Mechanical Engineering & Materials Science

The Department of Mechanical Engineering & Materials Science (MEMS) offers the Bachelor of Science in Mechanical Engineering (BSME) and the Bachelor of Science in Applied Science (Mechanical Engineering). In addition, minors in aerospace engineering, energy engineering, environmental engineering science, materials science & engineering, nanoscale science & engineering, robotics, mechatronics, and mechanical engineering, and in related scientific and engineering fields, are available to students.

The MEMS curriculum emphasizes the core principles of mechanics (the study of forces, materials and motion) that underlie mechanical engineering. The common curriculum during the student's early academic development encourages breadth of understanding, interdisciplinary thinking and creativity. First-year students, sophomore and early junior years are focused on learning fundamental concepts in statics, dynamics, fluid mechanics and thermodynamics. In the junior and senior years, students choose electives that emphasize their specific interests and prepare them for a particular professional or academic career. The undergraduate curriculum for the BSME degree provides Mechanical Engineering & Materials Science students with a strong base in fundamental mathematics, science and engineering; exposes the students to diverse applications of mechanics and materials; and provides the flexibility to explore creative ideas through undergraduate research and project-based courses.

Mechanical engineering is critical in a variety of important emerging technologies. Mechanical engineers design and develop artificial organs, prosthetic limbs, robotic devices, adaptive materials, efficient propulsion mechanisms, high-performance aerospace structures, and advanced renewable energy systems. The core concepts of mechanics, thermal systems and materials science are at the heart of these technologies.

Mission Statement

The Mechanical Engineering & Materials Science faculty is committed to providing the best possible undergraduate mechanical engineering education possible. We strive to nurture the intellectual, professional and personal development of the students, to continually improve the curriculum, to be professionally current, and to maintain state-of-the-art facilities for teaching and learning.

We seek to prepare students for professional practice with a scientifically grounded foundation in the major topics of mechanical engineering: solid mechanics, mechanical design, dynamics and vibrations, systems control, fluid mechanics, thermal science and materials science.

Bachelor of Science in Mechanical Engineering

The mission of the undergraduate program in mechanical engineering is to prepare students within the broad and evolving field of mechanical engineering. The program instills in students a capacity for creative design through critical and analytical thought. The BSME is the first step toward a career in industry, academia or government; it encourages a commitment to independent, lifelong learning and professional development. In addition to their technical studies, students learn to communicate their ideas clearly and to conduct themselves in an ethical and socially responsible manner.

The curriculum is a four-year program leading to the first professional degree, Bachelor of Science in Mechanical Engineering, which is accredited by the Engineering Accreditation Commission of ABET (http://www.abet.org). The curriculum prepares the student for professional practice or postgraduate education in a broad spectrum of mechanical and other engineering or professional fields. The curriculum provides critical knowledge in solid mechanics, fluid mechanics, thermodynamics and heat transfer, materials science, dynamics and control, and design. The curriculum has 34 units of mathematics and basic sciences, 58 units of engineering topics, and 28 units of general education for a total degree requirement of 120 units. The general education includes 18 units of social science and humanities.

Core courses must be taken for credit (grade). The social science and humanities courses may be taken pass/fail. The undergraduate program provides the necessary foundations in these areas and the opportunity to specialize in topics of particular interest. Specialization is accomplished by judicious choice of engineering electives taken in 300-, 400- or 500-level courses approved by the student's adviser. At the end of the four-year program, the student is ready to go on to graduate education, research or professional practice.

Program Educational Objectives

Program educational objectives are broad statements that describe what graduates are expected to attain within a few years of graduation. These objectives are based on the needs of the program's constituencies.

Within a few years from graduation, graduates of the Bachelor of Science in Mechanical Engineering program are expected to:

- Engage in professional practice and/or advanced study
- Further their knowledge and skills through education and/or professional development
• Serve society by using and communicating their knowledge and values

**Student Outcomes**

Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge and behaviors that students acquire as they progress through the program.

The Student Outcomes are:

(a) An ability to apply knowledge of mathematics, science and engineering

(b) An ability to design and conduct experiments, as well as to analyze and interpret data

(c) An ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability

(d) An ability to function on multidisciplinary teams

(e) An ability to identify, formulate and solve engineering problems

(f) An understanding of professional and ethical responsibility

(g) An ability to communicate effectively

(h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context

(i) A recognition of the need for, and an ability to engage in, lifelong learning

(j) A knowledge of contemporary issues

(k) An ability to use the techniques, skills and modern engineering tools necessary for engineering practice

**Bachelor of Science in Applied Science (Mechanical Engineering)**

The Bachelor of Science in Applied Science (Mechanical Engineering) degree program will offer a degree path for students to gain technical knowledge in mechanical engineering with more course selection flexibility. Students who do not desire to become licensed engineers, but seek to acquire analytical engineering thinking skills, may choose to pursue this program. The added degree flexibility will allow these students to pursue additional second majors and/or minors and increase their ability to participate in programs such as study abroad.

**Pre-Medical Option**

Research and practice in the biological and medical sciences increasingly involves advanced technology, including mechanical engineering. For those interested in a career in medicine, the pre-medical option in Mechanical Engineering & Materials Science makes it possible to obtain an accredited Bachelor of Science and simultaneously meet the admission requirements of most medical and dental schools. The program also provides a foundation for graduate study and research in biomedical engineering. The essential requirements of the pre-medical option are two semesters of general biology (Biol 2960, Biol 2970); two semesters of general chemistry with a laboratory, and two semesters of organic chemistry with a laboratory (Chem 111A, Chem 151, Chem 112A, Chem 152, Chem 261, Chem 262); and one semester of biochemistry (Biol 451). Psychology (Psych 100B) and sociology are highly recommended. One semester of organic chemistry may be counted as an upper-level MEMS elective; the student must take 6 units of other upper-level mechanical engineering electives to complete the 9-unit requirement. The pre-medical option is easier for those who have a high school background in biology or, by reason of advanced placement in math/science, have reduced requirements in the Common Studies portion of the curriculum. For additional information on the pre-medical option, please refer to the pre-medical education section located in the introduction to the School of Engineering & Applied Science’s Undergraduate Programs (http://bulletin.wustl.edu/undergrad/engineering) or contact the pre-health adviser, Ron Laue (ron.laue@wustl.edu), for additional information.

**Graduate Programs**

The department offers programs for graduate study at both the master’s and doctoral levels. All programs are designed to direct advanced study into an area of specialization and original research that includes recent scientific and technological advances.

A graduate degree can provide significant advantages and rewards to a mechanical engineer, including increased income and a wider range of career options. Graduate programs include professional, course-option master’s degrees (MS and MEng) and research-based master’s (MS) or doctoral (PhD) degrees. The undergraduate curriculum provides an excellent foundation for graduate study, and a careful selection of electives in the third and fourth years can facilitate the transition to graduate work. The master’s degrees can be pursued on a part-time or full-time basis, while PhD degrees are typically pursued by full-time students.

**Website:** https://mems.wustl.edu

**Faculty**

**Chair**

Philip V. Bayly (https://engineering.wustl.edu/Profiles/Pages/Philip-Bayly.aspx)

Lilyan and E. Lisle Hughes Professor of Mechanical Engineering

PhD, Duke University

Nonlinear dynamics, vibrations, biomechanics
Associate Chairs

Katharine M. Flores (Materials Science) (https://engineering.wustl.edu/Profiles/Pages/Kathy-Flores.aspx)
PhD, Stanford University
Mechanical behavior of structural materials

David A. Peters (Mechanical Engineering) (https://mems.wustl.edu/faculty/Pages/default.aspx?bio=92)
McDonnell Douglas Professor of Engineering
PhD, Stanford University
Aeroelasticity, vibrations, helicopter dynamics

Endowed Professors

Ramesh K. Agarwal (https://engineering.wustl.edu/Profiles/Pages/Ramesh-Agarwal.aspx)
William Palm Professor of Engineering
PhD, Stanford University
Computational fluid dynamics and computational physics

Mark J. Jakieła (https://engineering.wustl.edu/Profiles/Pages/Mark-Jakieła.aspx)
Lee Hunter Professor of Mechanical Design
PhD, University of Michigan
Mechanical design, design for manufacturing, optimization, evolutionary computation

Shankar M.L. Sastry (https://engineering.wustl.edu/Profiles/Pages/Shankar-Sastry.aspx)
Christopher I. Byrnes Professor of Engineering
PhD, University of Toronto
Materials science, physical metallurgy

Professor

Guy M. Genin (https://engineering.wustl.edu/Profiles/Pages/Guy-Genin.aspx)
PhD, Harvard University
Solid mechanics, fracture mechanics

Associate Professors

Srikanth Singamaneni (https://engineering.wustl.edu/Profiles/Pages/Srikanth-Singamaneni.aspx)
PhD, Georgia Institute of Technology
Microstructures of cross-linked polymers

Jessica E. Wagenseil (https://engineering.wustl.edu/Profiles/Pages/Jessica-Wagenseil.aspx)
DSc, Washington University
Arterial biomechanics

Assistant Professors

Damena D. Agonafer (https://mems.wustl.edu/faculty/Pages/default.aspx?bio=110)
PhD, University of Illinois at Urbana-Champaign
Computational fluid dynamics and computational physics

Parag Banerjee (https://engineering.wustl.edu/Profiles/Pages/Parag-Banerjee.aspx)
PhD, University of Maryland
Materials sciences and engineering, nanostructured materials, materials synthesis, and novel devices for storing and harvesting energy

Spencer P. Lake (https://engineering.wustl.edu/Profiles/Pages/Spencer-Lake.aspx)
PhD, University of Pennsylvania
Soft tissue biomechanics

J. Mark Meacham (https://engineering.wustl.edu/Profiles/Pages/Mark-Meacham.aspx)
PhD, Georgia Institute of Technology
Micro-/Nanotechnologies for thermal systems and the life sciences

Rohan Mishra (https://engineering.wustl.edu/Profiles/Pages/Rohan-Mishra.aspx)
PhD, Ohio State University
Computational materials science

Amit Pathak (https://engineering.wustl.edu/Profiles/Pages/Amit-Pathak.aspx)
PhD, University of California, Santa Barbara
Cellular biomechanics

Patricia B. Weisensee (https://mems.wustl.edu/faculty/Pages/default.aspx?bio=112)
PhD, University of Illinois at Urbana-Champaign
Thermal fluids

Professors of the Practice

Harold J. Brandon (https://mems.wustl.edu/faculty/Pages/Harold-Brandon.aspx)
DSc, Washington University
Energetics, thermal systems

Swami Karunamoorthy (https://mems.wustl.edu/faculty/Pages/Swami-Karunamoorthy.aspx)
DSc, Washington University
Helicopter dynamics, engineering education

Joint Faculty

Richard L. Axelbaum (EECE) (https://engineering.wustl.edu/Profiles/Pages/Richard-Axelbaum.aspx)
The Stifel & Quinette Jens Professor of Environmental Engineering Science
PhD, University of California, Davis
Combustion, nanomaterials

Elliot L. Elson (Biochemistry and Molecular Biophysics) (http://bmbweb.wustl.edu/faculty/faculty/elliot-elson)
Professor Emeritus of Biochemistry & Molecular Biophysics
PhD, Stanford University
Biochemistry and molecular biophysics
Michael D. Harris (Physical Therapy, Orthopaedic Surgery and MEMS) (https://pt.wustl.edu/faculty-staff/faculty/mike-harris-phd)
PhD, University of Utah
Whole body and joint-level orthopaedic biomechanics

Kenneth F. Kelton (Physics) (http://www.physics.wustl.edu/people/kelton_kenneth-f)
Arthur Holly Compton Professor of Arts & Sciences
PhD, Harvard University
Study and production of titanium-based quasicrystals and related phases

MD, University of Pennsylvania School of Medicine
Neurological surgery

Lori Setton (BME) (https://bme.wustl.edu/faculty/Pages/faculty.aspx?bio=105)
Lucy and Stanley Lopata Distinguished Professor of Biomedical Engineering
PhD, Columbia University
Biomechanics for local drug delivery: tissue regenerations specific to the knee joints and spine

Matthew J. Silva (Orthopaedic Surgery) (http://www.orthoresearch.wustl.edu/content/Laboratories/2963/Matthew-Silva/Silva-Lab/Overview.aspx)
Julia and Walter R. Peterson Orthopaedic Research Professor
PhD, Massachusetts Institute of Technology
Biomechanics of age-related fractures and osteoporosis

Simon Tang (Orthopaedic Surgery, BME) (http://www.orthoresearch.wustl.edu/content/Laboratories/3043/Simon-Tang/Tang-Lab/Overview.aspx)
PhD, Rensselaer Polytechnic Institute
Biological mechanisms

Senior Professors

Phillip L. Gould
PhD, Northwestern University
Structural analysis and design, shell analysis and design, biomechanical engineering

Kenneth L. Jerina
DSc, Washington University
Materials, design, solid mechanics, fatigue and fracture

Salvatore P. Sutera
PhD, California Institute of Technology
Viscous flow, biorheology

Barna A. Szabo
PhD, State University of New York–Buffalo
Numerical simulation of mechanical systems, finite-element methods

Lecturers

Emily J. Boyd
PhD, University of Texas at Austin
Thermofluids

J. Jackson Potter
PhD, Georgia Institute of Technology
Senior design

H. Shaun Sellers
PhD, Johns Hopkins University
Mechanics and materials

Louis G. Woodhams
BS, University of Missouri-St. Louis
Computer-aided design

Senior Research Associate

Ruth J. Okamoto
DSc, Washington University
Biomechanics, solid mechanics

Research Assistant Professor

Anupriya Agrawal
PhD, Ohio State University
Materials science

Adjunct Instructors

Ricardo L. Actis
DSc, Washington University
Finite element analysis, numerical simulation, aircraft structures

Robert G. Becnel
MS, Washington University
FE Review

John D. Biggs
MEng, Washington University
Thermal science

Andrew W. Cary
PhD, University of Michigan
Computational fluid dynamics

Dan E. Driemeyer
PhD, Washington University
Propulsion, thermodynamics, fluids

John M. Griffith
BS, Washington University
Manufacturing

Hanford Gross
BS, Washington University
Engineering project management
Bulletin 2017-18  
Mechanical Engineering & Materials Science  
(11/28/17)

Jason Hawks  
MS, Washington University  
Structural analysis

Richard R. Janis  
MS, Washington University  
Building environmental systems

Rigoberto Perez  
PhD, Purdue University  
Fatigue and fracture

Dale M. Pitt  
DSc, Washington University  
Aeroelasticity

Gary D. Renieri  
PhD, Virginia Polytechnic Institute and State University  
Structural applications, composite materials

Hiroshi Tada  
PhD, Lehigh University  
Solid mechanics

Matthew J. Watkins  
MS, Washington University  
Finite elements

Michael C. Wendl  
DSc, Washington University  
Mathematical theory and computational methods in biology and engineering

Laboratory and Design Specialist

Mary K. Malast  
DSc, Washington University  
Materials science

Professor Emeritus

Wallace B. Diboll Jr.  
MSME, Rensselaer Polytechnic Institute  
Dynamics, vibrations, engineering design

Majors

Please refer to the sections below for information about the Bachelor of Science in Mechanical Engineering (p. 5) and the Bachelor of Science in Applied Science (Mechanical Engineering) (p. 6).

Bachelor of Science in Mechanical Engineering

The Department of Mechanical Engineering & Materials Science offers a four-year curriculum leading to a professional baccalaureate degree, a Bachelor of Science in Mechanical Engineering (BSME). This degree is designed to prepare students for graduate school, a professional graduate program or industry. The program is accredited by the Engineering Accreditation Commission of ABET (http://www.abet.org). The BSME curriculum is structured around a basic core of 58 units and a complementary mechanical engineering program of at least 62 units to complete the degree requirement of a total of 120 units.

Basic Core Courses

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Humanities and social science (refer to SEAS degree requirements for details)</td>
<td>18</td>
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<tr>
<td>Engr 310</td>
<td>Technical Writing</td>
<td>3</td>
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<td>Total Units</td>
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Mathematics and Computation

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<tr>
<th>Code</th>
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<tbody>
<tr>
<td>Math 132</td>
<td>Calculus II</td>
<td>3</td>
</tr>
<tr>
<td>Math 233</td>
<td>Calculus III</td>
<td>3</td>
</tr>
<tr>
<td>Math 217</td>
<td>Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>ESE 318</td>
<td>Engineering Mathematics A</td>
<td>3</td>
</tr>
<tr>
<td>ESE 319</td>
<td>Engineering Mathematics B</td>
<td>3</td>
</tr>
<tr>
<td>ESE 326</td>
<td>Probability and Statistics for Engineering</td>
<td>3</td>
</tr>
<tr>
<td>CSE 131</td>
<td>Computer Science I</td>
<td>3</td>
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<tr>
<td>Total Units</td>
<td></td>
<td>21</td>
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Physical Sciences

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<tr>
<th>Code</th>
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<tbody>
<tr>
<td>Chem 111A</td>
<td>General Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>Chem 151</td>
<td>General Chemistry Laboratory I</td>
<td>2</td>
</tr>
<tr>
<td>Physics 117A</td>
<td>General Physics I</td>
<td>4</td>
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<tr>
<td>or Physics 197</td>
<td>Physics I</td>
<td></td>
</tr>
<tr>
<td>Physics 118A</td>
<td>General Physics II</td>
<td>4</td>
</tr>
<tr>
<td>or Physics 198</td>
<td>Physics II</td>
<td></td>
</tr>
<tr>
<td>Physical or Life Science (200-level or above natural science in Biology, Chemistry, Physics, Earth and Planetary Science, or Environmental Studies)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Total Units</td>
<td></td>
<td>16</td>
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</table>

Mechanical Engineering Courses

<table>
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<tr>
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<tbody>
<tr>
<td>MEMS 202</td>
<td>Computer-Aided Design</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 205</td>
<td>Mechanics and Materials Science Laboratory</td>
<td>2</td>
</tr>
<tr>
<td>MEMS 253</td>
<td>Engineering Mechanics I</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 255</td>
<td>Engineering Mechanics II</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 301</td>
<td>Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 305</td>
<td>Fluid Mechanics and Heat Transfer Laboratory</td>
<td>2</td>
</tr>
</tbody>
</table>
MEMS 3110 Machine Elements 3
MEMS 3410 Fluid Mechanics 3
MEMS 3420 Heat Transfer 3
MEMS 350 Engineering Mechanics III 3
MEMS 3610 Materials Science 3
MEMS 405 Vibrations and Machine Elements Laboratory 2
MEMS 411 Mechanical Engineering Design Project 3
MEMS 412 Design of Thermal Systems 3
MEMS 4301 Modeling, Simulation and Control 3
MEMS 4310 Dynamics and Vibrations 3
ESE 230 Introduction to Electrical and Electronic Circuits 4
MEMS senior electives 9
Other courses 4
Total Units 62

Optional Courses:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
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<tbody>
<tr>
<td>MEMS 1001</td>
<td>Machine Shop Practicum</td>
<td>1</td>
</tr>
<tr>
<td>MEMS 1003</td>
<td>Mechanical Engineering Design and Build</td>
<td>1</td>
</tr>
<tr>
<td>MEMS 101</td>
<td>Introduction to Mechanical Engineering and Mechanical Design</td>
<td>2</td>
</tr>
</tbody>
</table>

Bachelor of Science in Applied Science (Mechanical Engineering)

The Bachelor of Science in Applied Science (Mechanical Engineering) program provides substantive and consistent training in mechanical engineering with maximum flexibility. This program is advantageous if a student wishes to pursue a more flexible program than the accredited BSME degree program. It is especially suitable for a double major in combination with mathematics, physics, chemistry, biology, economics or another engineering discipline. The program can be planned to provide a background for graduate work in biological, medical or management fields. The BS in Applied Science is a nonprofessional degree and is not accredited by the Engineering Accreditation Commission of ABET (http://www.abet.org).

The degree requirements include the residency and general requirements of the university and the school. The Bachelor of Science in Applied Science (Mechanical Engineering) degree requirements are:

- Complete a total of at least 120 applicable units
- Complete a minimum of 60 units at Washington University
- Complete at least 42 units at the 300 level or higher
- Complete at least 48 units in mathematics, natural science and engineering
- Complete at least 30 units of mechanical engineering (MEMS) courses
- Satisfy the SEAS English composition requirement
- Satisfy the SEAS humanities and social science requirement
- Satisfy the residency requirement of 30 units of 200-level or higher engineering courses
- Earn at least a 2.0 cumulative GPA in all applicable courses taken at Washington University
- Earn at least a 2.0 cumulative GPA in engineering courses

Minors

Please refer to the sections below for information about the minors in aerospace engineering (p. 6), energy engineering (p. 7), environmental engineering science (p. 7), materials science & engineering (p. 7), nanoscale science & engineering (p. 9), robotics (p. 9), mechatronics (p. 9), and mechanical engineering (p. 10).

The Minor in Aerospace Engineering

Whether students are intent on a career in aviation, or simply enthusiastic about space and flight, a minor in aerospace engineering can satisfy their scientific curiosity, prepare them for a job, or uncover opportunities for technical contributions. The minor in aerospace engineering is available to all undergraduates but is most attractive to those pursuing a degree in mechanical engineering. The minor in aerospace engineering requires a minimum of 15 units of courses selected from the list below; it is possible to earn the minor without increasing the number of units (120) required for the BSME.

Aerospace engineering deals with the analysis, design and performance of flight vehicles such as transport and military aircraft, helicopters, missiles and launch vehicles, and spacecraft. Students learn about aerospace engineering by taking courses in aerodynamics, aircraft flight dynamics and control, aerospace propulsion, aerospace structures and aerospace vehicle design. Students also may have the opportunity to gain experience in aerospace engineering design through collaborative programs with local companies such as Boeing. Aerospace engineers from industry teach courses as adjunct instructors at Washington University, and many Washington University regular faculty members have extensive aerospace industry experience.

Units required: 15

Required courses:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
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<tbody>
<tr>
<td>MEMS 4301</td>
<td>Modeling, Simulation and Control</td>
<td>3</td>
</tr>
<tr>
<td>ESE 441</td>
<td>Control Systems</td>
<td></td>
</tr>
</tbody>
</table>
The Minor in Materials Science & Engineering

Materials science and engineering (MSE) is an interdisciplinary field that applies the fundamental knowledge of the physical sciences to create engineering innovations. In general, “engineering” implies actively designing a system for a given application; MSE enables the design of systems from the atoms up. MSE focuses on the interrelationship between a material's structure, from the subatomic-to the macro-scale, and the properties or behaviors that the material exhibits. Materials synthesis and processing techniques enable engineers to control and change the material structure in order to obtain the desired properties. Understanding the structure-properties-processing relationship requires a fundamental understanding of the underlying chemistry and physics, and is key to obtaining materials with the desired performance for engineering applications in a wide variety of fields, from computing to medicine to energy.

The minor in MSE builds upon the fundamental insights into material structure and properties gained through required introductory courses in chemistry and materials science. Students then select at least two courses from specialization "pick lists" to gain depth in a particular application area. A free elective provides the opportunity to gain additional depth in the fundamentals or exposure to another application area. Students will be approved for the minor after discussing appropriate course selection with the adviser for the minor. Some courses have prerequisites.

Requirements for the minor in MSE:

Units required: 17

<table>
<thead>
<tr>
<th>Courses</th>
<th>Units</th>
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<tbody>
<tr>
<td>3 required courses</td>
<td>8</td>
</tr>
<tr>
<td>2 courses from specialization &quot;pick lists&quot;</td>
<td>6</td>
</tr>
<tr>
<td>1 free elective</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
</tr>
</tbody>
</table>

Required courses: 1

The Minor in Environmental Engineering Science

The minor in environmental engineering science may be earned by students receiving any of the Bachelor of Science degrees offered by the School of Engineering & Applied Science or the Environmental Studies degree or the Earth and Planetary Sciences degree offered by the College of Arts & Sciences. The 21-22 unit program prepares a graduate to seek an entry-level position as an environmental engineer, scientist or analyst. The minor also provides a solid foundation for undertaking graduate study in environmental engineering. The detailed requirements for the minor can be found on the minor in environmental engineering science (http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/#minors) section of this Bulletin. Questions regarding the minor should be directed to a member of the committee for the environmental engineering minor: Professor Pratim Biswas (https://engineering.wustl.edu/Profiles/Pages/Pratim-Biswas.aspx) or Professor Jay Turner (https://engineering.wustl.edu/Profiles/Pages/Jay-Turner.aspx) (EECE).

The Minor in Energy Engineering

This minor will provide students with course work that will enhance their background, knowledge and skills in the topical area of energy engineering. The minor covers classes in several fields of science and engineering, encompassing the Department of Energy, Environmental & Chemical Engineering; the Department of Electrical & Systems Engineering; and the Department of Mechanical Engineering & Materials Science. A minor in energy engineering requires the completion of 18 units. It is open to undergraduate students pursuing an engineering major, students from the sciences (biology, chemistry, physics) in Arts & Sciences, and students pursuing the environmental studies major. The detailed requirements for the minor can be found on the minor in energy engineering (http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/#minors) section of this Bulletin. Questions regarding the minor should be directed to a member of the committee for the energy engineering minor: Professor Pratim Biswas (https://engineering.wustl.edu/Profiles/Pages/Pratim-Biswas.aspx) (EECE), Professor Hiro Mukai (https://engineering.wustl.edu/Profiles/Pages/Hiro-Mukai.aspx) (ESE) or Professor David Peters (https://engineering.wustl.edu/Profiles/Pages/David-Peters.aspx) (MEMS).

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<tr>
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<th>Units</th>
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<tbody>
<tr>
<td>MEMS 5701</td>
<td>Aerospace Propulsion</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5704</td>
<td>Aircraft Structures</td>
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</tbody>
</table>

Electives: (3-6 units)

Any course from the aerospace MS concentration list (https://mems.wustl.edu/graduate/programs/Pages/MS-In-Aerospace-Engineering.aspx) (found on the MS in Aerospace Engineering webpage) can be used as an aerospace minor elective.

To find out more about this minor, contact the department chair or the adviser for the minor in aerospace engineering or visit the minor webpage (http://mems.wustl.edu/undergraduate/programs/Pages/minors.aspx#aerospace).
### Code | Title | Units
--- | --- | ---
Chem 111A | General Chemistry I | 3
Chem 151 | General Chemistry Laboratory I | 2
MEMS 3610 | Materials Science | 3
or EECE 305 | Materials Science | 3

Total Units 8

1 Students majoring in geology, geophysics, geochemistry, or environmental earth science may substitute EPSc 352 Earth Materials, for the required combination of Chem 111A and Chem 151. In this case, EPSc 352 may not be used to fulfill the specialization pick list or free elective requirements.

**Specialization "pick lists":**

Students should select at least 2 courses from any one of the following categories.

#### Structural Materials:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMS 3601</td>
<td>Materials Engineering</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5506</td>
<td>Experimental Methods in Solid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5507</td>
<td>Fatigue and Fracture Analysis</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5560/ BME 4904</td>
<td>Interfaces and Attachments in Natural and Engineered Structures</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5601</td>
<td>Mechanical Behavior of Materials</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5602</td>
<td>Non-metallics</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5605</td>
<td>Mechanical Behavior of Composites</td>
<td>3</td>
</tr>
</tbody>
</table>

#### Electronic/Optical Materials:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem 542</td>
<td>Special Topics in Inorganic Chemistry (The Chemistry of Energy Storage)</td>
<td>3</td>
</tr>
<tr>
<td>Chem 543</td>
<td>Physical Properties of Quantum Nanostructures</td>
<td>3</td>
</tr>
<tr>
<td>ESE 336</td>
<td>Principles of Electronic Devices</td>
<td>3</td>
</tr>
<tr>
<td>ESE 531</td>
<td>Nano and Micro Photonics</td>
<td>3</td>
</tr>
<tr>
<td>ESE 536</td>
<td>Introduction to Quantum Optics</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 463</td>
<td>Nanotechnology Concepts and Applications</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5609</td>
<td>Electronic Materials Processing</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5611/ CSE 506M/ EECE 595</td>
<td>Principles and Methods of Micro and Nanofabrication</td>
<td>3</td>
</tr>
<tr>
<td>Physics 472</td>
<td>Solid State Physics</td>
<td>3</td>
</tr>
</tbody>
</table>

**Materials for Energy and Environmental Technologies:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem 542</td>
<td>Special Topics in Inorganic Chemistry (The Chemistry of Energy Storage)</td>
<td>3</td>
</tr>
<tr>
<td>EECE 504</td>
<td>Aerosol Science and Technology</td>
<td>3</td>
</tr>
<tr>
<td>EECE 505</td>
<td>Aquatic Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>EECE 571</td>
<td>Industrial and Environmental Catalysis</td>
<td>3</td>
</tr>
</tbody>
</table>

**Natural Materials:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPSc 336</td>
<td>Minerals and Rocks in the Environment</td>
<td>3</td>
</tr>
<tr>
<td>EPSc 352</td>
<td>Earth Materials</td>
<td>5</td>
</tr>
<tr>
<td>EECE 571</td>
<td>Industrial and Environmental Catalysis</td>
<td>3</td>
</tr>
</tbody>
</table>

**Free electives:**

To complete the minor, students may select one additional course from the categories above, or from the list of courses below.

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chem 465</td>
<td>Solid-State and Materials Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>EECE 418</td>
<td>Principles of Surface and Colloid Science</td>
<td>3</td>
</tr>
<tr>
<td>EECE 420</td>
<td>Properties of Materials</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 4101</td>
<td>Manufacturing Processes</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5102</td>
<td>Materials Selection in Design</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5603</td>
<td>Materials Characterization Techniques I</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5604</td>
<td>Materials Characterization Techniques II</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5610</td>
<td>Quantitative Materials Science and Engineering</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5612</td>
<td>Atomistic Modeling of Materials</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5801</td>
<td>Micro-Electro-Mechanical Systems I</td>
<td>3</td>
</tr>
<tr>
<td>Physics 217</td>
<td>Introduction to Quantum Physics</td>
<td>3</td>
</tr>
<tr>
<td>Physics 318</td>
<td>Introduction to Quantum Physics II</td>
<td>3</td>
</tr>
<tr>
<td>Physics 537</td>
<td>Kinetics of Materials</td>
<td>3</td>
</tr>
</tbody>
</table>

BME 461 | Protein Structure and Dynamics | 3
BME 523 | Biomedical Science | 3
The Minor in Nanoscale Science & Engineering

Nanotechnology deals with materials, structures or devices, one of whose dimensions are in the 1 to 100 nm length scale. These entities have properties (physical, chemical or biological) that are very different from their bulk counterparts and can be tuned to obtain novel and desired functionalities. The goal of this minor is to enhance the background, knowledge and skills in the topical area of nanotechnology. The minor covers classes in several fields of science and engineering, encompassing all the departments in the School of Engineering & Applied Science and several in the School of Arts & Sciences. It is open to any undergraduate student pursuing an Engineering or Arts & Sciences (chemistry, physics, biology, environmental studies) major. The departments of Mechanical Engineering & Materials Science; Energy, Environmental & Chemical Engineering; and Electrical & Systems Engineering sponsor the minor.

For more information and requirements, contact a member of the Committee to Oversee the Nanoscale Science Minor: Rohan Mishra (MEMS, Coordinator), Pratim Biswas (EECE), Jung-Tsung Shen (ESE), or visit the minor in nanoscale science section of this Bulletin.

The Minor in Robotics

Robotic systems have wide applications in modern technology and manufacturing. Robots can vary in complexity and use, from microrobots for surgical procedures to moderate-size robots common in manufacturing and undersea exploration to macrorobots used for disposal of nuclear wastes and as arms on space-station modules. The program designed for a minor in robotics provides a fundamental understanding of robotic operation and preliminary training in design and use of robots.

Units required: 18

Prerequisites:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math 217</td>
<td>Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>Physics 117A</td>
<td>General Physics I</td>
<td>4</td>
</tr>
<tr>
<td>or Physics 197</td>
<td>Physics I</td>
<td></td>
</tr>
<tr>
<td>Physics 118A</td>
<td>General Physics II</td>
<td>4</td>
</tr>
<tr>
<td>or Physics 198</td>
<td>Physics II</td>
<td></td>
</tr>
<tr>
<td>CSE 131</td>
<td>Computer Science I</td>
<td>3</td>
</tr>
</tbody>
</table>

Required courses:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMS 255</td>
<td>Engineering Mechanics II</td>
<td>3</td>
</tr>
<tr>
<td>ESE 351</td>
<td>Signals and Systems</td>
<td>3</td>
</tr>
<tr>
<td>or MEMS 4310</td>
<td>Dynamics and Vibrations</td>
<td></td>
</tr>
<tr>
<td>ESE 446</td>
<td>Robotics: Dynamics and Control</td>
<td>3</td>
</tr>
<tr>
<td>ESE 447</td>
<td>Robotics Laboratory</td>
<td>3</td>
</tr>
</tbody>
</table>

Total Units 12

Plus two courses chosen with the approval of the director of the program for a minor in robotics. Suggested courses are:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSE 417T</td>
<td>Introduction to Machine Learning</td>
<td>3</td>
</tr>
<tr>
<td>CSE 452A</td>
<td>Computer Graphics</td>
<td>3</td>
</tr>
<tr>
<td>CSE 546T</td>
<td>Computational Geometry</td>
<td>3</td>
</tr>
<tr>
<td>ESE 407</td>
<td>Analysis and Simulation of Discrete Event Systems</td>
<td>3</td>
</tr>
<tr>
<td>ESE 435</td>
<td>Electrical Energy Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ESE 441</td>
<td>Control Systems</td>
<td>3</td>
</tr>
<tr>
<td>or MEMS 4301</td>
<td>Modeling, Simulation and Control</td>
<td></td>
</tr>
<tr>
<td>MEMS 3110</td>
<td>Machine Elements</td>
<td>3</td>
</tr>
</tbody>
</table>

To find out more about this minor, contact the director (Heinz Schaettler) of the program.

The Minor in Mechatronics (ESE)

(Program Director: Heinz Schaettler)

Advancements in power electronics, electronic sensors, and computer hardware and software have led to an expanding role for “smart” systems, which combine electronic and mechanical components. Automotive examples illustrate this point. The replacement of carburetors by fuel injection systems is almost universal, and hybrid/electric cars are replacing traditional automobiles. Not only are auxiliary devices such as fuel pumps, air bags and air-conditioner compressors driven by electric motors controlled by microprocessors, but fundamental components such as intake and outtake valves soon will be driven in this way. The internal combustion engine itself may be replaced by fuel cells and motors. Medical devices, micro-electromechanical systems, robots, fly-by-wire aircraft and wind turbines also all rely on electronic sensing of mechanical parameters and actuation of motion. These examples suggest strongly that engineers who are adept in the design, analysis and simulation of electromechanical systems will be in demand. The minor in mechatronics is created to encourage our students to study this important subject and provide recognition to those who do so.
This program is primarily designed for students in the ESE and MEMS departments and has been approved by the two departments. It is available for others as well.

The proposed minor program consists of four required courses, two electives and one prerequisite:

**Four required courses:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMS 255</td>
<td>Engineering Mechanics II (Dynamics)</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 411</td>
<td>Mechanical Engineering Design Project (Mechtronics project)</td>
<td>3</td>
</tr>
<tr>
<td>ESE 444</td>
<td>Sensors and Actuators</td>
<td>3</td>
</tr>
<tr>
<td>ESE 446</td>
<td>Robotics: Dynamics and Control</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total Units</strong></td>
<td></td>
<td><strong>12</strong></td>
</tr>
</tbody>
</table>

**Two electives from the following:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMS 4301</td>
<td>Modeling, Simulation and Control</td>
<td>3</td>
</tr>
<tr>
<td>or ESE 441</td>
<td>Control Systems</td>
<td></td>
</tr>
<tr>
<td>MEMS 4310</td>
<td>Dynamics and Vibrations</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 5101</td>
<td>Analysis and Design of Fluid-Power Systems</td>
<td>3</td>
</tr>
<tr>
<td>ESE 337</td>
<td>Electronic Devices and Circuits</td>
<td>3</td>
</tr>
<tr>
<td>ESE 482</td>
<td>Digital Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>CSE 467S</td>
<td>Embedded Computing Systems</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total Units</strong></td>
<td></td>
<td><strong>12</strong></td>
</tr>
</tbody>
</table>

**Prerequisite:**

Basic programming course: CSE 131 Computer Science I

Visit the ESE website (http://ese.wustl.edu) for more information.

### The Minor in Mechanical Engineering

The minor in mechanical engineering complements studies in a field related to mechanical engineering, such as biomedical engineering, electrical engineering, physics, chemistry or architecture. The minor is intended to provide students with a credential that could enhance their opportunities for employment or graduate study. Completion of the minor demonstrates that the student has pursued a structured program approved by the faculty of the Department of Mechanical Engineering & Materials Science.

Students pursuing the minor in mechanical engineering must complete a total of 18 units of course work as described below. Courses selected for the minor program may count toward program requirements of the student's major. The subjects selected for a minor in mechanical engineering are expected to constitute a coherent program within the field of mechanical engineering. Courses taken under the pass/fail grading option cannot be used for a minor program.

**Required courses:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMS 253</td>
<td>Engineering Mechanics I</td>
<td>3</td>
</tr>
<tr>
<td>or BME 240</td>
<td>Biomechanics</td>
<td></td>
</tr>
<tr>
<td>MEMS 255</td>
<td>Engineering Mechanics II</td>
<td>3</td>
</tr>
<tr>
<td>or Physics 411</td>
<td>Mechanics</td>
<td></td>
</tr>
<tr>
<td>MEMS 350</td>
<td>Engineering Mechanics III</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total Units</strong></td>
<td></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>

**Three electives from the following:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMS 301</td>
<td>Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>or EECE 203</td>
<td>Thermodynamics I in EECE</td>
<td></td>
</tr>
<tr>
<td>or BME 320B</td>
<td>Bioengineering Thermodynamics</td>
<td></td>
</tr>
<tr>
<td>MEMS 3110</td>
<td>Machine Elements</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 3410</td>
<td>Fluid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 3610</td>
<td>Materials Science</td>
<td>3</td>
</tr>
<tr>
<td>MEMS 4310</td>
<td>Dynamics and Vibrations</td>
<td>3</td>
</tr>
</tbody>
</table>

To find out more about this minor, contact the department chair or the adviser for the minor in mechanical engineering or visit the minor webpage (http://mems.wustl.edu/undergraduate/programs/Pages/minors.aspx#mechanical).

**Courses**

Visit online course listings to view semester offerings for E37 MEMS (https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E37&crslvl=1:5).

**E37 MEMS 1001 Machine Shop Practicum**

Operation of basic machine tools including: lathe, drill press, grinder and mill. Machine tool use and safety are covered. Student shop privilege requires completion of this practicum. Credit 1 unit. EN: TU

**E37 MEMS 1003 Mechanical Engineering Design and Build**

The course provides an introduction to design and fabrication. Students formulate designs, build prototypes and compete in engineering exploration-based creative design projects. Emphasis is placed on producing working hardware and prototypes in response to design needs. Specialized learning modules focus on the knowledge required to complete projects, such as introductory topics in shop skills, machine elements, electronics, design, visualization and communication. Enrollment limited to engineering freshmen. Credit 1 unit.

**E37 MEMS 101 Introduction to Mechanical Engineering and Mechanical Design**

Mechanical engineers face new challenges in the areas of energy, materials and systems. This course introduces students to these areas through team-based, hands-on projects that emphasize engineering design, analysis and measurement skills. The course is strongly recommended for mechanical engineering majors. Students from other disciplines are welcome and encouraged to enroll.
E37 MEMS 103 Computer-Aided Design — AutoCAD
AutoCAD is the most used two-dimensional drawing software for architectural and engineering production drawings. Introduction to AutoCAD, title blocks, drawing setup, absolute and relative coordinates, drawing entities, layouts, drafting geometry, dimensioning, plotting drawings to scale, sectional and other special views, isometric pictorial views. Class work involves typical drawings from industry.
Credit 2 units. EN: TU

E37 MEMS 202 Computer-Aided Design
An introduction to computer-aided engineering design in the context of mechanical and structural engineering. Students learn the fundamentals of spatial reasoning and graphical representation. Freehand sketching skills, including pictorial and orthographic views, are applied to the design process. Computer modeling techniques provide accuracy, analysis, and visualization tools necessary for the design of structures, devices and machines. Topics include: detailing design for production, fasteners, dimensioning, tolerancing, creation of part and assembly drawings, computer-aided design, analysis and optimization of parts and assemblies; solid modeling of complex surfaces, assembly modeling, assembly constraints, and interference checking.
Credit 3 units. EN: TU

E37 MEMS 203 Advanced CAD
Computer-aided design, analysis and optimization of parts and assemblies; solid modeling of complex surfaces, creation of detail drawings, dimensioning and tolerancing; assembly modeling, assembly constraints, interference checking; motion constraints, force and acceleration analysis, thermal analysis; part optimization for weight, strength and thermal characteristics using Solidworks software. Prerequisite: MEMS 202 or equivalent.
Credit 3 units. EN: TU

E37 MEMS 205 Mechanics and Materials Science Laboratory
Laboratory experiments and exercises focusing on mechanical properties of engineering materials; metallography; heat treatment; beam deflection; stress and strain measurement; properties and structure of engineering materials; calibration and use of instrumentation; acquisition, processing and analysis of data; principles of experimentation and measurement; statistical analysis of data; preparation of laboratory reports; and presentation of data. Prerequisite: MEMS 253. Corequisite: MEMS 3610.
Credit 2 units. EN: TU

E37 MEMS 253 Engineering Mechanics I
Principles of statics, solid mechanics, force systems and equilibrium. Equivalent systems of forces and distributed forces. Applications to trusses, frames, machines, beams and cables. Mechanics of deformable solids and indeterminate problems. Stress, strain, deflection, yield and fracture in beams, columns and torsion members. Prerequisite: Physics 197 or 117A.
Corequisite: Math 217.
Credit 3 units. EN: TU

E37 MEMS 255 Engineering Mechanics II
Credit 3 units. EN: TU

E37 MEMS 301 Thermodynamics
This course of classical thermodynamics is oriented toward mechanical engineering applications. It includes properties and states of a substance, processes, cycles, work, heat and energy. Steady-state and transient analyses utilize the First and Second Laws of Thermodynamics for closed systems and control volumes, as well as the concept of exergy. Prerequisites: Chem 111A, Math 132, Physics 197 or 117A.
Credit 3 units. EN: TU

E37 MEMS 305 Fluid Mechanics and Heat Transfer Laboratory
Laboratory experiments and exercises focusing on fluid properties, flow phenomena, thermal science and heat transfer phenomena; calibration and use of instrumentation; acquisition, processing and analysis of data; principles of experimentation and measurement; statistical analysis of data; preparation of laboratory reports; and presentation of data. Prerequisite: MEMS 3410. Corequisite: MEMS 3420.
Credit 2 units. EN: TU

E37 MEMS 3110 Machine Elements
Overview of the steps in the engineering design process and an introduction to several classes of machine elements such as bearings, gears, belts, brakes and springs. Underlying analytical models of the machine elements are presented along with guidelines about designing and choosing such elements for practical applications. A case study of the steps of the design process as well as the rationale for choosing particular machine elements is discussed. Corequisites: MEMS 253 and MEMS 3610.
Credit 3 units. EN: TU

E37 MEMS 3410 Fluid Mechanics
Fundamental concepts of fluids as continua. Topics include: viscosity, flow fields, velocity, vorticity, streamlines, fluid statics, hydrostatic forces, manometers, conservation of mass and momentum, incompressible inviscid flow, dimensional analysis and similitude, flow in pipes and ducts, flow measurement, boundary-layer concepts, flow in open channels. Corequisite: MEMS 255. Prerequisites: Math 233 and Math 217.
Credit 3 units. EN: TU

E37 MEMS 3420 Heat Transfer
Introductory treatment of the principles of heat transfer by conduction, convection or radiation; analysis of steady and unsteady conduction with numerical solution methods; analytical and semi-empirical methods of forced and natural convection; boiling and condensation heat transfer; and radiation heat transfer. Prerequisites: MEMS 3410 and 301, ESE 318 and ESE 319.
Credit 3 units. EN: TU
E37 MEMS 350 Engineering Mechanics III
A continuation of MEMS 253 containing selected topics in the mechanics of deformable solids, presented at an intermediate level between introductory strength of materials and advanced continuum mechanics. Lectures discuss elastic and elasto-plastic response, failure criteria, composites, beams and structural stability, as well as an introduction of the tensorial formulation of stress and strain and the governing equations of 3-D linear elasticity. Mathematical methods from calculus, linear algebra and linear differential equations are used. Computer problems form a significant part of the class. Prerequisite: MEMS 255 not required. Prerequisite: MEMS 253. Corequisite: ESE 318. Credit 3 units. EN: TU

E37 MEMS 3601 Materials Engineering
The application of fundamental materials science principles in engineering disciplines. Topics include: design of new materials having unique property combinations, selection of materials for use in specific service environment, prediction of materials performance under service conditions, development of processes to produce materials with improved properties, structural and functional use of metals, polymers, ceramics and composites. Credit 3 units. EN: TU

E37 MEMS 3610 Materials Science
Introduction to properties, chemistry and physics of engineering materials; conduction, semiconductors, crystalline structures, imperfections, phase diagrams, kinetics, mechanical properties, ceramics, polymers, corrosion, magnetic materials, and thin films; relationship of atomic and molecular structure to physical and chemical properties; selection of materials for engineering applications; relationships between physical properties, chemical properties and performance of engineering materials. Prerequisites: Chem 111A and 151. Credit 3 units. EN: TU

E37 MEMS 400 Independent Study
Independent investigation on topic of special interest. Prerequisites: junior or senior standing and permission of department chair. Students must complete the Independent Study Approval form available in the department office. Credit variable, maximum 6 units.

E37 MEMS 4001 Fundamentals of Engineering Review
A review and preparation of the most recent NCEES Fundamentals of Engineering (FE) Exam specifications is offered in a classroom setting. Exam strategies will be illustrated using examples. The main topics for the review include: engineering mathematics, statics, dynamics, thermodynamics, heat transfer, mechanical design and analysis, material science and engineering economics. A discussion of the importance and responsibilities of professional engineering licensure along with ethics will be included. Credit 1 unit.

E37 MEMS 405 Vibrations and Machine Elements Laboratory
Laboratory experiments and exercises focusing on vibration of mechanical systems; kinematic response, dynamic response and design of mechanisms and machine components; displacements, velocities and accelerations in mechanical systems and components; response to static and dynamic forces; transient and steady state response; design of mechanical components for power transmission; calibration and use of instrumentation; acquisition, processing and analysis of data; principles of experimentation and measurement; statistical analysis of data; preparation of laboratory reports and presentation of data. Prerequisite: MEMS 3110. Corequisite: MEMS 4310. Credit 2 units. EN: TU

E37 MEMS 4101 Manufacturing Processes
Manufacturing processes and machinery are explained and described. Topics include: analytical tools of machine science, heat transfer, vibrations and control theory are applied to the solution of manufacturing problems, analytical development and application of engineering theory to manufacturing problems, machine tools and automated production equipment. Credit 3 units. EN: TU

E37 MEMS 411 Mechanical Engineering Design Project
Simulating an integrated product team (IPT) experience, student teams will complete a conceptual design study, select a design project, procure parts, build a prototype, track cost and schedule, and manage project risk. Projects will have multiple design constraints including cost, codes, standards, environmental, ethical, and societal constraints. SolidWorks CAD and SolidWorks simulation-based engineering analysis will support design and prototype activities. Student teams will publish a project report through WUSTL library's open scholarship repository. Lectures have an active learning format of outside reading assignments, guest speakers, group discussion, and design reviews. Prerequisite: MEMS 3110. Credit 3 units. EN: TU

E37 MEMS 412 Design of Thermal Systems
Analysis and design of advanced thermo-fluid systems. Student teams participate in the design process which could involve research, design synthesis, codes, standards, engineering economics, a design project report, and formal presentations. Topics include thermo-fluid systems and components such as: power, heating and refrigeration systems; pumps, fans, compressors, combustors, turbines, nozzles, coils, heat exchangers and piping. Prerequisite: MEMS 301 Thermodynamics. Credit 3 units. EN: TU

E37 MEMS 424 Introduction to Finite Element Methods in Structural Analysis
Application of finite element methods to beams, frames, trusses and other structural components. Modeling techniques for different types of structural engineering problems. Topics in stress analysis, applied loads, boundary conditions, deflections and internal loads, matrix methods, energy concepts, structural mechanics and the development of finite element modeling methods. Prerequisites: MEMS 253, MEMS 350 and ESE 318. Credit 3 units. EN: TU

E37 MEMS 4301 Modeling, Simulation and Control
Introduction to simulation and control concepts. Topics include: block diagram representation of single- and multiloop systems; control system components; transient and steady-state performance; stability analysis; Nyquist, Bode and root locus diagrams; compensation using lead, lag and lead-lag networks; design synthesis by Bode plots and root-locus diagrams; state-
variable techniques; state-transition matrix; state-variable feedback. Prerequisites: MEMS 255, ESE 318 and ESE 319. Credit 3 units. EN: TU

E37 MEMS 4310 Dynamics and Vibrations
Introduction to the analysis of vibrations in single- and multidegree of freedom systems; free and forced vibration of multidegree of freedom and distributed parameter mechanical systems and structures; methods of Laplace transform; complex harmonic balance; matrix formulation; Fourier series; and transient response of continuous systems by partial differential equations. Prerequisites: MEMS 255, ESE 318 and ESE 319. Credit 3 units. EN: TU

E37 MEMS 4401 Combustion and Environment
Introduction to combustion and its application in devices. Topics include: chemical thermodynamics and kinetics; ignition and explosion; deflagration and detonation waves; transport phenomena and the governing equations for heat and mass transfer in chemically reacting flows; laminar and turbulent flame propagation; non-premixed flames; the emission of combustion-generated pollutants and subsequent interaction with the environment; toxic-waste incineration; and practical combustion devices. Prerequisites: MEMS 301, MEMS 342 or equivalent. Credit 3 units. EN: TU

E37 MEMS 463 Nanotechnology Concepts and Applications
The aim of this course is to introduce students to the general meaning, terminology and ideas behind nanotechnology and its potential application in various industries. The topics covered include nanoparticles — properties, synthesis and applications, carbon nanotubes — properties, synthesis and applications, ordered and disordered nanostructured materials and their applications, quantum wells, wires and dots, catalysis and self-assembly, polymers and biological materials, nanoelectronics and nanophotonics, nanomanufacturing and functional nanodevices, health effects and nanotoxicity, etc. Prerequisite: none. Students with a background in general physics, chemistry and biology should be able to comprehend the material. Credit 3 units.

E37 MEMS 500 Independent Study
Independent investigation on topic of special interest. Prerequisites: graduate standing and permission of the department chair. Students must complete the Independent Study Approval Form available in the department office. Credit variable, maximum 6 units.

E37 MEMS 5001 Optimization Methods in Engineering
Analytical methods in design. Topics include: mathematical methods; linear and nonlinear programming; optimality criteria; fully stressed techniques for the design of structures and machine components; topological optimization; search techniques; and genetic algorithms. Prerequisites: calculus and computer programming. Credit 3 units. EN: TU

E37 MEMS 501 Graduate Seminar
This is a required pass/fail course for master’s and doctoral degrees. A passing grade is required for each semester of full-time enrollment. A passing grade is received by attendance at the weekly seminars.

E37 MEMS 5101 Analysis and Design of Fluid-Power Systems
Design of hydraulic and pneumatic control and power systems using advanced concepts and analytical tools. Topics include: analysis of fluid flow through orifices and between parallel and inclined planes, theory of spool and flapper valves, feasibility, synthesis, analysis and applications of fluid systems, configuration of pumps, motors, fluid lines and valves, accumulators and storage devices, integration of components into systems, power systems, servo-systems, hydrostatic transmissions, performance diagrams using MATLAB and Simulink, design and analysis of fluid power systems. Credit 3 units. EN: TU

E37 MEMS 5102 Materials Selection in Design
Analysis of the scientific bases of material behavior in the light of research contributions of the past 20 years. Development of a rational approach to the selection of materials to meet a wide range of design requirements for conventional and advanced applications. Although emphasis is placed on mechanical properties, acoustical, optical, thermal and other properties of interest in design are discussed. Credit 3 units. EN: TU

E37 MEMS 5104 CAE-Driven Mechanical Design
An introduction to the use of computer-aided engineering (CAE) tools in the mechanical design process. Topics include: integrating engineering analysis throughout the process; multidisciplinary optimization; and computer-aided design directed toward new manufacturing processes. Students will work with commercial and research software systems to complete several projects. Students should have experience and familiarity with a CAD tool, optimization and the finite element method. Prerequisite: MEMS 202 Computer-Aided Design or equivalent. Credit 3 units. EN: TU

E37 MEMS 5301 Nonlinear Vibrations
In this course, students are introduced to concepts in nonlinear dynamics and vibration and application of these concepts to nonlinear engineering problems. Specific topics include: modeling of lumped and continuous nonlinear systems (strings, beams and plates); vibrations of buckled structures; perturbation and other approximate analytical methods; the use and limitations of local linearization; properties of nonlinear behavior, such as dimension and Lyapunov exponents; stability of limit cycles; bifurcations; chaos and chaotic vibrations; experimental methods and data analysis for nonlinear systems. Concepts are reinforced with a number of examples from recently published research. Applications include aeroelastic flutter, impact dynamics, machine-tool vibrations, cardiac arrhythmias and control of chaotic behavior. Credit 3 units. EN: TU

E37 MEMS 5302 Theory of Vibrations
Analytical methods in vibrations. Topics include: Duhamel's integral, Laplace and Fourier transforms and Fourier series with applications to transient response, forced response and vibration isolation; Lagrange's equations for linear systems, discrete systems, degrees of freedom, reducible coordinates, holonomic constraints and virtual work; matrix methods and state variable approach with applications to frequencies and modes,
stability and dynamic response in terms of real and complex modal expansions, dynamic response of continuous systems by theory of partial differential equations, Rayleigh-Ritz and Galerkin energy methods, finite difference and finite element algorithms.
Credit 3 units. EN: TU

E37 MEMS 5401 General Thermodynamics
General foundations of thermodynamics valid for small and large systems, and for equilibrium and nonequilibrium states. Topics include: definitions of state, work, energy, entropy, temperature, heat interaction and energy interaction. Applications to simple systems: phase rule; perfect and semi-perfect gas; bulk-flow systems; combustion, energy and entropy balances; availability analysis for thermo-mechanical power generation; and innovative energy-conversion schemes. Prerequisite: graduate standing or permission of instructor.
Credit 3 units. EN: TU

E37 MEMS 5402 Radiation Heat Transfer
Formulation of the governing equations of radiation heat transfer. Topics include: electromagnetic theory of radiation; properties of ideal and real surfaces; techniques for solutions of heat transfer between gray surfaces; radiation in absorbing, emitting and scattering media.
Credit 3 units. EN: TU

E37 MEMS 5403 Conduction and Convection Heat Transfer
This course examines heat conduction and convection through various fundamental problems that are constructed from the traditional conservation laws for mass, momentum and energy. Problems include the variable-area fin, the unsteady Dirichlet, Robbins and Rayleigh problems, multidimensional steady conduction, the Couette flow problem, duct convection and boundary layer convection. Though some numerics are discussed, emphasis is on mathematical technique and includes the extended power series method, similarity reduction, separation of variables, integral transforms, and approximate integral methods.
Credit 3 units. EN: TU

E37 MEMS 5404 Combustion Phenomena
Introduction to fundamental aspects of combustion phenomena including relevant thermochemistry, fluid mechanics, and transport processes. Emphasis is on elucidation of the physico-chemical processes, problem formulation, and analytical techniques. Topics covered include ignition, extinction, diffusion flames, particle combustion, deflagrations and detonations. Prerequisites: graduate standing or permission of instructor. (Prior to FL2015, this course was numbered: E33 5404.)
Credit 3 units. EN: TU

E37 MEMS 5410 Fluid Dynamics I
Formulation of the basic concepts and equations governing a Newtonian, viscous, conducting, compressible fluid. Topics include: transport coefficients and the elements of kinetic theory of gases; vorticity, incompressible potential flow; singular solutions; flow over bodies and lifting surfaces; similarity method; viscous flow, boundary layer, low Reynolds number flows, laminar and turbulent flows.
Credit 3 units. EN: TU

E37 MEMS 5411 Fluid Dynamics II
Governing equations and thermodynamics relations for compressible flow. Topics include: kinetic theory of gases; steady, one-dimensional flows with friction and heat transfer; shock waves; Rankine-Hugoniot relations; oblique shocks; reflections from walls and flow interfaces, expansion waves, Prandtl-Meyer flow, flow in nozzles, diffusers and inlets, two- and three dimensional flows; perturbation methods; similarity rules; compressible laminar and turbulent boundary layers; acoustic phenomena. Emphasis is relevant to air vehicles.
Credit 3 units. EN: TU

E37 MEMS 5412 Computational Fluid Dynamics
Computational fluid dynamics relevant to engineering analysis and design. Topics include: fundamentals of finite-difference, finite-volume and finite-element methods; numerical algorithms for parabolic, elliptic and hyperbolic equations; convergence, stability and consistency of numerical algorithms; application of numerical algorithms to selected model equations relevant to fluid flow, grid-generation techniques and convergence acceleration schemes. Prerequisite: senior or graduate standing or permission of the instructor.
Credit 3 units. EN: TU

E37 MEMS 5413 Advanced Computational Fluid Dynamics
Credit 3 units. EN: TU

E37 MEMS 5414 Aeroelasticity and Flow-Induced Vibrations
This course deals with the interactions between aerodynamics, dynamics and structures in aerospace systems. Topics covered include unsteady aerodynamics, finite-state aerodynamic models, classical fixed-wing flutter, rotary-wing aerelasticity and experimental methods in aerelasticity. Emphasis is given to the prediction of flutter and limit cycles in aerelastic systems.
Credit 3 units.

E37 MEMS 5416 Turbulence
Credit 3 units. EN: TU

E37 MEMS 5420 HVAC Analysis and Design I
Fundamentals of heating, ventilating, and air conditioning — moist air properties, the psychrometric chart, classic moist air processes, design procedures for heating and cooling systems. Design of HVAC systems for indoor environmental comfort, health, and energy efficiency. Heat transfer processes
E37 MEMS 5421 HVAC Analysis and Design II
Fundamentals of heating, ventilating, and air conditioning — energy analysis and building simulation, design procedures for building water piping systems, centrifugal pump performance, design of building air duct systems, fan performance, optimum space air diffuser design for comfort, analysis of humidification and dehumidification systems, and advanced analysis of refrigeration systems. HVAC analytical techniques will include the use of commercial software. Course special topics can include LEED rating and certification, cleanrooms, aviation, aerospace, and naval applications, ventilation loads, animal control facilities, building automation control, and on-site campus tours of state-of-the-art building energy and environmental systems.
Credit 3 units. EN: TU

E37 MEMS 5422 Solar Energy Thermal Processes
Extraterrestrial solar radiation, solar radiation on Earth's surface, and weather bureau data. Review of selected topics in heat transfer. Methods of solar energy collection and solar energy storage. Transient and long-term solar system performance.
Prerequisite: MEMS 342 or equivalent.
Credit 3 units. EN: TU

E37 MEMS 5423 Sustainable Environmental Building Systems
Sustainable design of building lighting and HVAC systems considering performance, life cycle cost and downstream environmental impact. Criteria, codes and standards for comfort, air quality, noise/vibration and illumination. Life cycle and other investment methods to integrate energy consumption/conservation, utility rates, initial cost, system/component longevity, maintenance cost and building productivity. Direct and secondary contributions to acid rain, global warming and ozone depletion.
Credit 3 units. EN: TU

E37 MEMS 5424 Thermo-Fluid Modeling of Renewable Energy Systems
Overview of sustainable energy systems. Fundamentals of energy conversion. Renewable energy sources and energy conversion from wind, biomass, solar-thermal, geothermal and ocean/waves. Applications to energy storage, fuel cells, green air and ground transportation, energy-efficient buildings. Energy-economics modeling, emissions modeling, global warming and climate change.
Credit 3 units. EN: TU

E37 MEMS 5500 Elasticity
Credit 3 units. EN: TU

E37 MEMS 5501 Mechanics of Continua
A broad survey of the general principles governing the mechanics of continuous media. Topics include: general vector and tensor analysis, rigid body motions, deformation, stress and strain rate, large deformation theory, conservation laws of physics, constitutive relations, principles of continuum mechanics and thermodynamics, two-dimensional continua.
Prerequisites: ESE 501–502 or instructor’s permission.
Credit 3 units. EN: TU

E37 MEMS 5502 Plates and Shells
Introduction to the linear theory of thin elastic plates and shells. The emphasis is on application and the development of physical intuition. The first part of the course focuses on the analysis of plates under various loading and support conditions. The remainder of the course deals mainly with axisymmetric deformation of shells of revolution. Asymptotic methods are used to solve the governing equations. Applications to pressure vessels, tanks and domes.
Prerequisites: BME 240 or MEMS 253; ESE 318 and ESE 319 or equivalent.
Credit 3 units. EN: TU

E37 MEMS 5504 Fracture Mechanics
Classical fracture and fatigue analysis and their limitations. Topics include: Griffith-Irwin, linear-elastic fracture-mechanics analysis, historical aspects, formulation of stability criteria, subcritical crack growth, anisotropic and inhomogeneous effects, fracture-control analysis, with applications to fracture-safety analysis relating to nuclear reactors, aircraft, rotating machinery, elastic-plastic fracture-mechanics analysis and future prospects and applications.
Prerequisites: graduate standing or permission of instructor.
Credit 3 units. EN: TU

E37 MEMS 5506 Experimental Methods in Solid Mechanics
A broad survey of the general principles governing the behavior of solid continua. Two-dimensional continua. Prerequisites: graduate standing or permission of instructor.
Credit 3 units. EN: TU

E37 MEMS 5507 Fatigue and Fracture Analysis
The course objective is to demonstrate practical methods for computing fatigue life of metallic structural components. The course covers the three major phases of metal fatigue progression: fatigue crack initiation, crack propagation and fracture. Topics include: stress vs. fatigue life analysis, cumulative fatigue damage, linear elastic fracture mechanics, stress intensity factors, damage tolerance analysis, fracture toughness, critical crack size computation and load history development. The course focus is on application of this technology to design against metal fatigue and to prevent structural failure.
Credit 3 units. EN: TU


E37 MEMS 5510 Finite Element Analysis
Theory and application of the finite element method. Topics include: basic concepts, generalized formulations, construction of finite element spaces, extensions, shape functions, parametric mappings, numerical integration, mass matrices, stiffness matrices and load vectors, boundary conditions, modeling techniques, computation of stresses, stress resultants and natural frequencies, and control of the errors of approximation. Prerequisite: graduate standing or permission of instructor. Credit 3 units. EN: TU

E37 MEMS 5515 Numerical Simulation in Solid Mechanics I
Solution of 2-D and 3-D elasticity problems using the finite element method. Topics include: linear elasticity; laminated material; stress concentration; stress intensity factor; solution verification; J integral; energy release rate; residual stress; multi-body contact; nonlinear elasticity; plasticity; and buckling. Prerequisite: graduate standing or permission of instructor. Credit 3 units.

E37 MEMS 5516 Numerical Simulation in Solid Mechanics II
Solution of 2-D and 3-D elasticity problems using the finite element method. Topics include: nonlinear elasticity; plasticity; incremental theory of plasticity; residual stress; geometric nonlinearity; membrane and bending load coupling; multi-body contact; stress intensity factor; interference fit; and buckling analysis. Prerequisite: graduate standing or permission of instructor. Credit 3 units.

E37 MEMS 5520 Advanced Analytical Mechanics
Lagrange's equations and their applications to holonomic and nonholonomic systems. Topics include: reduction of degrees of freedom by first integrals, variational principles, Hamilton-Jacobi theory, general transformation theory of dynamics, applications such as theory of vibrations and stability of motion, and use of mathematical principles to resolve nonlinear problems. Prerequisite: senior or graduate standing or permission of instructor. Credit 3 units. EN: TU

E37 MEMS 5560 Interfaces and Attachments in Natural and Engineered Structures
Attachment of dissimilar materials in engineering and surgical practice is a challenge. Bimaterial attachment sites are common locations for injury and mechanical failure. Nature presents several highly effective solutions to the challenge of bimaterial attachment that differ from those found in engineering practice. This course bridges the physiologic, surgical, and engineering approaches to connecting dissimilar materials. Topics in this course are: natural bimaterial attachments; engineering principles underlying attachments; analysis of the biology of attachments in the body; mechanisms by which robust attachments are formed; concepts of attaching dissimilar materials in surgical practice and engineering; and bioengineering approaches to more effectively combine dissimilar materials. Credit 3 units. EN: TU

E37 MEMS 5561 Mechanics of Cell Motility
A detailed review of biomechanical inputs that drive cell motility in diverse extracellular matrices (ECMs). This class discusses cytoskeletal machineries that generate and support forces, mechanical roles of cell-ECM adhesions, and regulation of ECM deformations. Also covered are key methods for cell-level mechanical measurements, mathematical modeling of cell motility, and physiological and pathological implications of mechanics-driven cell motility in disease and development. Credit 3 units.

E37 MEMS 5562 Cardiovascular Mechanics
This course focuses on solid and fluid mechanics in the cardiac and cardiovascular system. Cardiac and cardiovascular physiology and anatomy. Solid mechanics of the heart, heart valves, arteries, veins and microcirculation. Flow through the heart chambers and blood vessels. Prerequisites: graduate standing or permission of instructor. Credit 3 units. EN: TU

E37 MEMS 5564 Orthopaedic Biomechanics-Cartilage/Tendon
Basic and advanced viscoelasticity and finite strain analysis applied to the musculoskeletal system, with a primary focus on soft orthopaedic tissues (cartilage, tendon and ligament). Topics include: mechanical properties of cartilage, tendon and ligament; applied viscoelasticity theory for cartilage, tendon and ligament; cartilage, tendon and ligament biology; tendon and ligament wound healing; osteoarthritis. This class is geared to graduate students and upper-level undergraduates familiar with statics and mechanics of deformable bodies. Prerequisites: BME 240 or equivalent. Note: BME 590Z (463/563) Orthopaedic Biomechanics—Bones and Joints is not a prerequisite. Credit 3 units. EN: TU

E37 MEMS 5565 Mechanobiology of Cells and Matrices
At the interface of the cell and the extracellular matrix, mechanical forces regulate key cellular and molecular events that profoundly affect aspects of human health and disease. This course offers a detailed review of biomechanical inputs that drive cell behavior in physically diverse matrices. In particular, cytoskeletal force-generation machineries, mechanical roles of cell-cell and cell-matrix adhesions, and regulation of matrix deformations are discussed. Also covered are key methods for mechanical measurements and mathematical modeling of cellular response. Implications of matrix-dependent cell motility in cancer metastasis and embryonic development are discussed. Prerequisite: graduate standing or permission of the instructor Credit 3 units. EN: TU

E37 MEMS 5601 Mechanical Behavior of Materials
A materials science-based study of mechanical behavior of materials with emphasis on mechanical behavior as affected by processes taking place at the microscopic and/or atomic level. The response of solids to external or internal forces as influenced by interatomic bonding, crystal/molecular structure, crystalline/noncrystalline defects and material microstructure are studied. The similarities and differences in the response of different kinds of materials viz., metals and alloys, ceramics, polymers and composites are discussed. Topics covered include physical basis of elastic, visco elastic and plastic deformation of solids; strengthening of crystalline materials; visco elastic deformation of polymers as influenced by molecular structure and morphology of amorphous, crystalline and fibrous polymers; deformation and fracture of composite materials; mechanisms of creep, fatigue and rupture; high strain-rate deformation of crystalline materials; and deformation of noncrystalline materials. Credit 3 units. EN: TU
E37 MEMS 5602 Non-metallics
Structure, mechanical and physical properties of ceramics and cermets, with particular emphasis on the use of these materials for space, missile, rocket, high-speed aircraft, nuclear and solid-state applications.
Credit 3 units. EN: TU

E37 MEMS 5603 Materials Characterization Techniques I
An introduction to the basic theory and instrumentation used in transmission electron, scanning electron and optical microscopy. Practical laboratory experience in equipment operations, experimental procedures and material characterization.
Credit 3 units. EN: TU

E37 MEMS 5604 Materials Characterization Techniques II
Introduction to crystallography and elements of X-ray physics. Diffraction theory and application to materials science including following topics: reciprocal lattice concept, crystal-structure analysis, Laue methods, rotating crystal methods, powder method, and laboratory methods of crystal analysis.
Credit 3 units. EN: TU

E37 MEMS 5605 Mechanical Behavior of Composites
Analysis and mechanics of composite materials. Topics include micromechanics, laminated plate theory, hydrothermal behavior, creep, strength, failure modes, fracture toughness, fatigue, structural response, mechanics of processing, nondestructive evaluation, and test methods. Prerequisite: graduate standing or permission of the instructor.
Credit 3 units. EN: TU

E37 MEMS 5606 Soft Nanomaterials
Soft nanomaterials, which range from self-assembled monolayers (SAMs) to complex 3-D polymer structures, are gaining increased attention owing to their broad-range applications. The course introduces the fundamental aspects of nanotechnology pertained to soft matter. Various aspects related to the design, fabrication, characterization and application of soft nanomaterials are discussed. Topics covered include but are not limited to SAMs, polymer brushes, layer-by-layer assembly, responsive polymers structures (films, capsules), polymer nanocomposites, biomolecules as nanomaterials and soft lithography.
Credit 3 units. EN: TU

E37 MEMS 5607 Introduction to Polymer Blends and Composites
The course covers topics in multicomponent polymer systems (polymer blends and polymer composites) such as: phase separation and miscibility of polymer blends, surfaces and interfaces in composites, microstructure and mechanical behavior, rubber toughened plastics, thermoplastic elastomers, block copolymers, fiber reinforced and laminated composites, techniques of polymer processing with an emphasis on composites processing, melt processing methods such as injection molding and extrusion, solution processing of thin films, selection of suitable processing methods and materials selection criteria for specific applications. Advanced topics include: nanocomposites such as polymer/CNT composites, bioinspired nanocomposites, and current research challenges. Prerequisite: MEMS 3610 or equivalent or permission of instructor.
Credit 3 units. EN: TU

E37 MEMS 5608 Introduction to Polymer Science and Engineering
Topics covered in this course are: the concept of long-chain or macromolecules, polymer chain structure and configuration, microstructure and mechanical (rheological) behavior, polymer phase transitions (glass transition, melting, crystallization), physical chemistry of polymer solutions (Flory-Huggins theory, solubility parameter, thermodynamics of mixing and phase separation), polymer surfaces and interfaces, overview of polymer processing (extrusion, injection molding, film formation, fiber spinning) and modern applications of synthetic and bio-polymers.
Credit 3 units. EN: TU

E37 MEMS 5609 Electronic Materials Processing
This course covers "unit processes" for manufacturing semiconductor chips. Topics include: crystal growth and doping of wafers, oxidation and diffusion, ion implantation, deposition, etching, cleaning and lithography. Processes are described with key concepts derived from science and engineering and process integration is covered for devices such as transistors and light emitting diodes. Nanoprocessing concepts are highlighted in the end to provide students with practical and advanced knowledge of semiconductor manufacturing. Prerequisites: undergraduate engineering mathematics, materials science and basic electronics or instructor's permission.
Credit 3 units. EN: TU

E37 MEMS 5610 Quantitative Materials Science and Engineering
Quantitative Materials Science and Engineering covers the mathematical foundation of primary concepts in materials science and engineering. Topics covered are: mathematical techniques in materials science and engineering; Fourier series; ordinary and partial differential equations; special functions; matrix algebra; and vector calculus. Each is followed by its application to concepts in: thermodynamics; kinetics and phase transformations; structure and properties of hard and soft matter; and characterization techniques. This course is intended especially for students pursuing graduate study in materials science.
Credit 3 units. EN: TU

E37 MEMS 5611 Principles and Methods of Micro and Nanofabrication
A hands-on introduction to the fundamentals of micro- and nanofabrication processes with emphasis on cleanroom practices. The physical principles of oxidation, optical lithography, thin film deposition, etching and metrology methods will be discussed, demonstrated and practiced. Students will be trained in cleanroom concepts and safety protocols. Sequential microfabrication processes involved in the manufacture of microelectronic and photonic devices will be shown. Training in imaging and characterization of micro- and nanostructures will be provided. Prerequisite: graduate or senior standing or permission of the instructor.
Credit 3 units. EN: TU

E37 MEMS 5612 Atomistic Modeling of Materials
This course will provide a hands-on experience using atomic scale computational methods to model, understand and predict
the properties of real materials. It will cover modeling using classical force-fields, quantum-mechanical electronic structure methods such as density functional theory, molecular dynamics simulations, and Monte Carlo methods. The basic background of these methods along with examples of their use for calculating properties of real materials will be covered in the lectures. Atomistic materials modeling codes will be used to calculate various material properties. Prerequisites: MEMS 3610 or equivalent or permission of instructor.
Credit 3 units. EN: TU

E37 MEMS 5700 Aerodynamics
Fundamental concepts of aerodynamics, equations of compressible flows, irrotational flows and potential flow theory, singularity solutions, circulation and vorticity, Kutta-Joukowski theorem, thin airfoil theory, finite wing theory, slender body theory, subsonic compressible flow and Prandtl-Glauert rule, supersonic thin airfoil theory, introduction to performance, basic concepts of airfoil design. Prerequisite: graduate standing or permission of instructor.
Credit 3 units. EN: TU

E37 MEMS 5701 Aerospace Propulsion
Propeller, jet, ramjet and rocket propulsion. Topics include: fundamentals of propulsion systems, gas turbine engines, thermodynamics and compressible flow, one-dimensional gas dynamics, analysis of engine performance, air breathing propulsion system, the analysis and design of engine components, and the fundamentals of ramjet and rocket propulsion.
Credit 3 units. EN: TU

E37 MEMS 5703 Analysis of Rotary-Wing Systems
This course introduces the basic physical principles that govern the dynamics and aerodynamics of helicopters, fans and wind turbines. Simplified equations are developed to illustrate these principles, and the student is introduced to the fundamental analysis tools required for their solution. Topics include: harmonic balance, Floquet theory and perturbation methods.
Credit 3 units. EN: TU

E37 MEMS 5704 Aircraft Structures
Basic elements of the theory of elasticity; application to torsion of prismatic bars with open and closed thin-wall sections; the membrane analogy; the principle of virtual work applied to 2-D elasticity problems. Bending, shear and torsion of open and closed thin-wall section beams; principles of stressed skin construction, structural idealization for the stress analysis of wings, ribs and fuselage structures. Margin of safety of fastened connections and fittings. Stability of plates, thin-wall section columns and stiffened panels. Application of the finite element method for the analysis of fastened connections, structural fittings and problems of local stability of aircraft structural components.
Credit 3 units.

E37 MEMS 5705 Wind Energy Systems
A comprehensive introduction to wind energy systems, a practical means of extracting green and sustainable energy. Topics include: a historical perspective of wind turbines; horizontal axis and vertical axis wind turbines; the basic parameters such as power rating and efficiency; the structural components ranging from blade and hub to nacelle and tower; wind turbine aerodynamics, aeroelasticity and control systems; blade fatigue; statistical wind modeling; unsteady airfoil aerodynamics and downstream wake; and environmental considerations such as noise and aesthetics. Prerequisite: senior or graduate standing in engineering or permission of the instructor.
Credit 3 units. EN: TU

E37 MEMS 5701 Micro-Electro-Mechanical Systems I
Introduction to MEMS: Microelectromechanical systems (MEMS) are ubiquitous in chemical, biomedical and industrial (e.g., automotive, aerospace, printing) applications. This course covers important topics in MEMS design, micro-/nanofabrication, and their implementation in real-world devices. The course includes discussion of fabrication and measurement technologies (e.g., physical/chemical deposition, lithography, wet/dry etching, and packaging), as well as application of MEMS theory to design/ fabrication of devices in a cleanroom. Lectures cover specific processes and how those processes enable the structures needed for accelerometers, gyros, FR filters, digital mirrors, microfluidics, micro total-analysis systems, biomedical implants, etc. The laboratory component allows students to investigate those processes first-hand by fabricating simple MEMS devices.
Credit 3 units. EN: TU

E37 MEMS 5704 Engineering Project Management
Basic fundamentals and advanced concepts of engineering project management applicable to projects and programs, both large and small. Project management skills, techniques, systems, software and application of management science principles are covered and related to research, engineering, architectural and construction projects from initial evaluations through approval, design, procurement, construction and startup. Credit 3 units. EN: TU

E37 MEMS 5703 Analysis of Rotary-Wing Systems
This course introduces the basic physical principles that govern the dynamics and aerodynamics of helicopters, fans and wind turbines. Simplified equations are developed to illustrate these principles, and the student is introduced to the fundamental analysis tools required for their solution. Topics include: harmonic balance, Floquet theory and perturbation methods.
Credit 3 units. EN: TU

E37 MEMS 5704 Aircraft Structures
Basic elements of the theory of elasticity; application to torsion of prismatic bars with open and closed thin-wall sections; the membrane analogy; the principle of virtual work applied to 2-D elasticity problems. Bending, shear and torsion of open and closed thin-wall section beams; principles of stressed skin construction, structural idealization for the stress analysis of wings, ribs and fuselage structures. Margin of safety of fastened connections and fittings. Stability of plates, thin-wall section columns and stiffened panels. Application of the finite element method for the analysis of fastened connections, structural fittings and problems of local stability of aircraft structural components.
Credit 3 units.

E37 MEMS 5705 Wind Energy Systems
A comprehensive introduction to wind energy systems, a practical means of extracting green and sustainable energy. Topics include: a historical perspective of wind turbines; horizontal axis and vertical axis wind turbines; the basic parameters such as power rating and efficiency; the structural components ranging from blade and hub to nacelle and tower; wind turbine aerodynamics, aeroelasticity and control systems; blade fatigue; statistical wind modeling; unsteady airfoil aerodynamics and downstream wake; and environmental considerations such as noise and aesthetics. Prerequisite: senior or graduate standing in engineering or permission of the instructor.
Credit 3 units. EN: TU

E37 MEMS 5801 Micro-Electro-Mechanical Systems I
Introduction to MEMS: Microelectromechanical systems (MEMS) are ubiquitous in chemical, biomedical and industrial (e.g., automotive, aerospace, printing) applications. This course covers important topics in MEMS design, micro-/nanofabrication, and their implementation in real-world devices. The course includes discussion of fabrication and measurement technologies (e.g., physical/chemical deposition, lithography, wet/dry etching, and packaging), as well as application of MEMS theory to design/ fabrication of devices in a cleanroom. Lectures cover specific processes and how those processes enable the structures needed for accelerometers, gyros, FR filters, digital mirrors, microfluidics, micro total-analysis systems, biomedical implants, etc. The laboratory component allows students to investigate those processes first-hand by fabricating simple MEMS devices.
Credit 3 units. EN: TU

E37 MEMS 5804 Engineering Project Management
Basic fundamentals and advanced concepts of engineering project management applicable to projects and programs, both large and small. Project management skills, techniques, systems, software and application of management science principles are covered and related to research, engineering, architectural and construction projects from initial evaluations through approval, design, procurement, construction and startup. Credit 3 units. EN: TU

E37 MEMS 5912 Biomechanics Journal Club
This journal club is intended for graduate students and advanced undergraduates with an interest in biomechanics. We review landmark and recent publications in areas such as brain, cardiovascular and orthopedic biomechanics, discussing both experimental and modeling approaches. This course meets once weekly at a time to be arranged.
Credit 1 unit. EN: TU

E37 MEMS 597 MEMS Research Rotation
Independent research project that will be determined jointly by the doctoral student and the instructor. Assignments may include background reading, presentations, experiments, theoretical, and/or modeling work. The goal of the course is for the doctoral student to learn the background, principles and techniques associated with research topics of interest and to determine a mutual fit for the student's eventual doctoral thesis laboratory. Credit 3 units.

E37 MEMS 598 Energy Design Project
Credit variable, maximum 6 units.