577

M E 576: Digital Feedback Control Systems
(Cross-listed with AER E, E E). (3-0) Cr. 3. F.
Prereq: E E 475 or AER E 432 or M E 411 or MATH 415; and MATH 267

M E 577: Linear Systems
(Cross-listed with AER E, E E, MATH). (3-0) Cr. 3. F.
Prereq: E E 324 or AER E 331 or MATH 415; and MATH 207

M E 578: Nonlinear Systems
(Cross-listed with AER E, E E, MATH). (3-0) Cr. 3. S.
Prereq: E E 577

M E 580: Virtual Environments, Virtual Worlds, and Application
(Cross-listed with HCI). (3-0) Cr. 3. F.
Prereq: Senior or Graduate status.
A systematic introduction to the underpinnings of Virtual Environments (VE), Virtual Worlds, advanced displays and immersive technologies; and an overview of some of the applications areas particularly virtual engineering.

M E 584: Technology, Globalization and Culture
(Dual-listed with M E 484). (Cross-listed with WLC). (3-0) Cr. 3. F.
Prereq: junior or senior classification for M E 484; graduate classification for M E 584
Cross-disciplinary examination of the present and future impact of globalization with a focus on preparing students for leadership roles in diverse professional, social, and cultural contexts. Facilitate an understanding of the threats and opportunities inherent in the globalization process as they are perceived by practicing professionals and articulated in debates on globalization. Use of a digital forum for presenting and analyzing globalization issues by on-campus and off-campus specialists.
Meets International Perspectives Requirement.

M E 590: Special Topics
Cr. 1-8. Repeatable.

M E 590Q: Special Topics: Independent Literature Investigation
Cr. 1-8. Repeatable.

M E 590T: Special Topics: Biological and Nanoscale Sciences
Cr. 1-8. Repeatable.

M E 590U: Special Topics: Complex Fluid Systems
Cr. 1-8. Repeatable.

M E 590V: Special Topics: Clean Energy Technologies
Cr. 1-8. Repeatable.
M E 590W: Special Topics: Design and Manufacturing Innovation  
Cr. 1-8. Repeatable.

M E 590Z: Special Topics: Simulation and Visualization  
Cr. 1-8. Repeatable.

M E 599: Creative Component  
Cr. arr. Repeatable.

Courses for graduate students:

M E 600: Seminar  
Cr. R. Repeatable.  
(1-0).

M E 625: Surface Modeling  
(3-0) Cr. 3. Alt. F., offered irregularly. Alt. S., offered irregularly.  
Prereq: M E 557, programming experience in C  

M E 632: Multiphase Flow  
(Cross-listed with CH E). (3-0) Cr. 3. Alt. S., offered odd-numbered years.  
Prereq: M E 538  
Single particle, multiparticle and two-phase fluid flow phenomena (gas-solid, liquid-solid and gas-liquid mixtures); particle interactions, transport phenomena, wall effects; bubbles, equations of multiphase flow. Dense phase (fluidized and packed beds) and ducted flows; momentum, heat and mass transfer. Computer solutions.

M E 637: Convection Heat Transfer  
(3-0) Cr. 3. Alt. F., offered irregularly. Alt. S., offered irregularly.  
Prereq: M E 436  
Convection heat transfer to internal or external flows under laminar or turbulent conditions. Dimensionless parameters. Classical solutions of Newtonian viscous flows. Forced and free convection. Special topics.

M E 638: Radiation Heat Transfer  
(3-0) Cr. 3. Alt. F., offered irregularly.  
Prereq: M E 436  

M E 647: Advanced Computational Fluid Dynamics  
(Cross-listed with AER E). (3-0) Cr. 3. S.  
Prereq: AER E 547  

M E 690: Advanced Topics  
Cr. arr. Repeatable.  
Investigation of advanced topics of special interest to graduate students in mechanical engineering.

M E 690G: Advanced Topics: Advanced Machine Design  
Cr. arr. Repeatable.  
Investigation of advanced topics of special interest to graduate students in mechanical engineering.

M E 690O: Advanced Topics: Engineering Computation  
Cr. arr. Repeatable.  
Investigation of advanced topics of special interest to graduate students in mechanical engineering.

M E 690Q: Advanced Topics: Independent Literature Investigation  
Cr. arr. Repeatable.  
Investigation of advanced topics of special interest to graduate students in mechanical engineering.

M E 690T: Advanced Topics: Biological and Nanoscale Sciences  
Cr. arr. Repeatable. F.S.SS.  
Investigation of Special Topics: Biological and Nanoscale Sciences of special interest to graduate students in mechanical engineering.

M E 690U: Advanced Topics: Complex Fluid Systems  
Cr. arr. Repeatable. F.S.SS.  
Investigation of Special Topics: Complex Fluid Systems of special interest to graduate students in mechanical engineering.

M E 690V: Advanced Topics: Clean Energy Technologies  
Cr. arr. F.S.SS.  
Investigation of Special Topics: Clean Energy Technologies of special interest to graduate students in mechanical engineering.

M E 690W: Advanced Topics: Design and Manufacturing Innovation  
Cr. arr. Repeatable.  
Investigation of Design & Manufacturing Innovation of special interest to graduate students in mechanical engineering.
M E 690Z: Advanced Topics: Simulation and Visualization
Cr. arr. Repeatable. F.S.S.
Investigation of Special Topics: Simulation and Visualization of special interest to graduate students in mechanical engineering.

M E 697: Engineering Internship
Cr. R. Repeatable.
Prereq: Permission of Director of Graduate Education, graduate classification
One semester and one summer maximum per academic year professional work period. Offered on a satisfactory-fail basis only.

M E 699: Research
Cr. arr. Repeatable.
Offered on a satisfactory-fail basis only.