Mechanical Engineering

Program Description

The Mechanical Engineering Department offers a design-oriented undergraduate program that emphasizes fundamental engineering principles. Students receive a strong foundation in mechanical engineering disciplines, and a working knowledge of modern engineering tools. Many courses are augmented through hands-on and project-based experiences. Successful graduates are well-prepared for a mechanical engineering career in a world of rapid technological change.

The program leading to the degree of Bachelor of Science in Mechanical Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Bachelor of Science in Mechanical Engineering

The Mechanical Engineering program intentionally embeds several professional and technical skills, e.g. working on teams, engineering design, technical communication and programming, throughout the Mechanical Engineering curriculum. During the freshman and sophomore years, students complete a set of core courses that include mathematics, basic sciences, and fundamental engineering disciplines. This includes early open-ended design experiences in Introduction to Design (EDNS151), Introduction to Mechanical Engineering: Programming and Hardware Interface (MEGN200), and Introduction to Mechanical Engineering: Field Session (MEGN201). Additionally, courses in humanities and social sciences allow students to explore the linkages between the environment, human society, and engineered systems.

In the middle years, Mechanical Engineering offers a four course project-based design sequence to learn engineering tools, including MATLAB, SolidWorks, and LabVIEW, to solve engineering problems in a hands-on environment. This experience teaches design methodology and stresses the creative aspects of the mechanical engineering profession. This course sequence helps prepare students for open-ended, industry-based project in the senior design experience.

In the junior and senior years, students complete an advanced mechanical engineering core that includes fluid mechanics, thermodynamics, heat transfer, numerical methods, control systems, machine design, computer-aided engineering, and manufacturing processes. This engineering core is complemented by courses in economics and electives in humanities and social sciences. Students must also take three advanced technical electives and three additional free electives to explore specific fields of interest. In the senior year, all students must complete a capstone design course focused on a multidisciplinary engineering project.

Students in mechanical engineering spend considerable time with design and testing equipment available in the CECS Garage, a large machine shop, and automation spaces for prototyping and testing equipment. Students are also encouraged to get involved in research with our faculty in the Department of Mechanical Engineering. These research areas include: biomechanics; solid mechanics and materials; thermal-fluid systems; and robotics. Our students also find internship opportunities to gain practical experience and explore the many industries under the mechanical engineering umbrella.

There are plenty of opportunities outside of the curriculum for students to explore their passions. We have an active Mines Maker Space, Robotics Club, and Abilities Research & Design Group, a group of students enabling those with disabilities to try new activities or advance their performance in a given sport. These are just a few of the clubs and societies where students engage with the community or compete in design challenges nation-wide.

Program Educational Objectives (Bachelor of Science in Mechanical Engineering)

The Mechanical Engineering program contributes to the educational objectives described in the Mines’ Graduate Profile and the ABET Accreditation Criteria. Accordingly, the Mechanical Engineering Program at Mines has established the following program educational objectives for the B.S. in Mechanical Engineering degree:

Within three to five years of completing their degree, graduates will be:

- Applying their Mechanical Engineering education as active contributors in the workforce or graduate school;
- Effective at communicating technical information in a diverse and globally integrated society;
- Demonstrating their commitment to continued professional development through training, coursework, and/or professional society involvement;
- Exemplifying ethical and social responsibility in their professional activities.

Bachelor of Science in Mechanical Engineering Degree Requirements:

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<td>Total Semester Hrs: 134.5</td>
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* Mechanical Engineering students are required to take three Mechanical Engineering elective courses. At least one of these courses must be from the Advanced Engineering Sciences list. The remaining must be from either the Advanced Engineering Sciences list or the Mechanical Engineering Electives list.

**Advanced Engineering Sciences:**
- MEGN412 | ADVANCED MECHANICS OF MATERIALS | 3.0 |
- MEGN416 | ENGINEERING VIBRATION | 3.0 |
- MEGN451 | FLUID MECHANICS II | 3.0 |
- MEGN461 | THERMODYNAMICS II | 3.0 |

**Mechanical Engineering Electives:**
- CEE305 | NUMERICAL METHODS FOR ENGINEERS | 3.0 |
- CEE306 | FINITE ELEMENT METHODS FOR ENGINEERS | 3.0 |
- EBG321 | ENGINEERING ECONOMICS | 3.0 |
- EDNS401 | PROJECTS FOR PEOPLE | 3.0 |
- EENG309 | FUNDAMENTALS OF ELECTRIC MACHINERY | 4.0 |
- EENG390 | ENERGY, ELECTRICITY, RENEWABLE ENERGY, AND ELECTRIC POWER GRID | 3.0 |
- EENG417 | MODERN CONTROL DESIGN | 3.0 |
- MEGN330 | INTRODUCTION TO BIOMECHANICAL ENGINEERING | 3.0 |
- MEGN430 | MUSCULOSKELETAL BIOMECHANICS | 3.0 |
- MEGN435 | MODELING AND SIMULATION OF HUMAN MOVEMENT | 3.0 |
- MEGN436 | COMPUTATIONAL BIOMECHANICS | 3.0 |
- MEGN441 | INTRODUCTION TO ROBOTICS | 3.0 |
- MEGN466 | INTRODUCTION TO INTERNAL COMBUSTION ENGINES | 3.0 |
- MEGN485 | MANUFACTURING OPTIMIZATION WITH NETWORK MODELS | 3.0 |
- MEGN486 | LINEAR OPTIMIZATION | 3.0 |
During the 2016-2017 Academic Year, the Undergraduate Council considered the policy concerning required major GPAs and which courses are included in each degree’s GPA. While the GPA policy has not been officially updated, in order to provide transparency, council members agreed that publishing the courses included in each degree’s GPA is beneficial to students.

The following list details the courses that are included in the GPA for this degree:

- CEEN241
- EENG281
- EENG307
- EGGN205
- EGGN250
- EGGN350
- EGGN450
- EGGN491
- EDNS491
- MEGN100 through MEGN699 inclusive

Combined Mechanical Engineering Baccalaureate and Masters Degrees

Mechanical Engineering offers a five year combined program in which students have the opportunity to obtain specific engineering skills supplemented with graduate coursework in mechanical engineering. Upon completion of the program, students receive two degrees, the Bachelor of Science in Mechanical Engineering and the Master of Science in Mechanical Engineering.

Admission into a graduate degree program as a Combined Undergraduate/Graduate degree student may occur as early as the first semester Junior year and must be granted no later than the end of registration the last semester Senior year. Students must meet minimum GPA admission requirements for the graduate degree.

Students are required to take an additional thirty credit hours for the M.S. degree. Up to nine of the 30 credit hours beyond the undergraduate degree requirements can be 400-level courses. The remainder of the courses will be at the graduate level (500-level and above). The Mechanical Engineering Graduate Bulletin provides detail into the graduate program and includes specific instructions regarding required and elective courses. Students may switch from the combined program, which includes a non-thesis Master of Science degree to a M.S. degree with a thesis option; however, if students change degree programs they must satisfy all degree requirements for the M.S. with thesis degree.

General CSM Minor/ASI requirements can be found here (catalog.mines.edu/undergraduate/undergraduateinformation/minorasi).

Mechanical Engineering Areas of Special Interest (ASI) and Minor Programs

General Requirements

The Mechanical Engineering Department offers minor and ASI programs. Students who elect an ASI or minor, must fulfill all prerequisite requirements for each course in a chosen sequence. Students in the sciences or mathematics must be prepared to meet prerequisite requirements in fundamental engineering and engineering science courses. Students in engineering disciplines are better positioned to meet the prerequisite requirements for courses in the minor and ASI Mechanical Engineering program. (See Minor/ASI section of the Bulletin for all requirements for a minor/ASI at CSM.)

For an Area of Special Interest in Mechanical Engineering, the student must complete a minimum of 12 hours from the following:

- MEGN312 INTRODUCTION TO SOLID MECHANICS 3.0
- MEGN315 DYNAMICS 3.0
- MEGN351 FLUID MECHANICS 3.0
- MEGN361 THERMODYNAMICS I 3.0

For a Minor in Mechanical Engineering, the student must complete a minimum of 18 hours from the following:

1. Required Courses (choose three, 9 credit hours)

   - MEGN312 INTRODUCTION TO SOLID MECHANICS 3.0
   - MEGN315 DYNAMICS 3.0
   - MEGN351 FLUID MECHANICS 3.0
   - MEGN361 THERMODYNAMICS I 3.0

2. Tracks (choose one track):

   a. Robotics, Automation & Design Track (10 credit hours)

      - MEGN424 COMPUTER AIDED ENGINEERING 3.0
      - MEGN481 MACHINE DESIGN 3.0
      - MEGN381 MANUFACTURING PROCESSES 3.0
      - MEGN441 INTRODUCTION TO ROBOTICS
      - MEGN416 ENGINEERING VIBRATION
      - MEGN485 MANUFACTURING OPTIMIZATION WITH NETWORK MODELS

   b. Solid Materials Track (9 credit hours)
Biomechanical Engineering Elective Courses

MEGN430 MUSCULOSKELETAL BIOMECHANICS 3.0
MEGN435 MODELING AND SIMULATION OF HUMAN MOVEMENT 3.0
or MEGN535 MODELING AND SIMULATION OF HUMAN MOVEMENT
MEGN436 COMPUTATIONAL BIOMECHANICS 3.0
or MEGN536 COMPUTATIONAL BIOMECHANICS
MEGN530 BIOMEDICAL INSTRUMENTATION 3.0
MEGN531 PROSTHETIC AND IMPLANT ENGINEERING 3.0
MEGN532 EXPERIMENTAL METHODS IN BIOMECHANICS 3.0
MEGN537 PROBABILISTIC BIOMECHANICS 3.0
MEGN553 INTRODUCTION TO COMPUTATIONAL TECHNIQUES FOR FLUID DYNAMICS AND TRANSPORT PHENOMENA 3.0

As the content of these courses varies, the course must be noted as relevant to the biomechanical engineering minor.

Minor and ASI in advanced Manufacturing

The interdisciplinary Advanced Manufacturing program will prepare undergraduates to meet the challenges of careers in advanced manufacturing. Undergraduate students have the following degree options:

- Area of Special Interest (12 credit hours)
  - Requirements: MEGN483 and 9 credit hours of electives (see Table 2)

- Minor (18 credit hours)
  - Requirements: MEGN483 and one other core course to be determined and 12 credit hours of electives (see Table 2)

The Advanced Manufacturing program will be anchored by four signature core courses (three of which will be new to the next catalog) and will offer a diverse array of electives drawn from an approved list of existing courses within the Mechanical Engineering, Metallurgical and Materials Engineering, Electrical Engineering, Computer Science, Physics and Applied Math and Statistics departments. The electives in Table 2 are categorized based on the program’s specialty areas:

- Additive Manufacturing of Structural Materials
- Data-Driven Materials Manufacturing

The four core courses in the Advanced Manufacturing program will explore the emerging technology of additive manufacturing; the existing structural materials used in additive manufacturing and the physical models for processing them; how to design parts specifically for additive manufacturing processes; and the foundational principles of statistical modeling and machine learning for the purpose of optimizing materials for manufacturing processes and optimizing manufacturing processes for specific parts.

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<th>Credits</th>
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<td>MEGNXXX</td>
<td>Additional Core Courses to Be Determined</td>
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The interdisciplinary Advanced Manufacturing program will prepare undergraduates to meet the challenges of careers in advanced manufacturing. Undergraduate students have the following degree options:

- Area of Special Interest (12 credit hours)
  - Requirements: MEGN483 and 9 credit hours of electives (see Table 2)

- Minor (18 credit hours)
  - Requirements: MEGN483 and one other core course to be determined and 12 credit hours of electives (see Table 2)

The Advanced Manufacturing program will be anchored by four signature core courses (three of which will be new to the next catalog) and will offer a diverse array of electives drawn from an approved list of existing courses within the Mechanical Engineering, Metallurgical and Materials Engineering, Electrical Engineering, Computer Science, Physics and Applied Math and Statistics departments. The electives in Table 2 are categorized based on the program’s specialty areas:

- Additive Manufacturing of Structural Materials
- Data-Driven Materials Manufacturing

The four core courses in the Advanced Manufacturing program will explore the emerging technology of additive manufacturing; the existing structural materials used in additive manufacturing and the physical models for processing them; how to design parts specifically for additive manufacturing processes; and the foundational principles of statistical modeling and machine learning for the purpose of optimizing materials for manufacturing processes and optimizing manufacturing processes for specific parts.

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<td>ADVANCED MECHANICS OF MATERIALS</td>
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<td>MTGN348</td>
<td>MICROSTRUCTURAL DEVELOPMENT</td>
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<td>MTGN414</td>
<td>ADVANCED PROCESSING AND SINTERING OF CERAMICS</td>
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<td>MTGN442</td>
<td>ENGINEERING ALLOYS</td>
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<td>MEGN486</td>
<td>LINEAR OPTIMIZATION</td>
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**Professor and Department Head**
John R. Berger

**George R. Brown Distinguished Professor**
Robert J. Kee

**Professors**
Cristian V. Ciobanu
Greg Jackson
Alexandra Newman
Brian G. Thomas

**Associate professors**
Joel M. Bach
Gregory Bogin
Robert Braun

Mark Deinert
Anthony Petrella
Jason Porter
Anne Silverman
Aaron Stebner
Neal Sullivan
Ruichong "Ray" Zhang

**Assistant professors**
Steven DeCaluwe
Andrew Osborne
Andrew Petruska
Paulo Tabares-Velasco
Nils Tilton
Garritt Tucker
Xiaoli Zhang

**Teaching Professors**
Kristine Csavina, Assistant Department Head
Ventzi Karaivanov

**Teaching Associate Professors**
Oyvind Nilsen
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**Teaching Assistant Professors**
Jeff Ackerman
Jeffrey Wheeler

**Emeriti Professors**
Robert King
Michael B. McGrath
Graham G.W. Mustoe

**Emerita Professor**
Joan P. Gosink

**Emeriti Associate Professor**
David Munoz
John Steele

**Research Professor**
George Gilmer
Research Associate Professors
Angel Abbud-Madrid
Sandrine Ricote
Huayang Zhu

Research Assistant Professors
Behnam Aminahmedi
Christopher B. Dryer
Branden Kappes
Canan Karakaya
Amy Schweikert

Affiliate Professor of Mechanical Engineering
Michael Mooney

Post-Doctoral Fellow
Ankit Gupta
Rajesh Jah
Yasuhito Suzuki

Courses

**AMFG401. ADDITIVE MANUFACTURING. 3.0 Semester Hrs.**
(II) Additive Manufacturing (AM), also known as 3D Printing in the popular press, is an emerging manufacturing technology that will see widespread adoption across a wide range of industries during your career. Subtractive Manufacturing (SM) technologies (CNCs, drill presses, lathes, etc.) have been an industry mainstay for over 100 years. The transition from SM to AM technologies, the blending of SM and AM technologies, and other developments in the manufacturing world has direct impact on how we design and manufacture products. This course will prepare students for the new design and manufacturing environment that AM is unlocking. Prerequisites: MEGN200 and MEGN201 or equivalent project classes. 3 hours lecture; 3 semester hours.

**AMFG498. SPECIAL TOPICS IN ADVANCED MANUFACTURING. 1-6 Semester Hr.**
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

**MEGN200. INSTRUMENTATION & AUTOMATION. 3.0 Semester Hrs.**
(I, II) This course will explore instrumentation and automation of electro-mechanical systems. Students will utilize LabView and electro-mechanical instrumentation to solve advanced engineering problems. Class activities and projects will highlight the utility of LabView for real-time instrumentation and control. Prerequisites: MEGN200, MEGN201. 2 hours lecture; 1 hour other; 3 semester hours.

**MEGN201. MECHANICAL FIELD SESSION. 3.0 Semester Hrs.**
Equivalent with EGGN235, (I, II, S) This course reinforces basic drawing skills from Cornerstone Design, introduces SolidWorks tools to advance modeling skills, introduces machine shop skills (including safety and use of mill, lathe and CNC) and introduces GD&T practices important in fabrication and manufacturing, and prob-stats relevant to manufacturing. Prerequisite: EDNS151 or EDNS155. 3 hours lecture; 3 semester hours.

**MEGN250. MULTIDISCIPLINARY ENGINEERING LABORATORY. 1.5 Semester Hr.**
Equivalent with EGGN250, (I, II) (WI) Laboratory experiments integrating instrumentation, circuits and power with computer data acquisitions and sensors. Sensor data is used to transition between science and engineering science. Engineering Science issues like stress, strains, thermal conductivity, pressure and flow are investigated using fundamentals of equilibrium, continuity, and conservation. Prerequisite: PHGN200. 0.6 hours lecture; 2.7 hours lab; 1.5 semester hours.

**MEGN298. SPECIAL TOPICS. 1-6 Semester Hr.**
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

**MEGN299. INDEPENDENT STUDY. 1-6 Semester Hr.**
(I, II) Individual research or special problem projects supervised by a faculty member, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: “Independent Study” form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

**MEGN300. INSTRUMENTATION & AUTOMATION. 3.0 Semester Hrs.**
(I, II) This course will explore instrumentation and automation of electro-mechanical systems. Students will utilize LabView and electro-mechanical instrumentation to solve advanced engineering problems. Class activities and projects will highlight the utility of LabView for real-time instrumentation and control. Prerequisites: MEGN200, MEGN201. 2 hours lecture; 1 hour other; 3 semester hours.

**MEGN301. MECHANICAL INTEGRATION & DESIGN. 2.0 Semester Hrs.**
(I, II) Students will utilize the engineering design process and knowledge in systems level design to produce a mechanical product/process. Students will reverse engineer a product/process to emphasize the steps in the design process. Students will select a longer course project, which is intended to reinforce engineering skills from other courses. The project topics would parallel one of the four research disciplines in ME, and students would be able to choose a topic pathway that emphasizes opportunities for mechanical engineering graduates. Prerequisites: MEGN200, MEGN201, and MEGN300. 1 hour lecture, 1 hour other; 2 semester hours.
MEGN312. INTRODUCTION TO SOLID MECHANICS. 3.0 Semester Hrs.
(I, II, S) Introduction to the theory and application of the principles of Solid Mechanics by placing an early focus on free body diagrams, stress and strain transformations, and failure theories. Covered topics include: stress and stress transformation, strain and strain transformation, mechanical properties of materials, axial load, torsion, bending, transverse shear, combined loading, pressure vessels, failure theories, stress concentrations, thermal stress, deflection of beams and shafts, and column buckling. Upon completion of the course, students will be able to apply the principles of Solid Mechanics to the analysis of elastic structures under simple and combined loading, use free body diagrams in the analysis of structures, use failure theories to assess safety of design, and effectively communicate the outcomes of analysis and design problems. May not also receive credit for CEEN311. Prerequisites: CEEN241 (C- or better). Co-requisites: MEGN200. 3 hours lecture; 3 semester hours.

MEGN315. DYNAMICS. 3.0 Semester Hrs.
Equivalent with EGGN315.
(I,II,S) Absolute and relative motions. Kinetics, work-energy, impulse-momentum, vibrations. Prerequisites: CEEN241 (C- or better) and MATH225 (C- or better). 3 hours lecture; 3 semester hours.

MEGN330. INTRODUCTION TO BIOMECHANICAL ENGINEERING. 3.0 Semester Hrs.
Equivalent with BELS325,BELS420,EGGN325,EGGN420.
(I) The application of mechanical engineering principles and techniques to the human body presents many unique challenges. The discipline of Biomedical Engineering (more specifically, Biomechanical Engineering) has evolved over the past 50 years to address these challenges. Biomechanical Engineering includes such areas as biomechanics, biomaterials, bioinstrumentation, medical imaging, and rehabilitation. This course is intended to provide an introduction to, and overview of, Biomechanical Engineering and to prepare the student for more advanced Biomechanical coursework. At the end of the semester, students should have a working knowledge of the special considerations necessary to apply various mechanical engineering principles to the human body. Prerequisites: MEGN312 or CEEN311 and PHGN200. Co-requisites: MEGN315. 3 hours lecture; 3 semester hours.

MEGN340. COOPERATIVE EDUCATION. 3.0 Semester Hrs.
Equivalent with EGGN340,EGGN340M,
(I,Ii,S) Supervised, full-time engineering related employment for a continuous six-month period in which specific educational objectives are achieved. Students must meet with the Department Head prior to enrolling to clarify the educational objectives for their individual Co-op program. Prerequisites: Second semester sophomore status and a cumulative grade-point average of at least 2.00. 3 semester hours credit will be granted once toward degree requirements. Credit earned in MEGN340, Cooperative Education, may be used as free elective credit hours if, in the judgment of the Department Head, the required term paper adequately documents the fact that the work experience entailed high-quality application of engineering principles and practice. Applying the credits as free electives requires the student to submit a Declaration of Intent to Request Approval to Apply Co-op Credit toward Graduation Requirements form obtained from the Career Center to the Department Head.

MEGN350. MULTIDISCIPLINARY ENGINEERING LABORATORY II. 1.5 Semester Hr.
Equivalent with EGGN350,
(I, II) (WI) Laboratory experiments integrating electrical circuits, fluid mechanics, stress analysis, and other engineering fundamentals using computer data acquisition and transducers. Fluid mechanics issues like compressible and incompressible fluid flow (mass and volumetric), pressure losses, pump characteristics, pipe networks, turbulent and laminar flow, cavitation, drag, and others are covered. Experimental stress analysis issues like compression and tensile testing, strain gage installation, Young's Modulus, stress vs. strain diagrams, and others are covered. Experimental stress analysis and fluid mechanics are integrated in experiments which merge fluid power of the testing machine with applied stress and displacement of material specimen. Co-requisites: MEGN351 or CEEN310 and CEEN311 or MEGN312. 0.6 hours lecture; 2.7 hours lab; 1.5 semester hours.

MEGN351. FLUID MECHANICS. 3.0 Semester Hrs.
Equivalent with EGGN351,
(I, II) Fluid properties, fluid statics, control-volume analysis, Bernoulli equation, differential analysis and Navier-Stokes equations, dimensional analysis, internal flow, external flow, open-channel flow, and turbomachinery. May not also receive credit for CEEN310 or PEGN251. Prerequisite: CEEN241 (C- or better) or MNGN317 (C- or better). 3 hours lecture; 3 semester hours.

MEGN361. THERMODYNAMICS I. 3.0 Semester Hrs.
Equivalent with EGGN371,
(I, II, S) A comprehensive treatment of thermodynamics from a mechanical engineering point of view. Thermodynamic properties of substances inclusive of phase diagrams, equations of state, internal energy, enthalpy, entropy, and ideal gases. Principles of conservation of mass and energy for steady-state and transient analyses. First and Second Law of thermodynamics, heat engines, and thermodynamic efficiencies. Application of fundamental principles with an emphasis on refrigeration and power cycles. May not also receive credit for CBEN210. Prerequisite: MATH213 (C- or better). 3 hours lecture; 3 semester hours.

MEGN381. MANUFACTURING PROCESSES. 3.0 Semester Hrs.
Equivalent with EGGN390,MEGN380,
(I, II, S) Introduction to a wide variety of manufacturing processes with emphasis on process selection and laboratory measurements of process conditions with product variables. Consideration of relations among material properties, process settings, tooling features and product attributes. Design and implementation of a process for manufacture of a given component. Manual and Automated manufacturing and their implementation in plant layouts. Understanding how to eliminate waste in manufacturing processes and enhance scheduling and satisfying client needs. Quality, tolerances and standards will be discussed along with their importance in a manufacturing setting. Prerequisites: MEGN312 and MTGN202. 3 lecture hours, 3 semester hours.
MEGN391. AUTOMOTIVE DESIGN: SAE COLLEGIATE DESIGN SERIES (FORMULA SAE). 1.0 Semester Hr.
(I, II) This course introduces students to automotive design and fabrication. Students will design, fabricate, test, and analyze a formula style race car for the Formula SAE Collegiate Design Series international competition. Provide engineering students an opportunity to develop engineering skills beyond the classroom in a team oriented, competitive, and hands-on environment. Students will learn about a broad range of automobile design topics to include vehicle dynamics, propulsion, chassis design, electrical systems and aerodynamic devices. Both theoretical and "hands on" skills will be exercised. Additionally, students will learn basic mechanical drawing, analysis and fabrication skills. Special emphasis will be placed on workplace safety, teamwork and peer leadership. Finally, students will gain experience in program management to include budgeting, resource management, scheduling and solving real world "open-ended" problems. Prerequisites: MEGN200. 1 hour lecture, 1 semester hour. Repeatable to 3 hours.

MEGN398. SPECIAL TOPICS IN MECHANICAL ENGINEERING. 1-6 Semester Hr.
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MEGN399. INDEPENDENT STUDY. 1-6 Semester Hr.
(I, II) Individual research or special problem projects supervised by a faculty member, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MEGN408. INTRODUCTION TO SPACE EXPLORATION. 1.0 Semester Hr.
Equivalent with EGGN408.
(I) Overview of extraterrestrial applications of science and engineering by covering all facets of human and robotic space exploration, including its history, current status, and future opportunities in the aerospace and planetary science fields. Subtopics include: the space environment, space transportation systems, destinations (Low-Earth orbit, Moon, Mars, asteroids, other planets), current research, missions, and projects, the international and commercial perspectives, and discussion of potential career opportunities. This seminarstyle class is taught by CSM faculty, engineers and scientists from space agencies and research organizations, aerospace industry experts, and visionaries and entrepreneurs of the private space commerce sector. 1 lecture hour; 1 semester hour.

MEGN412. ADVANCED MECHANICS OF MATERIALS. 3.0 Semester Hrs.
Equivalent with EGGN422.
(I, II) General theories of stress and strain; stress and strain transformations, principal stresses and strains, octahedral shear stresses, Hooke's law for isotropic material, and failure criteria. Introduction to elasticity and to energy methods. Torsion of non-circular and thin-walled members. Unsymmetrical bending and shear-center, curved beams, and beams on elastic foundations. Introduction to plate theory. Thick-walled cylinders and contact stresses. Prerequisite: CEEN311 (C- or better) or MEGN312 (C- or better). 3 hours lecture; 3 semester hours.

MEGN416. ENGINEERING VIBRATION. 3.0 Semester Hrs.
Equivalent with EGGN478.

MEGN424. COMPUTER AIDED ENGINEERING. 3.0 Semester Hrs.
Equivalent with EGGN413.
(I, II, S) This course introduces the student to the concept of computer-aided engineering. The major objective is to provide the student with the necessary background to use the computer as a tool for engineering analysis and design. The Finite Element Analysis (FEA) method and associated computational engineering software have become significant tools in engineering analysis and design. This course is directed to learning the concepts of FEA and its application to civil and mechanical engineering analysis and design. Note that critical evaluation of the results of a FEA using classical methods (from statics and mechanics of materials) and engineering judgment is employed throughout the course. Prerequisite: MEGN312 (C- or better) or CEEN311 (C- or better). 3 hours lecture; 3 semester hours.

MEGN425. ADVANCED COMPUTER AIDED ENGINEERING. 3.0 Semester Hrs.
(I,S) This course studies advanced topics in engineering analysis using the finite element method. The analyses are conducted using commercial FEA software. The advanced topics include: nonlinear large deformations and elasto-plastic behavior, steady and transient heat transfer and thermally induced stresses, mechanical vibrations and transient dynamic phenomena, deformations and stresses in mechanical and structural assemblies, and stress intensity phenomena. Note, the accuracy and validity of FEA results is assessed by comparison with results obtained with exact or approximate analytical methods wherever possible. Prerequisites: MEGN424. 3 hours lecture; 3 semester hours.

MEGN430. MUSCULOSKELETAL BIOMECHANICS. 3.0 Semester Hrs.
Equivalent with BELS425,EGGN425.
(I) This course is intended to provide mechanical engineering students with a second course in musculoskeletal biomechanics. At the end of the semester, students should have in-depth knowledge and understanding necessary to apply mechanical engineering principles such as statics, dynamics, and mechanics of materials to the human body. The course will focus on the biomechanics of injury since understanding injury will require developing an understanding of normal biomechanics. Prerequisite: MEGN315, CEEN311 or MEGN312, MEGN330. 3 hours lecture; 3 semester hours.

MEGN435. MODELING AND SIMULATION OF HUMAN MOVEMENT. 3.0 Semester Hrs.
Equivalent with BELS426,EGGN426.
(I, II) Introduction to modeling and simulation in biomechanics. The course includes a synthesis of musculoskeletal properties and interactions with the environment to construct detailed computer models and simulations. The course will culminate in individual class projects related to each student's individual interests. Prerequisites: MEGN315 and MEGN330. 3 hours lecture; 3 semester hours.
MEGN436. COMPUTATIONAL BIOMECHANICS. 3.0 Semester Hrs.
Equivalent with BELS428,BELS428,EGGN428,
Computational Biomechanics provides an introduction to the application of computer simulation to solve some fundamental problems in biomechanics and bioengineering. Musculoskeletal mechanics, medical image reconstruction, hard and soft tissue modeling, joint mechanics, and inter-subject variability will be considered. An emphasis will be placed on understanding the limitations of the computer model as a predictive tool and the need for rigorous verification and validation of computational techniques. Clinical application of biomechanical modeling tools is highlighted and impact on patient quality of life is demonstrated. Prerequisites: MEGN424, MEGN330. 3 hours lecture, 3 semester hours. Fall odd years.

MEGN441. INTRODUCTION TO ROBOTICS. 3.0 Semester Hrs.
Equivalent with EGGN400,
(I, II) Overview and introduction to the science and engineering of intelligent mobile robotics and robotic manipulators. Covers guidance and force sensing, perception of the environment around a mobile vehicle, reasoning about the environment to identify obstacles and guidance path features and adaptively controlling and monitoring the vehicle health. A lesser emphasis is placed on robot manipulator kinematics, dynamics, and force and tactile sensing. Surveys manipulator and intelligent mobile robotics research and development. Introduces principles and concepts of guidance, position, and force sensing; vision data processing; basic path and trajectory planning algorithms; and force and position control. EENG307 is recommended to be completed before this course. Prerequisites: CSCI261 and EENG281 or EENG282 or PHGN215. 2 hours lecture; 3 hours lab; 3 semester hours.

MEGN450. MULTIDISCIPLINARY ENGINEERING LABORATORY III.
1.0 Semester Hr.
Equivalent with EGGN450,
(I, II) Laboratory experiments integrating electrical circuits, fluid mechanics, stress analysis, and other engineering fundamentals using computer data acquisition and transducers. Students will design experiments to gather data for solving engineering problems. Examples are recommending design improvements to a refrigerator, diagnosing and predicting failures in refrigerators, computer control of a hydraulic fluid power circuit in a fatigue test, analysis of structural failures in an off-road vehicle and redesign, diagnosis and prediction of failures in a motor/generator system. Prerequisites: MEGN350 or EENG382. Co-requisites: EENG307. 3 hours lab; 1 semester hour.

MEGN451. FLUID MECHANICS II. 3.0 Semester Hrs.
Equivalent with EGGN473,
(II) Review of elementary fluid mechanics and engineering, two-dimensional external flows, boundary layers, flow separation; Compressible flow, isentropic flow, normal and oblique shocks, Prandtl-Meyer expansion fans, Fanno and Rayleigh flow; Introduction to flow instabilities (e.g., Kelvin-Helmholtz instability, Raleigh Benard convection). Prerequisite: MEGN351 (C- or better). 3 hours lecture; 3 semester hours.

MEGN461. THERMODYNAMICS II. 3.0 Semester Hrs.
Equivalent with EGGN403,
(I) This course extends the subject matter of Thermodynamics I (MEGN361) to include the study of exergy, ideal gas mixture properties, psychrometrics and humid air processes, chemical reactions, and the 1st, 2nd and 3rd Laws of Thermodynamics as applied to reacting systems. Chemical equilibrium of multi-component systems, and simultaneous chemical reactions of real combustion and reaction processes are studied. Phase equilibrium, ionization, and the thermodynamics of compressible flow (nozzles and shock) are also introduced. Concepts of the above are explored through the analysis of advanced thermodynamic systems, such as cascaded and absorption refrigeration systems, cryogenics, and advanced gas turbine and combined power cycles. Prerequisites: MEGN351 (C- or better), MEGN361 (C- or better). 3 hours lecture; 3 semester hours.

MEGN466. INTRODUCTION TO INTERNAL COMBUSTION ENGINES. 3.0 Semester Hrs.
(II) Introduction to Internal Combustion Engines (ICEs); with a specific focus on Compression Ignition (CI) and Spark Ignition (SI) reciprocating engines. This is an applied thermo science course designed to introduce students to the fundamentals of both 4-stroke and 2-stroke reciprocating engines ranging in size from model airplane engines to large cargo ship engines. Course is designed as a one ? semester course for students without prior experience with IC engines, however, the course will also include advanced engine technologies designed to deliver more horsepower, utilize less fuel, and meet stringent emission regulations. Discussion of advancements in alternative fueled engines will be covered as well. This course also includes an engine laboratory designed to provide hands-on experience and provide further insight into the material covered in the lectures. Prerequisites: MEGN351, MEGN361. Co-requisites: MEGN471. 3 hours lecture; 1.0 hour lab; 3 semester hours.

MEGN467. HVAC AND BUILDING ENERGY SYSTEMS. 3.0 Semester Hrs.
(I) Senior year undergraduate and first year graduate course that covers the fundamentals of building energy systems, heating, ventilation, and air conditioning (HVAC) systems and the use of numerical models for heat and mass transfer to analyze and/or design different building elements. Prerequisites: MEGN351, MEGN361, MEGN471. 3 hours lecture; 3 semester hours.

MEGN469. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.
Equivalent with CBEN469,CHEN469,EGGN469,MTGN469,
(I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials-science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. Prerequisites: MEGN361 or CBEN357 or MTGN351. 3 hours lecture; 3 semester hours.

MEGN471. HEAT TRANSFER. 3.0 Semester Hrs.
Equivalent with EGGN471,
(I, II) Engineering approach to conduction, convection, and radiation, including steady-state conduction, nonsteady-state conduction, internal heat generation conduction in one, two, and three dimensions, and combined conduction and convection. Free and forced convection including laminar and turbulent flow, internal and external flow. Radiation of black and grey surfaces, shape factors and electrical equivalence. Prerequisites: MEGN351 (C- or better), MEGN361 (C- or better), and MATH307 (C- or better). 3 hours lecture; 3 semester hours.
MEGN481. MACHINE DESIGN. 3.0 Semester Hrs.
Equivalent with EGGN411.
(I, II) In this course, students develop their knowledge of machine components and materials for the purpose of efficient and effective mechanical design. Emphasis is placed on developing analytical methods and tools that aid the decision making process. The course focuses on determination of stress, strain, and deflection for static, static multiaxial, impact, dynamic, and dynamic multiaxial loading. Students will learn about fatigue failure in mechanical design and calculate how long mechanical components are expected to last. Specific machine components covered include shafts, springs, gears, fasteners, and bearings. Prerequisites: MEGN315 (C- or better) or PHGN350 (C- or better), and MEGN424 (C- or better). Corequisite: MEGN489. 3 hours lecture; 3 semester hours.

MEGN482. MECHANICAL DESIGN USING GD&T. 3.0 Semester Hrs.
Equivalent with EGGN410.
(I) The mechanical design process can be broadly grouped into three phases: requirements and concept, design and analysis, details and drawing package. In this class students will learn concepts and techniques for the details and drawing package phase of the design process. The details of a design are critical to the success of a design project. The details include selection and implementation of a variety of mechanical components such as fasteners (threaded, keys, retaining rings), bearing and bushings. Fits and tolerances will also be covered. Statistical tolerance analysis will be used to verify that an assembly will fit together and to optimize the design. Mechanical drawings have become sophisticated communication tools that are used throughout the processes of design, manufacturing, and inspection. Mechanical drawings are interpreted either by the ANSI or ISO standard which includes Geometric Dimensioning and Tolerancing (GD&T). In this course the student will learn to create mechanical drawings that communicate all of the necessary information to manufacture the part, inspect the part, and allow the parts to be assembled successfully. Prerequisite: MEGN201. 3 hours lecture, 3 semester hours.

MEGN483. ADDITIVE MANUFACTURING. 3.0 Semester Hrs.
(II) Additive Manufacturing (AM), also known as 3D Printing in the popular press, is an emerging manufacturing technology that will see widespread adoption across a wide range of industries during your career. Subtractive Manufacturing (SM) technologies (CNCs, drill presses, lathes, etc.) have been an industry mainstay for over 100 years. The transition from SM to AM technologies, the blending of SM and AM technologies, and other developments in the manufacturing world has direct impact on how we design and manufacture products. This course will prepare students for the new design and manufacturing environment that AM is unlocking. Prerequisites: MEGN200 and MEGN201 or equivalent project classes. 3 hours lecture; 3 semester hours.

MEGN485. MANUFACTURING OPTIMIZATION WITH NETWORK MODELS. 3.0 Semester Hrs.
Equivalent with EBBN456,
(I) We examine network flow models that arise in manufacturing, energy, mining, transportation and logistics: minimum cost flow models in transportation, shortest path problems in assigning inspection effort on a manufacturing line, and maximum flow models to allocate machine-hours to jobs. We also discuss an algorithm or two applicable to each problem class. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Prerequisites: MATH111. 3 hours lecture; 3 semester hours.

MEGN486. LINEAR OPTIMIZATION. 3.0 Semester Hrs.
(I) This course addresses the formulation of linear programming models, linear programs in two dimensions, standard form, the Simplex method, duality theory, complementary slackness conditions, sensitivity analysis, and multi-objective programming. Applications of linear programming models include, but are not limited to, the areas of manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. Prerequisite: MATH332 or EBBN509. 3 hours lecture; 3 semester hours.

MEGN487. NONLINEAR OPTIMIZATION. 3.0 Semester Hrs.
Equivalent with MEGN587.
(I) This course addresses both unconstrained and constrained nonlinear model formulation and corresponding algorithms (e.g., Gradient Search and Newton’s Method, and Lagrange Multiplier Methods and Reduced Gradient Algorithms, respectively). Applications of state-of-the-art hardware and software will emphasize solving real-world engineering problems in areas such as manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with an algorithm such as MINOS) these optimization problems is introduced. Offered every other year. Prerequisite: MATH111. 3 hours lecture; 3 semester hours.

MEGN488. INTEGER OPTIMIZATION. 3.0 Semester Hrs.
Equivalent with MEGN588.
(I) This course addresses the formulation of integer programming models, the branch-and-bound algorithm, total unimodularity and the ease with which these models are solved, and then suggest methods to increase tractability, including cuts, strong formulations, and decomposition techniques, e.g., Lagrangian relaxation, Benders decomposition. Applications include manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. Prerequisite: MATH111. 3 hours lecture; 3 semester hours.

MEGN489. MACHINE DESIGN LAB. 1.0 Semester Hr.
(I, II) This lab course supports MEGN 481, Machine Design. This lab component includes 2-3 projects in which students work in teams during lab to solve an ill-defined engineering problem. The lab portion of the course hones students’ professional communication via written deliverables intended for the general engineering client audience (professional engineering reports). The lab culminates in an oral presentation and sales pitch to the general engineering client for the purpose of moving forward with the team’s design. Corequisite: MEGN481. 3 hours lab; 1 semester hour.

MEGN493. ENGINEERING DESIGN OPTIMIZATION. 3.0 Semester Hrs.
Equivalent with EBBN493,
(II) The application of gradient, stochastic and heuristic optimization algorithms to linear and nonlinear optimization problems in constrained and unconstrained design spaces. Students will consider problems with continuous, integer and mixed-integer variables, problems with single or multiple objectives and the task modeling design spaces and constraints. Design optimization methods are becoming of increasing importance in engineering design and offer the potential to reduce design cycle times while improving design quality by leveraging simulation and historical design data. Prerequisites: MATH213 and MATH225 (Required), CSCI260 or CSCI261 or other experience with computer programming languages (Suggested). 3 hours lecture; 3 semester hours.
MEGN498. SPECIAL TOPICS IN MECHANICAL ENGINEERING. 1-6
Semester Hr.
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MEGN499. INDEPENDENT STUDY. 1-6 Semester Hr.
(I, II) Individual research or special problem projects supervised by a faculty member, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.