MECHANICAL ENGINEERING

http://me.jhu.edu

The Department of Mechanical Engineering offers undergraduate and graduate programs of instruction and research. Undergraduate programs are offered in Mechanical Engineering and in Engineering Mechanics. The B.S. in the Mechanical Engineering and Engineering Mechanics degree programs are accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. Graduate programs are offered leading to the M.S.E. and the Ph.D. degrees. A five-year accelerated B.S./M.S.E. program is also available.

Mechanical Engineering is of great importance in most contemporary technologies. Examples include aerospace, power generation and conversion, fluid machinery, design and construction of mechanical systems, transportation, manufacturing, production, biomechanics, and others. This wide range of applications is reflected in the four main stems of the undergraduate curriculum-thermal and fluid systems, mechanics and materials, robotics and control systems, and biomechanics. Engineering Mechanics is a more flexible program that enables students to pursue particular interests while centering on a smaller core of courses. Students may use this flexibility to follow specific interests in physics, mathematics, economics, biology, and other disciplines while receiving an engineering degree.

Design is a major component of both undergraduate programs. In the two-semester Engineering Design Project course taken by undergraduates during their senior year, students work in teams of three or four to design, construct, and test a mechanical device or system for an industrial sponsor.

A major effort of the department is directed toward the creation of a stimulating intellectual environment in which both undergraduate and graduate students can develop to their maximum potential. Faculty members encourage undergraduate students to participate in both fundamental and applied research along with the graduate students. In most junior and senior undergraduate classes, and in graduate classes, small enrollments permit close contact with faculty members. Students have excellent opportunities to participate actively in the classroom and laboratories and to follow special interests within a subject area.

Facilities

Most teaching and research facilities of the department, as well as the departmental office, are located in Latrobe, Clark, Krieger, Wyman, Maryland, Malone, and Hackerman Halls. The undergraduate laboratories are equipped with sophisticated data acquisition and analysis systems. Students have access to a manual machine shop, which includes a wire EDM for the purpose of fabricating parts for special projects, a computer-controlled CO₂ laser cutter, and 3-D printers. The Mechatronics laboratory allows students to design and build their own robots for a class competition. The Senior Design laboratories are used by seniors to construct and test their prototypes in the yearlong design project course. Computer facilities are readily available throughout the department and the Whiting School.

Research facilities include laboratories in several disciplines. The Laboratory for Impact Dynamics and Rheology includes facilities for the study of failure, instabilities, impact and dynamic phenomena. The Hopkins Extreme Materials Institute addresses fundamental science issues associated with materials under extreme conditions, such as dynamic environments, human tissues, and impacts on planets and asteroids. The Laboratory for Active Materials and Biomimetics contains facilities for the characterization of tissues, active materials and biomaterials. These, coupled with electron microscopy facilities, enable innovative research on the mechanical properties of materials.

The Microspecimen Testing Laboratory has special tensile test machines for specimens as thin as 60 nanometers. The Computational Solid Mechanics Laboratory uses state-of-the-art finite-element techniques to study the physics of impact, wear, and more generally, the behavior of materials under high deformation and high-deformation rates. The calculations are conducted at length scales ranging from the nanoscale up to the macroscale.

A large hydrodynamics laboratory is the home of laser-based flow simulation and analysis research, and the Corrsin Wind Tunnel is equipped with modern instrumentation for turbulence research. The heat transfer laboratory is equipped for research using holographic interferometry to study heat transfer in complex geometries with single- and two-phase flows.

The Photonics for Quantitative Biology and Medicine laboratory focuses on diverse spectroscopic modalities that exploit intrinsic contrast in biological media to provide information on pathological conditions. In the BioMEMS and Single Molecule Dynamics Lab, engineering innovation in microfluidics, single molecule spectroscopy, and functional nanoparticles drive the development of biomarker-based diagnostics and monitoring of disease. The SXS Lab explores quantitative questions in cellular biomechanics to explain cell movement, cell division, and biological force generation.

The Laboratory for Computational Sensing and Robotics consists of numerous laboratories and collaborating research centers covering multiple domains. The robotics and mechatronics laboratory is fully equipped for the construction and testing of prototypes of novel robotic systems. The Dynamical Systems and Control laboratory is equipped for design, fabrication, and testing of advanced robotic arms and underwater robots. Experimental equipment includes a test-bed remotely operated underwater vehicle. The Locomotion in Mechanical and Biological Systems (LIMBS) laboratory is equipped with an industrial six-axis manipulator, and as well as the facilities for the development of mobile and medical robots.

Financial Aid

Scholarships and other forms of financial assistance for undergraduates are described under Admissions and Finances (http://e-catalog.jhu.edu/undergrad-students/admissions-and-finances). In addition, selected undergraduates may be employed as laboratory assistants on research projects. Assistance in various forms is available for graduate students, including tuition fellowships, fellowships with stipend, research assistantships, and competitively-awarded hourly teaching assistant positions. Applications for graduate study must be received by October 15 for the Spring semester and December 15 for the Fall semester for consideration.

Research assistantships support graduate students who work with professors on their research contracts and grants.

The Department of Mechanical Engineering offers two undergraduate programs: the Bachelor of Science in Mechanical Engineering and the Bachelor of Science in Engineering Mechanics. Both programs are accredited by the Engineering Accreditation Commission of ABET. The department offers concentrations in biomechanical engineering and aerospace engineering. For additional information regarding both the
mechanical engineering and engineering mechanics academic programs, please consult the undergraduate advising manuals which are available on the departmental website at [http://me.jhu.edu/undergraduate-studies/academic-advising-undergraduate/](http://me.jhu.edu/undergraduate-studies/academic-advising-undergraduate/). For details and an explanation of ABET requirements, visit [www.abet.org](http://www.abet.org).

**Requirements for the Bachelor's Degree**

See also General Requirements for Departmental Majors (http://e-catalog.jhu.edu/undergrad-students/academic-policies/requirements-for-a-bachelors-degree); Writing Requirement, and the department’s undergraduate advising manuals.

**The Mechanical Engineering Program**

The mission of the B.S. in mechanical engineering degree program is to provide a rigorous educational experience that prepares a select group of students for leadership positions in the profession and a lifetime of learning. The faculty is committed to maintaining a modern and flexible curriculum which, building on a foundation of basic sciences and mathematics, develops a solid education in the mechanical engineering sciences. The aim of the Mechanical Engineering program is to build competence in the design and development of thermal, fluid, and mechanical systems, to promote a broad knowledge of the contemporary social and economic context, and to develop the communication skills necessary to excel.

The program provides a basic background in thermal and mechanical systems. Laboratory instruction, as well as the senior design project, gives the student hands-on experience. Each student’s program of study is planned in consultation with his or her faculty advisor. Students are encouraged to develop depth in one or two areas of focus within mechanical engineering chosen from fluid mechanics, mechanics of solids and design, heat transfer and energy, robotics, and biomechanics. The choice of focus is decided in the junior year after consultation with the student’s faculty advisor.

The objectives for the B.S. in mechanical engineering degree program are designed to provide a high-quality educational experience that is tailored to the needs and interests of the student. The program will educate an exceptional group of engineers who, after graduation, will be:

- ...successful and on track to become leaders among their peers in industry, government laboratories and other organizations, and
- ...advanced students in the best graduate programs.

Students graduating with a B.S. in Mechanical Engineering will have demonstrated:

(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 life-long learning

(j) ...a knowledge of contemporary issues

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

**The Mechanical Engineering Curriculum is Structured as Follows**

**Mathematics (19 credits)**

<table>
<thead>
<tr>
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<th>Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.109</td>
<td>Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.202</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.211</td>
<td>Honors Multivariable Calculus</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.291</td>
<td>Linear Algebra and Differential Equations</td>
<td>4</td>
</tr>
<tr>
<td>Statistics Elective at 300-level or above:</td>
<td></td>
<td>3-4</td>
</tr>
<tr>
<td>EN.560.348</td>
<td>Probability &amp; Statistics for Engineers</td>
<td>3</td>
</tr>
<tr>
<td>or EN.553.310</td>
<td>Probability &amp; Statistics</td>
<td>3</td>
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</table>

Other qualified statistics courses can be taken upon advisor’s approval.

**Science (12 Credits)**

<table>
<thead>
<tr>
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<tr>
<td>AS.030.101</td>
<td>Introductory Chemistry I</td>
<td>3</td>
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<tr>
<td>EN.530.123</td>
<td>Introduction to Mechanics I</td>
<td>3</td>
</tr>
<tr>
<td>AS.171.102</td>
<td>General Physics: Physical Science Major II</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.108</td>
<td>General Physics for Physical Science Majors (AL)</td>
<td>4</td>
</tr>
<tr>
<td>AS.173.112</td>
<td>General Physics Laboratory II</td>
<td>1</td>
</tr>
</tbody>
</table>

**Humanities (18 credits)**

Six humanities and/or social science electives, of which one must specifically teach writing (either AS.220.105, AS.060.113 or AS.060.114).

**Required Engineering Courses (48 credits)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>EN.530.107</td>
<td>Mechanical Engineering Undergraduate Seminar I</td>
<td>5</td>
</tr>
<tr>
<td>Beginning Spring 2018, EN.530.108 Mechanical Engineering Seminar II - 0.5 credits - will be offered and is a required course</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>EN.530.111</td>
<td>Intro to Mechanical Engineering Design and CAD</td>
<td>2</td>
</tr>
<tr>
<td>Beginning Spring 2018, EN.530.112 Intro to MechE Computing - 2 credits - will be offered and is a required course.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>EN.530.115</td>
<td>Mechanical Engineering Freshman Lab I</td>
<td>1</td>
</tr>
<tr>
<td>Beginning Spring 2018, EN.530.116 Mechanical Engineering Freshman Lab II - 1 credit - will be offered and is a required course.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>EN.530.201</td>
<td>Statics and Mechanics of Materials</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.202</td>
<td>Mechanical Engineering Dynamics</td>
<td>4</td>
</tr>
<tr>
<td>Beginning Spring 2018, Dynamics will be split into EN.530.202 (3 credit lecture) and EN.530.212 (1 credit lab).</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>EN.530.215</td>
<td>Mechanics-Based Design</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.216</td>
<td>Mechanics Based Design Laboratory</td>
<td>1</td>
</tr>
</tbody>
</table>
Mechanical Engineering

MechE Senior Design Project I & EN.530.404 and Engineering Design Project II

Mechanical Engineering Electives (9 credits)

Three courses (300-level or higher) in mechanical engineering

Technical Electives (9 credits)

Three engineering, quantitative studies, or natural sciences courses at or above the 300-level, chosen from any combination of courses in engineering, basic sciences, or mathematics selected in consultation with the student's advisor.

* To obtain coherence and depth in these humanities and social science electives, at least six credits must be at the 300-level or higher. While a course grade of C- or higher is preferred, up to 10 credits with a D or D+ grade will be accepted. For examples of areas of concentration and more details, see the undergraduate academic advising manual at http://www.me.jhu.edu/advising.html.

** These courses are intended to complement the mechanical engineering electives. One of the three technical electives may be a computer language course taken at any level.

A program of not less than 126 credits must be completed to be eligible for the bachelor's degree. All undergraduate students must follow a program approved by a faculty member in the department who is selected as the student's advisor.

Aerospace Track

A student may specialize in aerospace engineering once a solid background in the fundamentals of mechanical engineering has been developed through the basic Mechanical Engineering courses. This track requires knowledge and background in several fields including advanced dynamics, flight mechanics, propulsion, aerospace materials and structures, signal processing, control systems, astrophysics and space systems. Students pursuing the Aerospace Engineering Track are required to take at least five of the following courses (which can be counted toward the Mechanical Engineering elective and Technical Elective requirements in the general Mechanical Engineering program):

EN.530.231 Mechanical Engineering Thermodynamics
EN.530.232 Mechanical Engineering Thermodynamics Laboratory
EN.530.241 Electronics & Instrumentation
or EN.520.230 Mastering Electronics
EN.520.230 is the alternate effective Fall 2017.
EN.530.254 Manufacturing Engineering
EN.530.327 Introduction to Fluid Mechanics
EN.530.329 Introduction to Fluid Mechanics Laboratory
EN.530.334 Heat Transfer
EN.530.335 Heat Transfer Laboratory
EN.530.343 Design and Analysis of Dynamical Systems
EN.530.344 Dynamic Systems Laboratory
EN.530.352 Materials Selection
EN.660.361 Engineering Business and Management

EN.530.328 Fluid Mechanics II
EN.530.418 Aerospace Structures & Materials
or EN.530.619 Aerospace Structures and Materials
EN.530.424 Dynamics of Robots and Spacecraft
or EN.530.624 Dynamics of Robots and Spacecraft (Graduate)
EN.530.425 Mechanics of Flight
EN.530.432 Jet & Rocket Propulsion
EN.530.435 Guidance and Control of Flight Vehicles
EN.530.470 Space Vehicle Dynamics & Control
AS.171.321 Introduction to Space, Science, and Technology
AS.270.318 Remote Sensing of the Environment

Other courses relevant to the track which don't count toward the requirements include:

AS.171.118 Stars and the Universe: Cosmic Evolution

Biomechanics Track

A student may specialize in biomechanics once a solid background in the fundamentals of mechanical engineering has been developed through the core Mechanical Engineering or Engineering Mechanics courses. The essence of mechanics is the interplay between forces and motion. In biology, mechanics is important at the macroscopic, cellular, and subcellular levels.

At the macroscopic length scale biomechanics of both soft and hard tissues plays an important role in computer-integrated surgical systems and technologies, e.g., medical robotics. At the cellular level, issues such as cell motility and chemotaxis can be modeled as mechanical phenomena. At the subcellular level, conformational transitions in biological macromolecules can be modeled using molecular dynamics simulation, which is nothing more than computational Newtonian mechanics; statistical mechanics, or using coarse-grained techniques that rely on principles from the mechanics of materials.

In addition, much of structural biology can be viewed from the perspective of Kinematics, e.g., finding spatial relationships in data from the Protein Data Bank.

Each student who pursues the Biomechanics track will, in consultation with his or her academic advisor, choose the set of technical and mechanical engineering course electives that best matches the student's interests. Upon completion of the track, notification of this achievement is placed on the student's academic record and transcript.

A student may specialize in biomechanics once a solid background in the fundamentals of mechanical engineering has been developed through the basic courses. Students pursuing the biomechanics concentration within mechanical engineering are required to take at least four of the following courses. Two among the four should be chosen from the biomechanics-oriented courses, indicated by an asterisk (*).

EN.510.435 Mechanical Properties of Biomaterials
EN.530.410 Biomechanics of the Cell *
EN.530.426 Biofluid Mechanics *
EN.530.436 Bioinspired Science and Technology
EN.530.441 Introduction to Biophotonics
EN.530.445 Introduction to Biomechanics *
EN.530.446 Experimental Methods in Biomechanics *
EN.530.448 Biosolid Mechanics *
EN.530.473 Molecular Spectroscopy and Imaging
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>EN.530.485</td>
<td>Physics and Feedback in Living Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.486</td>
<td>Mechanics of Locomotion</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.495</td>
<td>Microfabrication Laboratory</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.572</td>
<td>Biosensing &amp; BioMEMS</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.405</td>
<td>The Design of Biomolecular Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.440</td>
<td>Micro/Nanotechnology: The Science and Engineering of Small Structures</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.221</td>
<td>Molecules and Cells</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.421</td>
<td>Systems Bioengineering I</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.422</td>
<td>Systems Bioengineering II</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.423</td>
<td>Systems Bioengineering Lab</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.424</td>
<td>Systems Bioengineering Lab</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.451</td>
<td>Cell and Tissue Engineering Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.452</td>
<td>Cell and Tissue Engineering Lab</td>
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<tr>
<td>EN.580.456</td>
<td>Introduction to Rehabilitation Engineering</td>
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<tr>
<td>EN.530.107</td>
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<td>EN.530.202</td>
<td>Calculus III</td>
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<tr>
<td>EN.530.203</td>
<td>Statics and Mechanics of Materials</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.204</td>
<td>Dynamics I</td>
<td>4</td>
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<tr>
<td>EN.530.205</td>
<td>Thermodynamics</td>
<td>3</td>
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<td>EN.530.206</td>
<td>Introduction to Fluid Mechanics</td>
<td>1</td>
</tr>
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<td>EN.530.215</td>
<td>Mechanical Engineering Thermodynamics</td>
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<td>Mechanical Engineering Thermodynamic Laboratory</td>
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<td>EN.530.241</td>
<td>Electronics Instrumentation</td>
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<tr>
<td>EN.530.327</td>
<td>Manufacturing Engineering</td>
<td>3</td>
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<td>EN.530.334</td>
<td>Heat Transfer</td>
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<td>EN.530.335</td>
<td>Heat Transfer Laboratory</td>
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<tr>
<td>EN.530.343</td>
<td>Design and Analysis of Dynamical Systems</td>
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<td>EN.530.344</td>
<td>Dynamic Systems Laboratory</td>
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<td>EN.530.352</td>
<td>Materials Selection</td>
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</tr>
<tr>
<td>EN.530.403</td>
<td>MechE Senior Design Project</td>
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<tr>
<td>EN.530.404</td>
<td>Engineering Design Project</td>
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<tr>
<td>EN.660.461</td>
<td>Engineering Business and Management</td>
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<td>EN.660.462</td>
<td>Engineering Elective</td>
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</tr>
<tr>
<td>EN.553.291</td>
<td>Linear Algebra and Differential Equations</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.222</td>
<td>Molecules and Cells</td>
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### Sample Program

**First Year**

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<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
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<tbody>
<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
<td>AS.110.109</td>
<td>Calculus II (For Physical Sciences and Engineering)</td>
</tr>
<tr>
<td>EN.530.107</td>
<td>Mechanical Engineering Undergraduate Seminar I</td>
<td>3</td>
<td>Humanities/Social Sciences Elective</td>
</tr>
<tr>
<td>EN.530.111</td>
<td>Intro to Mechanical Engineering Design and CAD</td>
<td>2</td>
<td>EN.530.112 Intro to MechE Computing</td>
</tr>
<tr>
<td>EN.530.115</td>
<td>Mechanical Engineering Freshman Lab I</td>
<td>1</td>
<td>EN.530.116 MechE Freshman Lab II</td>
</tr>
<tr>
<td>EN.530.123</td>
<td>Introduction to Mechanics I</td>
<td>3</td>
<td>EN.530.124 Intro to Mechanics II</td>
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<tr>
<td>Humanities/Social Sciences Elective</td>
<td>Writing Intensive (060.113, 060.114, or 220.105)</td>
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<td>Humanities/Social Sciences Elective</td>
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**Second Year**

<table>
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<th>Fall</th>
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<tr>
<td>AS.110.202</td>
<td>Calculus III</td>
<td>4</td>
<td>EN.530.202 Mechanical Engineering Dynamics</td>
</tr>
<tr>
<td>EN.530.201</td>
<td>Statics and Mechanics of Materials</td>
<td>4</td>
<td>Beginning Spring 2018, EN.530.202 (3 credits) and EN.530.212 (1 credit)</td>
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<tr>
<td>EN.530.231</td>
<td>Mechanical Engineering Thermodynamics</td>
<td>3</td>
<td>EN.530.215 Mechanics-Based Design</td>
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<td>Mechanical Engineering Thermodynamic Laboratory</td>
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<td>EN.530.216 Mechanics Based Design Laboratory</td>
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<td>AS.171.102</td>
<td>General Physics: Physical Science Major II</td>
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<td>EN.530.241 Electronics Instrumentation</td>
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<td>AS.173.112</td>
<td>General Physics Laboratory II</td>
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<td>EN.553.291 Linear Algebra and Differential Equations</td>
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**Third Year**

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<tbody>
<tr>
<td>EN.530.254</td>
<td>Manufacturing Engineering</td>
<td>3</td>
<td>EN.530.334 Heat Transfer</td>
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<tr>
<td>EN.530.327</td>
<td>Introduction to Fluid Mechanics</td>
<td>3</td>
<td>EN.530.335 Heat Transfer Laboratory</td>
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<tr>
<td>EN.530.329</td>
<td>Introduction to Fluid Mechanics Laboratory</td>
<td>1</td>
<td>EN.530.343 Design and Analysis of Dynamical Systems</td>
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<td>EN.530.352</td>
<td>Materials Selection</td>
<td>4</td>
<td>EN.530.344 Dynamic Systems Laboratory</td>
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<td>EN.530.403</td>
<td>MechE Senior Design Project I</td>
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<td>EN.530.404 Engineering Design Project II</td>
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<tr>
<td>EN.660.461</td>
<td>Engineering Business and Management</td>
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<td>Mechanical Engineering Elective</td>
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<td>Technical Elective</td>
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<td>Humanities/Social Sciences Elective</td>
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**Fourth Year**

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<tr>
<td>EN.530.403</td>
<td>MechE Senior Design Project I</td>
<td>4</td>
<td>EN.530.404 Engineering Design Project II</td>
</tr>
<tr>
<td>EN.660.461</td>
<td>Engineering Business and Management</td>
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<td>Mechanical Engineering Elective</td>
</tr>
<tr>
<td>Technical Elective</td>
<td>Mechanical Engineering Elective</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Humanities/Social Sciences Elective</td>
<td>Technical Elective</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

16.5  15.5
modeling, and design aspects of solid and fluid engineering systems. Although specific core courses are required, the student is encouraged and guided by his or her advisor to select an individual program of study, within ABET guidelines, according to the student’s particular goals. This program of study may range from a general study of mechanics or engineering science to more specialized programs in a variety of areas, such as robotics, fluid dynamics, environmental engineering, mechanics of solids, experimental mechanics, dynamical systems, mechanics of materials, or biomechanics.

This flexibility makes the program ideal for double-majors and for those wishing to tailor a strong foundation for graduate work in a wide range of disciplines. All mathematics elective and technical elective courses must be at the 300-level or higher, unless approved by their faculty advisor.

**Mathematics (23 credits)**

(grades below C- not accepted)

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.108 Calculus I</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.109 Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.202 Calculus III or AS.110.211 Honors Multivariable Calculus or AS.110.212 Honors Linear Algebra</td>
<td>4</td>
</tr>
<tr>
<td>Mathematics elective</td>
<td>4</td>
</tr>
<tr>
<td>Statistics Elective at 300-level or above</td>
<td>3-4</td>
</tr>
<tr>
<td>EN.560.348 Probability &amp; Statistics for Engineers or EN.553.31 Probability &amp; Statistics</td>
<td></td>
</tr>
<tr>
<td>Other qualified statistics courses can be taken upon advisor’s approval.</td>
<td></td>
</tr>
<tr>
<td>EN.553.291 Linear Algebra and Differential Equations</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.212 Honors Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>or AS.110.201 Linear Algebra &amp; AS.110.302 and Differential Equations and Applications</td>
<td></td>
</tr>
</tbody>
</table>

**Basic Science (16-17 credits)**

(Grades below C- not accepted)

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.030.101 Introductory Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>AS.171.102 General Physics: Physical Science Major II</td>
<td>4</td>
</tr>
<tr>
<td>AS.173.112 General Physics Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.123 Introduction to Mechanics I</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.124 Introduction to Mechanics II</td>
<td>2</td>
</tr>
<tr>
<td>Another basic science elective</td>
<td>4</td>
</tr>
</tbody>
</table>

**Humanities (18 credits)**

Six humanities and/or social science electives *

**Introductory Engineering and Computing**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.530.107 Mechanical Engineering Undergraduate Seminar I</td>
<td>5</td>
</tr>
<tr>
<td>EN.530.108 Mechanical Engineering Undergraduate Seminar II</td>
<td>5</td>
</tr>
<tr>
<td>EN.530.111 Intro to Mechanical Engineering Design and CAD</td>
<td>2</td>
</tr>
<tr>
<td>EN.530.112 Intro to Mechanical Engineering Design and CAD</td>
<td>2</td>
</tr>
<tr>
<td>EN.530.115 Mechanical Engineering Freshman Lab I</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.116 MechE Freshman Lab II</td>
<td>1</td>
</tr>
<tr>
<td>Alternate introductory courses are available. If EN.530.107/108, EN.530.111/112, EN.530.115/116, and EN.530.123/124 are not taken, students must take one course from each of the engineering and computing course lists below:</td>
<td></td>
</tr>
<tr>
<td>Introductory Engineering:</td>
<td></td>
</tr>
<tr>
<td>EN.500.101 What Is Engineering?</td>
<td></td>
</tr>
</tbody>
</table>

The Engineering Mechanics Program

The mission of the B.S. in engineering mechanics degree program is to provide a rigorous educational experience that prepares a select group of students for leadership positions in the profession and a lifetime of learning. The faculty is committed to maintaining a modern and flexible curriculum which, building on a foundation of basic sciences and mathematics, develops a solid education in the mechanical engineering sciences. The aim of the Engineering Mechanics program is to build competence in the analysis, design, and modeling of fluid and solid systems, to promote a broad knowledge of the contemporary social and economic context, and to develop the communication skills necessary to excel.

The educational objectives for the B.S. in engineering mechanics degree are designed to educate a select group of science-oriented engineers who, after graduation, will be successful and on track to become leaders among their peers:

- ...in the best graduate programs in engineering, science, medical schools, or law schools, and
- ...in industry, government laboratories, and other organizations.

Students graduating with a B.S. in Mechanical Engineering will have demonstrated:

(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 life-long learning
(j) ...a knowledge of contemporary issues
(k) ...an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The curriculum is intended to enable graduates to explore fundamental questions in many fields of engineering. Emphasis is placed on the basic sciences (mathematics, physics, and chemistry) and on the analysis,
EN.520.137  Introduction To Electrical & Computer Engineering
EN.570.108  Introduction Environmental Engineering
EN.580.202  Bme In The Real World

Computing:
EN.500.200  Computing for Engineers and Scientists (recommended)
EN.510.202  Computation and Programming for Materials Scientists and Engineers
EN.560.220  Civil Engineering Analysis
EN.580.200  Introduction to Scientific Computing in BME using Python, Matlab, and R
AS.250.205  Introduction to Computing 3
EN.601.107  Introductory Programming in Java 3

Any other computing course approved by the faculty advisor. EN.601.107 should be taken as a last resort if none of the other computing options fits the student's schedule, as it is important to learn MATLAB and Intro to Java does not offer that program.

Other Required Engineering Courses
EN.530.201  Statics and Mechanics of Materials 4
EN.530.231  Mechanical Engineering Thermodynamics 3
EN.530.232  Mechanical Engineering Thermodynamics Laboratory 1.0
EN.530.327  Introduction to Fluid Mechanics 3
EN.530.329  Introduction to Fluid Mechanics Laboratory 1.0
EN.560.202  Dynamics 4
EN.530.215  Mechanics-Based Design 3
or EN.530.405  Mechanics of Advanced Engineering Structures
EN.530.216  Mechanics Based Design Laboratory 1
EN.530.216 is required only if EN.530.215 is taken.

Capstone Design (8 credits)
(Grades below C- are not accepted)
EN.530.403  MechE Senior Design Project I 8
& EN.530.404  and Engineering Design Project II

Engineering Science Electives (12 credits)
(Grades below C- are not accepted) 12
One course in the mechanics of solids (see below)
One course in the mechanics of fluids (see below)
One additional course in the mechanics of either solids or fluids (see below)
One course in either materials or dynamics (see below)

Engineering Mechanics Electives (6 credits)
(Grades below C- are not accepted) 6
Two additional elective courses in the same area of engineering mechanics (solid mechanics, fluid mechanics, or dynamics, see below).

Technical Electives (minimum of 18 credits) **
(Grades below C- are not accepted)
Engineering, Quantitative Studies, or Natural Science courses at or above the 300-level, chosen in consultation with the student’s advisor from any combination of courses in engineering, basic sciences, or mathematics.

++  One must specifically teach writing (either AS.060.113 Expository Writing or AS.060.114 Expository Writing, or AS.220.105 Fiction/Poetry Writing I). To obtain coherence and depth in these humanities and social science electives, at least six credits must be at the 300-level or higher.
Required Engineering Courses (minimum of 26 credits; grades below C- not accepted)

Fluid mechanics courses may be chosen from courses such as:
EN.530.328  Fluid Mechanics II 3
EN.530.425  Mechanics of Flight 3
EN.530.426  Biofluid Mechanics 3
EN.570.301  Environmental Engineering Fundamentals I 3

Dynamics courses may be chosen from courses such as:
EN.530.343  Design and Analysis of Dynamical Systems 3
EN.530.420  Robot Sensors/Actuators 4
EN.530.424  Dynamics of Robots and Spacecraft 3
EN.553.391  Dynamical Systems 4

Mechanics of Materials courses may be chosen from courses such as:
EN.530.215  Mechanics-Based Design 3
EN.530.405  Mechanics of Advanced Engineering Structures 3
EN.530.414  Computer-Aided Design 3
EN.530.448  Biosolid Mechanics 3
EN.560.320  Structural Design I 3
EN.560.330  Foundation Design 3
EN.560.730  Finite Element Methods 3

Students may not use the satisfactory/unsatisfactory option for required courses, including Humanities and Social Sciences, unless approved by their faculty advisor. The department will accept D or D+ grades only up to a maximum of 10 credits except where indicated. All undergraduate students must follow a program approved by a faculty member in the department who is selected as the student’s advisor.

Biomechanics Track

Engineering Mechanics (EM) is a highly flexible program offered by the Department of Mechanical Engineering, which is ideal for students who want to specialize in any area of mechanics, including biomechanics. The essence of mechanics is the interplay between forces and motion.

In biology, mechanics is important at the macroscopic, cellular, and subcellular levels. At the macroscopic length scale biomechanics of both soft and hard tissues plays an important role in computer-integrated surgical systems and technologies (e.g., medical robotics). At the cellular level, issues such as cell motility and chemotaxis can be modeled as mechanical phenomena. At the subcellular level, conformational transitions in biological macromolecules can be modeled using molecular dynamics simulation (which is nothing more than computational Newtonian mechanics), statistical mechanics, or using coarse-grained techniques that rely on principles from the mechanics of materials. In addition, much of structural biology can be viewed from the perspective
of Kinematics (e.g., finding spatial relationships in data from the Protein Data Bank).

Each student who pursues the biomechanics track within the EM major will, in consultation with his or her EM advisor, choose the set of technical and EM electives that best matches the student’s interests. Many electives from other departments are acceptable. The electives for the EM major are structured as follows:

**Engineering Science Electives (12 credits)**
One course in solid mechanics
One course in fluid mechanics
One additional course in mechanics of either solids or fluids
One course in either materials or dynamics

**Engineering Mechanics Electives (6 credits)**
Two additional courses in the same area of mechanics (i.e., fluids, solids, or dynamics)

**Technical Electives (18 credits)**
Chosen from 300-level courses in engineering and the sciences in consultation with the student’s faculty advisor.

Examples of bio-oriented courses which can be applied to the above three categories include (but are not limited to):

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.530.426</td>
<td>Biofluid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.441</td>
<td>Introduction to Biophotonics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.445</td>
<td>Introduction to Biomechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.446</td>
<td>Experimental Methods in Biomechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.448</td>
<td>Biosolid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.473</td>
<td>Molecular Spectroscopy and Imaging</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.485</td>
<td>Physics and Feedback in Living Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.486</td>
<td>Mechanics of Locomotion</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.495</td>
<td>Microfabrication Laboratory</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.672</td>
<td>Biosensing &amp; BioMEMS</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.440</td>
<td>Micro/Nanotechnology: The Science and Engineering of Small Structures</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.221</td>
<td>Molecules and Cells</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.421</td>
<td>Systems Bioengineering I</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.423</td>
<td>Systems Bioengineering Lab I</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.451</td>
<td>Cell and Tissue Engineering Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.452</td>
<td>Cell and Tissue Engineering Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.456</td>
<td>Introduction to Rehabilitation Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.457</td>
<td>Rehabilitation Engineering Design Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.495</td>
<td>Microfabrication Lab</td>
<td>4</td>
</tr>
</tbody>
</table>

This is not a complete list of possible courses that can be taken, and not all of these courses must be taken. Rather, students who wish to pursue the biomechanics track will take at least five courses such as those listed above. These five should be concentrated either at the cellular/subcellular length scale or in macroscopic biomechanics. Note that given the flexibility of the EM program, it would be possible for students to satisfy both of these kinds of tracks simultaneously if they apply all 12 of their elective courses toward this end.

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**Sample Program**

### First Year

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.108 Calculus I</td>
<td>4</td>
<td>AS.110.109 (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.107 Mechanical Engineering Undergraduate Seminar I</td>
<td>.5</td>
<td>EN.530.112 Intro to MechE Computing</td>
<td>2</td>
</tr>
<tr>
<td>EN.530.111 Intro to Mechanical Engineering Design and CAD</td>
<td>2</td>
<td>EN.530.116 MechE Freshman Lab II</td>
<td>1</td>
</tr>
</tbody>
</table>

### Second Year

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.202 Calculus III</td>
<td>4</td>
<td>EN.530.202 Mechanical Engineering Dynamics</td>
<td>4</td>
</tr>
<tr>
<td>AS.171.102 General Physics: Physical Science Major II</td>
<td>4</td>
<td>Beginning Spring 2018 - Dynamics will be split into EN.530.202 (Lecture - 3 credits) and EN.530.212 (Lab - 1 credit)</td>
<td></td>
</tr>
<tr>
<td>EN.530.201 Statics and Mechanics of Materials</td>
<td>4</td>
<td>EN.530.216 Mechanics Based Design Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.231 Mechanical Engineering Thermodynamics</td>
<td>3</td>
<td>EN.530.291 Linear Algebra and Differential Equations</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.232 Mechanical Engineering Thermodynamic Laboratory</td>
<td>1</td>
<td>Technical Elective (1)</td>
<td>3</td>
</tr>
</tbody>
</table>

17 15
To apply for admission, students must submit an application, plus a statement of purpose, college transcript, and three letters of recommendation, two of which should be from Mechanical Engineering faculty.

Upon acceptance into the program, students will be asked to develop an outline of their proposed academic program with their advisor.

Admissions and Advising
To be admitted to graduate study in the Department of Mechanical Engineering, applicants must submit credentials sufficient to convince the faculty that they will thrive in a program of advanced course work and/or research. No academic degree is required, but the applicant should have at least two years of relevant undergraduate training, or the equivalent, and should have achieved very high marks or have given other evidence of outstanding ability. Graduate Record Examination scores must be submitted.

Upon arrival, each graduate student is assigned to a faculty advisor to help map a tentative program for the first year and enter the intellectual life of the department. The student will remain in regular communication with the advisor. The advisor may use a variety of methods to assess the student’s progress, sometimes including special oral or written examinations. It is not necessary that a student have the same advisor in successive years. After serious research for a dissertation has begun, the research supervisor will automatically function as advisor. All Ph.D. students are required, and master’s students are encouraged to attend the weekly Mechanical Engineering Graduate Seminars.

Requirements for the M.S.E. Degree

Essay Option: For the Master of Science in Engineering degree at least eight one-semester courses are required. At least half of them must be selected among those listed as graduate courses in this catalog. The remaining courses can be chosen from .300- and .400-level courses in this catalog, with the advisor’s approval. 50% of all substantive courses must be offered by Mechanical Engineering (EN.530.xxx), including at least two courses at the .600-level or .700-level. A completed piece of original research conducted under the guidance of a full-time faculty member of the department and reported as a master’s essay is required. All students must follow a course of study approved by their individual advisor.

Non-Essay Option: The student must successfully complete a coordinated sequence of ten courses, which requires one year of full-time resident graduate study. At least six of the ten courses must be selected among the graduate courses of this catalog. 50% of all substantive courses must be offered by Mechanical Engineering (EN.530.xxx), including at least two courses at the .600-level or .700-level. The intent of this program is to provide the student with an intensive exposure to fundamental and advanced topics within mechanical engineering and engineering mechanics. Students must follow a course of study approved by their individual advisor.

Requirements for the Ph.D. Degree
As soon as the student is prepared to do so, he/she should fulfill the requirements for candidacy. In addition to general university requirements, the student must pass two exams. The first is an oral Departmental Qualifying Exam based on core courses. This exam is usually taken after the third semester. The second is a preliminary Graduate Board Oral examination satisfying the Graduate Board requirements. This is a comprehensive examination in which students must demonstrate proficiency at the graduate level in their field of specialization.

Although there are no formal course requirements, students are presumed to be prepared by studies equal to six 600-level courses in their field of specialization and six courses in related fields. All candidates for the doctorate must complete two semesters as a teaching assistant as part of their training. All students are required to follow a course of study approved by their individual advisor.
The final and principal requirement for the doctorate is a piece of original research worthy of publication. Candidates must write a dissertation describing their work in detail and successfully defend it in a final oral presentation and examination.

Additional details on Ph.D. requirements and departmental academic policy for the Ph.D. degree can be found on the Mechanical Engineering Graduate Advising page at http://me.jhu.edu/graduate-studies/ academic-advising-graduate/.

For current faculty and contact information go to http://www.me.jhu.edu/ faculty.html

**Faculty**

**Chair**
Gretar Tryggvason
Chair: multiphase and free surface flows, phase changes including boiling and solidification, vortex flows and combustion, numerical methods

**Full Time Professors**

Ishan Barman
Assistant Professor: elucidation of morphological and chemical information of different patho-physiological states through an interdisciplinary approach featuring novel optical, spectroscopic and microfluidic measurements, mechanistic modeling and advanced numerical methods for analysis and interpretation of the acquired data.

Jeremy Brown
Assistant Professor: haptic feedback, upper-limb prosthetics, surgical robotics, rehabilitation robotics, human-machine interaction.

Yun Chen
Assistant Professor: cell mechanics, biophysical properties of cancer microenvironment, mechanosignaling pathways, drug delivery, bioenergetics in mitochondria.

Gregory S. Chirikjian
Professor: computational structural biology (in particular, computational mechanics of large proteins), conformational statistics of biological macromolecules, developed theory for ‘hyper-redundant’ (snake-like) robot motion planning, designs and builds hyper-redundant robotic manipulator arms, applied mathematics (applications of group theory in engineering), self-replicating robotic systems.

Noah J. Cowan
Associate Professor: robot dynamics, animal biomechanics, and sensorimotor control; theory and application of control systems and system identification techniques for closed-loop systems (especially biological systems); biological motor control and systems neuromechanics; medical robotics.

Andrew S. Douglas
Professor (Vice Dean for Academic Affairs, Whiting School of Engineering): nonlinear mechanics of solids, mechanical response of compliant biological tissues, finite deformation elasticity, Static and dynamic fracture of ductile materials.

Jaafar El-Awady
Assistant Professor: multiscale materials modeling, damage and fracture mechanisms of materials in mechanical design, material degradation in extreme environments, nano-materials and structures, impact dynamics and wave propagation.

Dennice Gayme
Assistant Professor: Dynamics and control of nonlinear, networked and spatially distributed systems such as the electric power grid, and wind farms. Modeling of turbulence and transition to turbulence in wall bounded shear flows and wind farms. Grid integration of renewable energy sources.

Kevin J. Hemker
Professor, Alonzo G. Decker, Jr. Chair in Mechanical Engineering: Professor Hemker and his students seek to identify the underlying atomic-scale processes that govern the mechanical behavior of advanced material systems. They are making key observations and discoveries that define the way the mechanics and materials community thinks about and understands the properties of: nanocrystalline materials, MEMS and micro-lattice materials, thermal barrier coatings, armor ceramics, and high temperature structural materials.

Soohung Claire Hur
Assistant Professor: inertial microfluidics, nonlinear fluid dynamics, multiphase flow, cellular biophysics, cell mechanics, single cell manipulations, personalized medicine, regenerative medicine.

Ryan Hurley
Assistant Professor: mechanics of structurally complex materials, granular and geologic materials, multiscale materials modeling, 3D materials characterization, impact and wave propagation.

Sung Hoon Kang
Assistant Professor: Complex behaviors of material systems and structures with novel properties based on inspiration from nature; rational design followed by rapid prototyping using a 3D printer; designing experimental model systems and/or using computational models to identify key design parameters of systems to make desired structures and properties by tailoring behaviors of systems.

Joseph M. Katz
Professor, Whiting School Mechanical Engineering Chaired Professor, Gilman Scholar: cavitation phenomena, attached partial cavitation, cavitation in turbulent shear flows, jets and wakes. Multiphase flows: interaction between bubbles and flow structure, mixing mechanisms and droplet formation in water-fuel stratified shear flows, transport of microscopic particles and droplets in turbulent flows. Development of optical flow diagnostics techniques, including Particle Image Velocimetry (PIV) and Holographic Particle Image Velocimetry (HPIV). Applications of PIV and HPIV for measuring the characteristics of turbulence and addressing turbulence modeling issues. Complex flow structure and turbulence within turbo-machines: Wake-wake and blade-wake interactions in multistage axial turbomachines, flow and rotating stall in centrifugal pumps, development of optical diagnostics techniques for measurements in turbomachines. Oceanography: flow structure and turbulence in the bottom boundary layer of the coastal ocean; measurement of spatial distributions of plankton, particles and bubbles in the ocean; development of optical instrumen-tation, including submersible holography and PIV systems. Prevention of nozzle wear in abrasive water suspension jets (AWSJ) using porous lubricated nozzles. Flow-induced vibrations and noise, mechanisms of noise generation in turbulent separated flows and in turbomachines.

Marin Kobliarov
Assistant Professor: developing intelligent robotic vehicles that can perceive, navigate, and accomplish challenging tasks in uncertain, dynamic, and highly constrained environments. Performing research in analytical and computational methods for mechanics, control, motion planning, and reasoning under uncertainty, and in the design and...
integration of novel mechanisms and embedded systems. Application areas include mobile robots, aerial vehicles, and nanosatellites.

Chen Li
Assistant Professor: Terradynamics, locomotion, biomechanics, bio-inspired robotics, physics of living systems

Charles Meneveau
Professor, Louis M. Sardella Chair in Mechanical Engineering, Director of the Center for Environmental and Applied Fluid Mechanics: theoretical, experimental, and numerical studies in turbulence, large-eddy-simulation, turbulence modeling, fractals and scaling in complex systems, small-scale structure of turbulence and velocity gradient dynamics, applications of LES to environmental flows, wind energy, development of data-intensive science tools to study turbulence.

Rajat Mittal
Professor: computational fluid dynamics, low Reynolds number aerodynamics, biomedical flows, active flow control, LES/DNS, immersed boundary methods, fluid dynamics of locomotion (swimming and flying), biomimetics and bioinspired engineering, turbomachinery flows.

K. T. Ramesh
Professor, Alonzo G. Decker, Jr. Professor of Science and Engineering, Director of the Center for Advanced Metallic and Ceramic Systems (CAMCS) and the Hopkins Extreme Materials Institute (HEMI): Nanomaterials, planetary impact, dynamic failure mechanisms, shock, impact, and wave propagation, high-strain-rate behavior of materials, injury biomechanics, constitutive and failure modeling.

Sean Sun
Vice Chair, Professor: mechanobiology of the cell, molecular biomechanics and biophysics, molecular motors and muscle, statistical mechanics and nonlinear phenomena.

Jeff Tza-Huei Wang
Professor: bioMEMS and microfluidics, single molecule manipulation and detection, nano/micro scale fabrication, conformational dynamics of biomolecules.

Louis Whitcomb
Professor: Control Systems: adaptive and model-based control of linear and nonlinear systems, observers, nonlinear systems analysis, with focus on problems arising in mechanical systems, robots, and robotic vehicles. Underwater Robotics: dynamics, control, instrumentation, and navigation of underwater vehicles and inhabited submersibles—with focus on deep submergence oceanographic vehicles. Industrial and Medical Robotics: dynamics, control, instrumentation, and operation of precision robotics for novel medical and industrial applications.

Tamer Zaki
Associate Professor: Transitional and turbulent shear flows: receptivity, linear and non-linear instability waves, secondary instability, breakdown to turbulence, direct numerical simulations, transition modelling. Two-fluid shear flows: linear and non-linear instability methods, interface tracking, the interaction of vortical disturbances with interfaces, direct numerical simulations, laminar-to-turbulence transition. Turbulence: boundary layer turbulence, separation, stratification, drag reduction, turbulence structures, direct numerical simulations, large-scale high-performance computing.

Secondary Faculty Appointments
Stephen Belkoff

Robert C. Cammarata
Joint, Part-Time, and Research Appointments: Professor (Materials Science and Engineering): structure, properties, and processing of thin films and nanostructured materials, thermodynamics and mechanics of surfaces, mechanical behavior of materials, nonequilibrium testing, stresses in thin films, novel electrochemical deposition methods, computer simulations.

Gregory L. Eyink

Lori Graham-Brady
Professor, Civil Engineering: stochastic finite element methods, probabilistic mechanics, stochastic simulation of material properties, micromechanics.

Nitish V. Thakor
Joint, Part-Time, and Research Appointments: Professor (Biomedical Engineering): biomedical image analysis, computer vision, nanotechnologies, neurological instrumentation, signal processing, computer applications.

Robert C. Cammarata
Joint, Part-Time, and Research Appointments: Associate Professor (Orthopedic Surgery): biomechanics, orthopaedic implants, fracture fixation in osteoporotic bone, mechanism of injury, vertebroplasty.

Russell H. Taylor
Joint, Part-Time, and Research Appointments: Professor (Computer Science): medical robotics, computer-assisted surgery.

Timothy Weihs
Joint, Part-Time, and Research Appointments: Professor (Materials Science and Engineering), Director of the Center for Leadership Education: self-propagating exothermic reaction and joining with reactive multilayer foils, processing and characterization of thin films, layered materials, and thin film reactions, mechanical testing of metals and biological materials.
Associate Teaching Professor
David Kraemer
Associate Teaching Professor: Fluid-structure interaction; dynamic systems; ocean wave energy conversion, engineering pedagogy.

Steven Marra
Associate Teaching Professor: Soft and hard tissue biomechanics, nonlinear mechanics of solids, mechanics of tissue damage.

Senior Lecturer
Nathan Scott
Senior Lecturer: Principles and practice of engineering design education.

Professor emeritus
Cila Herman
Professor Emeritus: experimental heat transfer and fluid mechanics, optical measurement techniques, image processing. Thermocoustic refrigeration, influence of electric fields on boiling in terrestrial conditions and microgravity, heat exchangers, heat transfer in boiling, optical tomography, holographic interferometry, cooling of electronic equipment, digital image processing, heat transfer augmentation.

William N. Sharpe Jr.
Professor Emeritus: experimental solid mechanics; microelectromechanical systems (MEMS), microsample testing.

Research Scientist
Alan Brandt

Research Professor
Ilene Busch-Vishniac
Research Professor (University of Saskatchewan).

Shiyi Chen
Research Professor (Peking University).

Allison Okamura
Research Professor (Stanford University).

Alexander Spector
Research Professor, Biomedical Engineering: biosolid mechanics, cell mechanics and biophysics, molecular motors, mathematical and computational modeling.

Pazhayannur Swaminathan
Research Professor (Applied Physics Laboratory).

David Van Wie
Research Professor (Applied Physics Laboratory).

Associate Research Professor
Mehran Armand
Associate Research Professor (Applied Physics Laboratory).

Juan I. Arvelo Jr.
Assistant Research Professor (Applied Physics Laboratory).

Iulian Iordachita
Assistant Research Professor: robotics, medical robotics and instrumentation, mechanisms and mechanical transmissions for robots, advance electro-mechanical design, biologically-inspired mechanisms.

Associate Research Professor
Lester Su
Associate Research Professor: (Stanford University).

Liming Voo
Associate Research Professor (Applied Physics Laboratory).

Assistant Research Professor
Nitin Daphalapurkar
Assistant Research Professor.

Jin Seob Kim
Assistant Research Professor

John Thomas
Assistant Research Professor (Applied Physics Laboratory).

Adjunct Research Professor
Thomas Wright
Adjunct Research Professor: theoretical solid mechanics, wave propagation, dynamic failure, adiabatic shear localization, instabilities.

Adjunct Professor
William Blake
Adjunct Professor

Adjunct Associate Professors
Luciano Castillo
Adjunct Associate Professor (Texas Tech University).

Thomas Dragone
Adjunct Associate Professor: aerospace structures and materials, airframe structure design and development, materials science.

Ryan Eustice
Adjunct Assistant Professor (Department of Naval Architecture and Marine Engineering, University of Michigan).

Adjunct Assistant Professor
Jian Sheng
Adjunct Assistant Professor (Texas Tech University).

Associate Research Scientist
Tihomir Hristov
Associate Research Scientist.

Assistant Research Scientist
Kourosh Shoele
Assistant Research Scientist

Adam Sierakowski
Assistant Research Scientist MARCC

Gidong Sim
Assistant Research Scientist

Kelvin Xie
Assistant Research Scientist

Adjunct Research Scientist
David Smallwood
Adjunct Research Scientist

John Smith
Adjunct Principal Research Scientist
Adjunct Associate Research Scientist
Edwin Malkiel
Adjunct Associate Research Scientist.

Lecturers
Soraya Bailey
Lecturer, Senior Design

Yury Ronzhes
Joint, Part-Time, and Research Appointments: Lecturer.

Homewood Professor of Engineering
Andrea Prosperetti
Homewood Professor of Engineering: Multiphase flow; theoretical and computational fluid mechanics and acoustics; gas and vapor bubbles.

For current course information and registration go to https://sis.jhu.edu/classes/

Courses

EN.530.107. Mechanical Engineering Undergraduate Seminar I. 1.0 Credit.
A series of weekly seminars to inform students about careers in mechanical engineering and to discuss technological, social, ethical, legal, and economic issues relevant to the profession. Part 1 of a year-long sequence.
Instructor(s): S. Marra
Area: Engineering.

EN.530.111. Intro to Mechanical Engineering Design and CAD. 2.0 Credits.
This course introduces students to the basic engineering design process and to fundamental concepts and knowledge used in the design of mechanical devices and systems. Students will explore the range of tools utilized in design practice, beginning with the skills of hand-drawing, exploring ways to articulate visual ideas, and concluding with the standards of presentation and CAD tools typical in professional practice.
Corequisites: EN.530.115
Instructor(s): S. Marra
Area: Engineering.

EN.530.115. Mechanical Engineering Freshman Lab I. 1.0 Credit.
Hands-on laboratory complementing EN.530.111, including experiments, mechanical dissections, sketching and CAD, and a cornerstone design project. Experiments and mechanical dissections connect physical principles to practical engineering applications. Sketching and CAD work build the students' design and communication skills. The design project allows students to synthesize a working system by combining knowledge of mechanics and design with practical engineering skills.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): S. Marra
Area: Engineering.

EN.530.123. Introduction to Mechanics I. 3.0 Credits.
This course offers an in-depth study of the fundamental elements of classical mechanics, including particle and rigid body kinematics and kinetics, and work-energy and momentum principles. Part 1 of a year-long sequence.
Instructor(s): J. Thomas
Area: Engineering.

EN.530.104. Engineering Design Graphics, Visualization, and Fundamentals of CAD. 3.0 Credits.
This course will serve as an introduction to the foundational representational techniques for design, and help students to develop design literacy and three-dimensional visualization skills. Students will explore the range of tools utilized in design practice, beginning with the skills of hand-drawing, exploring ways to articulate visual ideas, and concluding with the standards of presentation and CAD tools typical in professional practice. This class will enable students to better develop, express and communicate their ideas as engineers.
Instructor(s): C. Phinney; S. Marra
Area: Engineering.

EN.530.201. Statics and Mechanics of Materials. 4.0 Credits.
Equilibrium of rigid bodies, free-body diagrams, design of trusses. One-dimensional stress and strain, Hooke's law. Properties of areas. Stress, strain, and deflection of components subjected to uniaxial tension, simple torsion, and bending. Co-listed with EN.560.201. Recommended Course Background: AS.171.101 or EN.530.103 and EN.530.104 or Permission Only.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): R. Sangree
Area: Engineering.

EN.530.202. Mechanical Engineering Dynamics. 4.0 Credits.
Basic principles of classical mechanics applied to the motion of particles, system of particles and rigid bodies. Kinematics, analytical description of motion; rectilinear and curvilinear motions of particles; rigid body motion. Kinetics: force, mass, and acceleration; energy and momentum principles. Introduction to vibration. Includes laboratory experience.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. (EN.530.101 AND EN.530.201) AND (AS.171.101 OR AS.171.107 OR AS.171.105 OR (EN.530.103 AND EN.530.104) ) AND AS.110.109; grade of C- or higher required from EN.530.201 OR EN.560.201
Instructor(s): D. Kraemer; S. Bailey; S. Marra
Area: Engineering.

EN.530.215. Mechanics-Based Design. 3.0 Credits.
Prerequisites: EN.530.201 OR EN.560.201
Instructor(s): K. Ramesh; R. Mittal; T. Nguyen
Area: Engineering.

EN.530.216. Mechanics Based Design Laboratory. 1.0 Credit.
This is the laboratory that supports EN.530.215 Mechanics Based Design.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Corequisites: EN.530.215
Instructor(s): S. Marra
Area: Engineering.
EN.530.231. Mechanical Engineering Thermodynamics. 3.0 Credits.
Properties of pure substances, phase equilibrium, equations of state.
First law, control volumes, conservation of energy. Second law, entropy,
efficiency, reversibility. Carnot and Rankine cycles. Internal combustion
engines, gas turbines. Ideal gas mixtures, air-vapor mixtures. Introduction
to combustion.
Prerequisites: ( AS.171.102 OR AS.171.108 ) AND
EN.530.232;AS.110.109
Instructor(s): J. Katz
Area: Engineering.
EN.530.232. Mechanical Engineering Thermodynamics Laboratory. 1.0 Credit.
This course is the complementary laboratory course and a required
corequisite for EN.530.231. Corequisite: EN.530.231 There will be four lab
sessions, days and times TBA.
Prerequisites: Students must have completed Lab Safety training prior to
registering for this class.
Instructor(s): S. Marra
Area: Engineering, Natural Sciences.
EN.530.241. Electronics & Instrumentation. 4.0 Credits.
Introduction to basic analog electronics and instrumentation with
emphasis on basic electronic devices and techniques relevant to
mechanical engineering. Topics include basic circuit analysis, laboratory
instruments, discrete components, transistors, filters, op-amps,
amplifiers, differential amplifiers, power amplification, power regulators,
AC and DC power conversion, system design considerations (noise,
precision, accuracy, power, efficiency), and applications to engineering
instrumentation.
Prerequisites: AS.171.102 or AS.171.108 or AS.171.106;Students must have
completed Lab Safety training prior to registering for this class.;Co
or Pre-requisites: EN.553.291 OR ( AS.110.201 AND AS.110.302 ) OR
( AS.110.212 AND AS.110.302 )
Instructor(s): D. Kraemer
Area: Engineering.
EN.530.254. Manufacturing Engineering. 3.0 Credits.
An introduction to the various manufacturing processes used to
produce metal and nonmetal components. Topics include casting,
forming and shaping, and the various processes for material removal
including computer-controlled machining. Simple joining processes
and surface preparation are discussed. Economic and production
aspects are considered throughout. Special Notes: Labs and field trips
will be scheduled with class separately. Mechanical Engineering and
Engineering Mechanics Sophomores and Juniors only.
Prerequisites: Students must have completed Lab Safety training prior to
registering for this class.
Instructor(s): Y. Ronzhes
Area: Engineering.
EN.530.327. Introduction to Fluid Mechanics. 3.0 Credits.
This course introduces the fundamental mathematical tools and physical
insight necessary to approach realistic fluid flow problems in engineering
systems. The topics covered include: fluid properties, fluid statics, control
volumes and surfaces, kinematics of fluids, conservation of mass, linear
momentum, Bernoulli’s equation and applications, dimensional analysis,
the Navier-Stokes equations, laminar and turbulent viscous flows, internal
and external flows, and lift and drag. The emphasis is on mathematical
formulation, engineering applications and problem solving.
Prerequisites: Co-requisite: EN.530.329;Prerequisites: EN.530/560.202
and either AS.110.302 or EN.553.291 or AS.110.306
Instructor(s): D. Kraemer
Area: Engineering.
EN.530.328. Fluid Mechanics II. 3.0 Credits.
Linear and angular momentum in integral form, applications to
turbomachines. The Navier-Stokes equations. Inviscid flow. Laminar
using computational tools, design of pipe network.
Instructor(s): C. Meneveau
Area: Engineering.
EN.530.329. Introduction to Fluid Mechanics Laboratory. 1.0 Credit.
This course is the complementary laboratory course and a required co-
requirement for EN.530.327. Corequisite: EN.530.327 There will be four lab
sessions, days and times TBA.
Prerequisites: Students must have completed Lab Safety training prior to
registering for this class.
Instructor(s): S. Marra
Area: Engineering.
EN.530.334. Heat Transfer. 3.0 Credits.
Steady and unsteady conduction in one, two, and three dimensions.
Elementary computational modeling of conduction heat transfer.
External and internal forced convection. Performance and design of
heat exchangers. Boiling and condensation. Black-body and gray-body
radiation, Stefan-Boltzmann law view factors and some applications.
Prerequisites: EN.530.231AND EN.530.327
Instructor(s): A. Prosperteti; C. Meneveau; R. Mittal
Area: Engineering.
EN.530.335. Heat Transfer Laboratory. 1.0 Credit.
This is the laboratory that supports EN.530.334 Heat Transfer.
Prerequisites: Students must have completed Lab Safety training prior to
registering for this class.
Corequisites: EN.530.334
Instructor(s): S. Marra
Area: Engineering.
EN.530.343. Design and Analysis of Dynamical Systems. 3.0 Credits.
Modeling and analysis of damped and undamped, forced and free
vibrations in single and multiple degree-of-freedom linear dynamical
systems. Introduction to stability and control of linear dynamical
systems.
Prerequisites: Prereq: (110.108 and 110.109 and (110.202 or 110.211)
and (550.291) or (110.201 and 110.302) or (110.201 and 110.306)),
and C- or better or concurrent enrollment in 530.202 or 560.202. MechE
 Majors must also have taken 530.241;Students must have completed Lab
Safety training prior to registering for this class.
Instructor(s): N. Cowan; S. Marra
Area: Engineering.
EN.530.344. Dynamic Systems Laboratory. 1.0 Credit.
Prerequisites: Students must have completed Lab Safety training prior to
registering for this class.
Corequisites: EN.530.343
Instructor(s): S. Marra
Area: Engineering.
EN.530.352. Materials Selection. 4.0 Credits.
An introduction to the properties and applications of a wide variety of
materials: metals, polymers, ceramics, and composites. Considerations
include availability and cost, formability, rigidity, strength, and toughness.
This course is designed to facilitate sensible materials choices so as to
avoid catastrophic failures leading to the loss of life and property.
Prerequisites: Prereq: EN.530.215 or permission of instructor
Instructor(s): S. Kang
Area: Engineering.
EN.530.354. Manufacturing Engineering. 3.0 Credits.
An introduction to the various manufacturing processes used to produce metal and nonmetal components. Topics include casting, forming and shaping, and the various processes for material removal including computer-controlled machining. Simple joining processes and surface preparation are discussed. Economic and production aspects are considered throughout. Special Notes: Labs and field trips will be scheduled with class separately. Mechanical Engineering and Engineering Mechanics Sophomores and Juniors only.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): Y. Ronzhes
Area: Engineering.

EN.530.366. Spacecraft Instrumentation Project. 3.0 Credits.
Investigation into the content relevant to an ongoing spacecraft instrumentation project. An interdisciplinary team will enhance the skills and knowledge of science and engineering students. Topics include mission background, planetary science, sensor design, spacecraft systems, and mission planning, and sensor fabrication, calibration, integration, and testing, data analysis and interpretation, scientific/technical writing and publication.
Instructor(s): D. Kraemer; S. Horst
Area: Engineering, Natural Sciences.

EN.530.371. Quantitative Applications in Mechanical Engineering. 3.0 Credits.
Solution of practical mechanical engineering problems with differential equations and linear algebra using numerical tools. Applications include topics like ballistics with viscous drag, fluid flow, solid mechanics, and kinematics. Numerical exercises with Matlab and other tools are used to reinforce concepts. Laboratory sessions will be scheduled in place of lectures a few times during the semester.
Prerequisites: EN.553.291 OR (AS.110.201 AND AS.110.302)
Instructor(s): D. Kraemer
Area: Engineering, Quantitative and Mathematical Sciences.

EN.530.381. Engineering Design Process. 3.0 Credits.
This course is to get you into the world of Senior Design, which means into our spaces, into the machine shop and into the mind set of doing design-build-test work. You will be assigned to be an assistant to one of our Senior Design teams. In industrial design practice this is absolutely typical and project teams grow or shrink as the need demands. It is also a good way for younger engineers to learn the ropes. You will have your own portfolio of design work to do, but it will be in the context of a large project where there has already been a lot of progress. You will have to fit in with that larger context – as usual for engineers – while also making your own contributions. There will be a lecture series which will introduce some key ideas and tools of the engineering designer. Rapid sketching of design ideas; more careful hand drawings that are like fast technical drawings; how to generate ideas and then develop the ideas into workable, feasible, affordable, desirable solutions; how to identify prototypes that will show the way forward, and then actually make them; how to work with a team and negotiate about time, deliverables and design detail; how to find parts from commercial suppliers, size them, order them and get them delivered; how to document design work in a fast and effective way. Some of the lectures will be in the form of case studies of excellent design work, and will be student-driven i.e. you will prepare a case study to present to the class which we then discuss.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): N. Scott
Area: Engineering.

EN.530.403. MechE Senior Design Project I. 4.0 Credits.
This senior year “capstone design” course is intended to give some practice and experience in the art of engineering design. Students working in teams of two to four will select a small-scale, industry-suggested design problem in the area of small production equipment, light machinery products, or manufacturing systems and methods. A solution to the problem is devised and constructed by the student group within limited time and cost boundaries. Preliminary oral reports of the proposed solution are presented at the end of the first semester. A final device, product, system, or method is presented orally and in writing at the end of the second semester. Facilities of the Engineering Design Laboratory (including machine shop time) and a specified amount of money are allocated to each student design team for purchases of parts, supplies, and machine shop time where needed. Recommended Course Background: ME Majors: EN.530.215, EN.530.327; EM & BME Majors: EN.530.215 or EN.530.405, and EN.530.327.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): N. Scott; S. Bailey
Area: Engineering.

EN.530.404. Engineering Design Project II. 4.0 Credits.
The Senior Design Project, a unique two-semester course, is the capstone of Johns Hopkins’s Mechanical Engineering Program. In the class, students working in small teams tackle specific design challenges presented by industry, government, and nonprofit organizations. The sponsors provide each team with a budget, access to world-class resources, and technical contacts. Ultimately, each team conceptualizes a novel solution to the sponsor’s problem and then designs, constructs, and tests a real-world prototype before presenting the finished product and specifications to the sponsor. The course requires students to draw upon the four years of knowledge and experience they’ve gained in their engineering studies and put it to practical use. Throughout the year, they produce progress reports as they design, build, and test the device they are developing. Combining engineering theory, budget and time management, and interactions with real clients, the senior design project is critical to students’ preparation for the transition from school to the workplace.
Prerequisites: EN.530.403
Instructor(s): N. Scott; S. Bailey
Area: Engineering
Writing Intensive.

EN.530.405. Mechanics of Advanced Engineering Structures. 3.0 Credits.
This course provides an introduction to the mathematical and theoretical foundations of the mechanics of solids and structures. We will begin with the mathematical preliminaries used in continuum mechanics: vector and tensor calculus, then introduce kinematics and strain measures, descriptions of stress in a body, frame indifference, conservation laws: mass, momentum, energy balance, and entropy. These concepts will be applied to develop the constitutive equations for solids and fluids, methods for solving boundary values problems that occur in engineering structures, energy methods and foundations of the finite element method.
Instructor(s): J. El-Awady
Area: Engineering, Natural Sciences.
EN.530.410. Biomechanics of the Cell. 3.0 Credits.
Mechanical aspects of the cell are introduced using the concepts in continuum mechanics. Discussion of the role of proteins, membranes and cytoskeleton in cellular function and how to describe them using simple mathematical models.
Instructor(s): S. Sun
Area: Engineering, Natural Sciences.

EN.530.414. Computer-Aided Design. 3.0 Credits.
The course outlines a modern design platform for 3D modeling, analysis, simulation, and manufacturing of mechanical systems using the "Pro/E" package by PTC. The package includes the following components: • Pro/ENGINEER: is the kernel of the design process, spanning the entire product development, from creative concept through detailed product definition to serviceability. • Pro/MECHANICA: is the main analysis and simulation component for kinematic, dynamic, structural, thermal and durability performance. • Pro/NC: is a numeric-control manufacturing package. This component provides NC programming capabilities and tool libraries. It creates programs for a large variety of CNC machine tools.
Instructor(s): D. Stoianovici
Area: Engineering.

EN.530.417. Fabricatology - Advanced Materials Processing. 3.0 Credits.
The "Fabricatology" is a course that students can learn how to make desired shapes, structures, and surfaces across various length scales. It will introduce rich scientific and engineering knowledge related to fabrication at multiple length scales and the generated materials and mechanical systems can be utilized for studying diverse topics including energy harvesting, metamaterials, wetting, and information storage. From this course, students can learn principles and technologies to control shapes at various length scales and processes to control internal structures or surface properties for desired properties/functions. They will be also introduced to exciting recent development in the field so that they can have a comprehensive knowledge about the subject. Recommended Course Background: coursework in introduction to materials chemistry or engineering materials.
Instructor(s): S. Kang
Area: Engineering.

EN.530.418. Aerospace Structures & Materials. 3.0 Credits.
An introduction to the design of aircraft and spacecraft structures and components. This course will build on skills learned in EN.530.215 and EN.530.352. Recommended Course Background: EN.530.352 or instructor permission.
Instructor(s): T. Dragone
Area: Engineering.

EN.530.420. Robot Sensors/Actuators. 4.0 Credits.
Introduction to modeling and use of actuators and sensors in mechatronic design. Topics include electric motors, solenoids, micro-actuators, position sensors, and proximity sensors.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. ( ( AS.171.101 AND AS.171.102 ) OR ( AS.171.107 AND AS.171.108 ) OR ( EN.530.103 AND EN.530.104 ) ) AND ( AS.110.106 OR AS.110.108 ) AND AS.110.109 AND ( AS.110.202 OR AS.110.211 ) AND ( EN.553.291 OR AS.110.302 ) AND ( EN.530.241 OR EN.520.230 OR ( EN.520.213 AND EN.520.345 ) )
Instructor(s): D. Kraemer; N. Cowan
Area: Engineering.

EN.530.421. Mechatronics. 3.0 Credits.
Students from various engineering disciplines are divided into groups of two to three students. These groups each develop a microprocessor-controlled electromechanical device, such as a mobile robot. The devices compete against each other in a final design competition. Topics for competition vary from year to year. Class instruction includes fundamentals of mechanism kinematics, creativity in the design process, an overview of motors and sensors, and interfacing and programming microprocessors.
Prerequisites: EN.530.420 or EN.520.240 or permission of instructor; Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): C. Rizk
Area: Engineering.

EN.530.424. Dynamics of Robots and Spacecraft. 3.0 Credits.
An introduction to Lagrangian mechanics with application to robot and spacecraft dynamics and control. Topics include rigid body kinematics, efficient formulation of equations of motion, stability theory, and Hamilton's principle.
Instructor(s): G. Chirikjian; J. Kim
Area: Engineering.

EN.530.425. Mechanics of Flight. 3.0 Credits.
Instructor(s): K. Phillips
Area: Engineering.

EN.530.426. Biofluid Mechanics. 3.0 Credits.
Course will cover selected topics from physiological fluid dynamics, including respiratory flow patterns, blood flow and pulse propagation, aerodynamics of phonation and speech, rheology of blood flow in the microcirculation, aquatic animal propulsion, and animal flight.
Instructor(s): R. Mittal
Area: Engineering.

EN.530.430. Applied Finite Element Analysis. 3.0 Credits.
This course will introduce finite element methods for analysis of solids, structures and heat transfer problems. Following topics will be considered. Procedure to defining a mechanics problem: governing equations, constitutive equations, boundary and initial value problems. Theory and implementation of the finite element methods for static analysis using linear elasticity. Finite element analysis (FEA) using ABAQUS software. Verification and validation, understanding uncertainty. Introduction to other FEA topics: structural elements, dynamic analysis using linear elasticity. Finite element analysis (FEA) using ABAQUS software. Verification and validation, understanding uncertainty. Introduction to other FEA topics: structural elements, dynamic analysis, heat transfer and thermodynamics using ABAQUS. The course will include assignments and a term project. The term project is mandatory for graduate students and will involve applying FEA to an engineering problem or a research problem, interpretation of results and documenting a term paper.
Prerequisites: Prerequisite: EN.553.291 OR AS.110.302, and matrix analysis / algebra and programming recommended.
Instructor(s): N. Daphalapurkar
Area: Engineering.
EN.530.432. Jet & Rocket Propulsion. 3.0 Credits.
The course covers associated aircraft and spacecraft and power generation. The first part reviews the relevant thermodynamics and fluid mechanics, including isentropic compressible flow, Rayleigh and Fanno lines, shock and expansion waves. Subsequently, the performance of various forms of aviation gas turbines, including turbo-jet, turbo-fan, turbo-prop and ram-jet engines is discussed, followed by component analyses, including inlet nozzles, compressors, combustion chambers, turbines and afterburners. Axial and centrifugal turbomachines are discussed on detail, including applications in aviation, power generation and liquid transport. The section on foundations of combustion covers fuels, thermodynamics of combustion, and energy balance. The last part focuses on rockets, including classification, required power for space flight, chemical rocket components, and combustion involving liquid and solid fuels.
Prerequisites: Prereqs: EN.530.231 AND EN.530.327
Instructor(s): J. Katz
Area: Engineering.

EN.530.435. Guidance and Control of Flight Vehicles. 3.0 Credits.
This course introduces the fundamental concepts of guidance and control of rockets and will highlight methodologies often employed in industry. The topics covered include: aerodynamic control, review of flight control principles (transfer functions, block diagram reduction, root locus, frequency domain methods), nonlinear representation of an airframe, linearization of an airframe, flight control design of a rocket, three-loop autopilot design, and fundamentals of tactical guidance (proportional navigation guidance theory, zero effort miss). Co-listed with EN.530.635
Prerequisites: EN.530.343
Instructor(s): K. Phillips
Area: Engineering.

EN.530.436. Bioinspired Science and Technology. 3.0 Credits.
Nature has been a source of inspiration for scientists and engineers and it receives particular attention recently to address many challenges the human society encounter. The course will study novel natural materials/structures with unique properties, the underlying principles, and the recent development of the bio-inspired materials and systems. From this course, students can learn about ingenious and sustainable strategies of organisms, open eyes about various phenomena in nature, and get inspiration for opening new directions of science and technology.
Instructor(s): N. Cowan; S. Kang
Area: Engineering, Natural Sciences.

EN.530.441. Introduction to Biophotonics. 3.0 Credits.
The primary aim for this course is to explore the unique and diverse properties of light that makes it suited for diagnosis, imaging, manipulation and control of biological structure and function from the nanoscale to the tissue level. The course will focus on different optical spectroscopic and microscopic modalities that provide biochemical and morphological information, while introducing new ideas on analysis and interpretation of the acquired data. We will also discuss manipulation methods, including optical tweezers and laser scissors, and low-level light therapy. In all of these areas, the idea is to develop a basic understanding of the subject and to use it for finding solutions to real-world problems in healthcare. Discussions and open exchanges of ideas will be strongly emphasized.
Instructor(s): I. Barman
Area: Engineering.

EN.530.443. Fundamentals of Microscale Phenomena. 3.0 Credits.
This course will introduce fundamental physical and chemical principles involved in unique microscale phenomena. Topics to be covered include issues associated with being in micrometers in science and engineering, fluid mechanics in micro systems, diffusion, surface tension, surfactants, and interfacial forces, Interfacial hydrodynamics, Mechanical properties of materials in microscale. Students will learn about applications, enabled by the discussed principles. Recommended Pre-Requisites: EN.530.334 Suggested Pre-Requisites: EN.530.328, EN.580.451
Prerequisites: EN.530.327 AND EN.530.231
Instructor(s): S. Hur
Area: Engineering, Quantitative and Mathematical Sciences.

EN.530.445. Introduction to Biomechanics. 3.0 Credits.
An introduction to the mechanics of biological materials and systems. Both soft tissue such as muscle and hard tissue such as bone will be studied as well the way they interact in physiological functions. Special emphasis will be given to orthopedic biomechanics. Recommended Course Background: EN.530.215/EN.530.216 and Lab or equivalent. If you have not taken this course or an equivalent, please contact the instructor before registering to ensure you have the appropriate background knowledge to succeed in this course.
Instructor(s): S. Belkoff
Area: Engineering.

EN.530.446. Experimental Methods in Biomechanics. 3.0 Credits.
An introduction to experimental methods used in biomedical research. Standard experimental techniques will be applied to biological tissues, where applicable and novel techniques will be introduced. Topics include strain gauges, extensometers, load transducers, optical kinematic tracking, digital image correlation, proper experimental design, calibration and error analysis. Of particular emphasis will be maintaining native tissue temperature and hydration. Laboratory will include “hands-on” testing.
Instructor(s): S. Belkoff
Area: Engineering, Natural Sciences.

EN.530.448. Biosolid Mechanics. 3.0 Credits.
This class will introduce fundamental concepts of statics and solid mechanics and apply them to study the mechanical behavior bones, blood vessels, and connective tissues such as tendon and skin. Topics to be covered include concepts of small and large deformation, stress, constitutive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity, and experimental methods. Recommended Course Background: AS.110.201 and AS.110.302, as well as a class in statics and mechanics
Area: Engineering.

EN.530.455. Additive Manufacturing. 3.0 Credits.
The emergence of additive manufacturing (AM) as a viable technology for depositing materials with intricate shapes and architectures enables personal fabrication and threatens to transform global supply chains. This course will give a comprehensive introduction to AM of polymers, metals and ceramics, including: processing fundamentals, processing-structure-property relations and applications. Implications for the design, qualification and introduction of AM products will be addressed, and a variety of applications will be reviewed and used as case studies. Recommended knowledge of Materials Science equivalent to 530.352 Materials Selection. Concurrent enrollment in 530.352 Materials Selection is welcome.
Instructor(s): K. Hemker
Area: Engineering.
EN.530.464. Energy Systems Analysis. 3.0 Credits.
This course discusses the grid integration of renewable energy systems. The main emphasis is on grid level effects of renewable energy, particularly wind power systems. It begins with an introduction to basic power system concepts along with power flow analysis (and optimization). Then, important concepts for wind power systems are discussed. Following that, integration issues for wind power at the transmission level and solar cell integration at the distribution level are introduced. The last part of the course will focus on current research in these areas. Students will choose a system to research and present a project or literature review at the end of the term. Prior knowledge of optimization is helpful, but not required. Co-listed with EN530.664
Instructor(s): D. Gayme
Area: Engineering.

EN.530.470. Space Vehicle Dynamics & Control. 3.0 Credits.
In this course we study applied spacecraft orbital and attitude dynamics and their impact on other subsystems. In the orbital dynamics part of the course, we discuss some of the issues associated with orbital insertion, control and station keeping. Focus is on the two-body problem regime where conic solutions are valid. Orbit perturbations are also considered. For attitude dynamics, different attitude representations such as direction cosines, quaternions, and angles are introduced. Then we look at the forces and moments acting on space vehicles. Attitude stability and control considerations are introduced.
Instructor(s): M. Ozimek; T. McGee
Area: Engineering.

EN.530.473. Molecular Spectroscopy and Imaging. 3.0 Credits.
The overarching objective of this course is to understand, employ and innovate molecular spectroscopy and optical imaging tools. The emphasis will be to bridge the domain between molecular spectroscopy, which provides exquisite chemical information, and the imaging capabilities of microscopy to seamlessly traverse between structural and biochemical spaces. The course will build on the foundational principles of light-matter interactions and an understanding of light sources, geometrical and wave optics, and detectors. Using vibrational and fluorescence spectroscopy as the tools of choice, we will discuss the design and fabrication of molecular reporters that offer unprecedented sensitivity, specificity and multiplexing capabilities in imaging of live biological specimen. Finally, we will learn about spectral and image-processing algorithms that have fundamentally changed the nature and quantity of useful information and have directly lead to breakthroughs in super-resolution imaging and multi-modal image fusion. All through the course, the focus will be on the underlying concepts and physical insights as we navigate through a diverse array of biophotonics applications.
Instructor(s): I. Barman
Area: Engineering.

EN.530.475. Locomotion I: Mechanics. 3.0 Credits.
This is a course on the mechanics of locomotion in animals and machines (particularly bio-inspired and biomimetic robots). Locomotion emerges from effective physical interaction of an animal or a machine with the surrounding environment; therefore, the ability to generate appropriate forces (besides appropriate sensing and control) is essential to successful locomotion. From a mechanics point of view, we will discuss why animals move amazingly well in almost any environment, how they have inspired some highly successful machines, and yet why the majority of robots still struggle in environments that are only modestly complex and how they may be improved by better understanding the mechanics of locomotion. Primary focus will be on terrestrial locomotion, but aerial and aquatic locomotion will be also discussed, all with numerous examples. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Students from ME and other departments are welcome. A strong understanding of Newtonian mechanics is required. Visit http://li.me.jhu.edu/teaching for more information. Recommended Course Background: B+ or higher in EN.530.202 Dynamics or EN.560.202 Dynamics
Instructor(s): C. Li
Area: Engineering.

EN.530.476. Locomotion in Mechanical and Biological Systems. 3.0 Credits.
This is a course on the mechanics of locomotion in animals and machines (particularly bio-inspired and biomimetic robots). It will introduce you to the breadth of diverse topics within the field of animal and robot locomotion. We will discuss why animals move amazingly well in all kinds of environments, how they have inspired some highly successful machines, and yet why the majority of robots still struggle in environments that are only modestly complex. Terrestrial, aerial, and aquatic locomotion will be discussed, with numerous examples. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Students from ME and other departments are welcome. Please visit http://li.me.jhu.edu/teaching for updated information.
Instructor(s): C. Li
Area: Engineering.

EN.530.480. Image Processing and Data Visualization. 3.0 Credits.
The course will be divided into two parts. In the first part, students will learn the basics of image processing, including handling noisy background, creating 2D/3D filters, Fourier domain operations, and building processing pipelines. In the second part, students will learn the importance of data visualization, as well as the skills to use the aids such as virtual reality goggles and haptic devices to help scientists gain insights for data interpretation. Recommended experience programming in Matlab.
Instructor(s): Y. Chen
Area: Engineering, Quantitative and Mathematical Sciences.
EN.530.485. Physics and Feedback in Living Systems. 3.0 Credits.
The complex mechanisms of living systems cannot be reduced to a set of
base pairs: genes are only one part of mystery of life. Rather, organisms
must develop, move, interact, and function in their natural environment,
and thus are constrained by the laws of physics. For example, during
locomotion an animal must accelerate according to Newton’s laws by
applying forces between itself and the environment. Beyond physical
principles alone, biological systems extensively use feedback to enhance
stability and facilitate adaptation in the presence of a changing world.
This course examines the critical roles that physical principles and
feedback mechanisms play in life, with special emphasis on animal
locomotion and its control. Juniors and Seniors only.
Instructor(s): N. Cowan
Area: Engineering.

EN.530.486. Mechanics of Locomotion. 3.0 Credits.
This is a course on the mechanics of locomotion in animals and
machines (particularly bio-inspired and biomimetic robots). It will
introduce you to the breadth of diverse topics within the field of animal
and robot locomotion. We will discuss why animals move amazingly
well in all kinds of environments, how they have inspired some highly
successful machines, and yet why the majority of robots still struggle
in environments that are only modestly complex. Terrestrial, aerial, and
aquatic locomotion will be discussed, with numerous examples. General
principles and integration of knowledge from engineering, biology, and
physics will be emphasized. Students from ME and other departments
are welcome. Please visit http://li.me.jhu.edu/teaching for updated
information. Co-listed with EN.530.686
Prerequisites: EN.530.202 OR EN.560.202 with grade of B+ or higher.
Instructor(s): C. Li
Area: Engineering, Quantitative and Mathematical Sciences.

EN.530.495. Microfabrication Laboratory. 4.0 Credits.
This laboratory course is an introduction to the principles of
microfabrication for microelectronics, sensors, MEMS, and other
synthetic microsystems that have applications in medicine and biology.
Course comprised of laboratory work and accompanying lectures that
cover silicon oxidation, aluminum evaporation, photoresist deposition,
photolithography, plating, etching, packaging, design and analysis CAD
tools, and foundry services. Seniors only or Permission Required.
Instructor(s): A. Andreou; J. Wang
Area: Engineering, Natural Sciences.

EN.530.501. Undergraduate Research. 1.0 - 3.0 Credits.
Students pursue research problems individually or in pairs. Although the
research is under the direct supervision of a faculty member, students are
encouraged to pursue the research as independently as possible.
All students taking three or more credits of undergraduate research are
required to present a research poster at the Johns Hopkins University’s
DREAMS Undergraduate Research Day each spring. Announcements will
be sent in advance to arrange to submit the poster.
Instructor(s): Staff.

EN.530.511. Group Undergraduate Research. 1.0 - 3.0 Credits.
Students pursue research problems individually or in pairs. Although the
research is under the direct supervision of a faculty member, students are
encouraged to pursue the research as independently as possible.
The professor and students will meet weekly in required meetings. All
students taking three or more credits of undergraduate research are
required to present a research poster at the Johns Hopkins University’s
DREAMS Undergraduate Research Day each spring.
Instructor(s): Staff.

EN.530.525. Independent Research. 1.0 - 3.0 Credits.
Students pursue research problems individually or in pairs. Although the
research is under the direct supervision of a faculty member, students are
encouraged to pursue the research as independently as possible. (Note,
this course number will no longer be used after Spring 2016. Please see
EN.530.501 and EN.530.511 for Independent Research choices.)
Instructor(s): Staff.

EN.530.526. Undergrad Independent Study. 1.0 - 3.0 Credits.
Students pursue research problems individually or in pairs. Although the
research is under the direct supervision of a faculty member, students are
encouraged to pursue the research as independently as possible.
Instructor(s): Staff.

EN.530.527. Independent Study. 1.0 - 3.0 Credits.
Students pursue research problems individually or in pairs. Although the
research is under the direct supervision of a faculty member, students are
encouraged to pursue the research as independently as possible.
Instructor(s): Staff.

EN.530.559. Independent Study. 1.0 - 4.0 Credits.
Instructor(s): Staff.

EN.530.600. MSE Graduate Research. 3.0 - 10.0 Credits.
Instructor(s): Staff.

EN.530.602. Master’s Thesis Research and Writing. 3.0 - 10.0 Credits.
This course will be taken by Mechanical Engineering students when
doing research and/or writing for the Master’s Thesis or Essay.
Instructor(s): Staff.

EN.530.603. Applied Optimal Control. 3.0 Credits.
The course focuses on the optimal control of dynamical systems subject
to constraints and uncertainty by studying analytical and computational
methods leading to practical algorithms. Topics include calculus of
variations, nonlinear local optimization, global stochastic search,
dynamic programming, linear quadratic (gaussian) control, numerical
trajectory optimization, model-predictive control. Advanced topics include
approximate dynamic programming and optimal control on manifolds.
The methods and algorithms will be illustrated through implementation of
various simulated examples. Recommended Course Background: Linear
Algebra and Differential Equations; experience with control systems;
programming in MATLAB.
Instructor(s): M. Kobilarov.

EN.530.605. Mechanics of Solids and Materials. 3.0 Credits.
This course provides an introduction to the mathematical and theoretical
foundations of the mechanics of solids and materials. We will begin
with the mathematical preliminaries of continuum mechanics: vectors
and tensors calculus, then introduce the kinematics of deformation
and descriptions of stress in a continuum: Eulerian and Lagrangian
descriptions, followed by conservation laws: mass, momentum, and
energy balance, and entropy. These concepts will be applied to develop
the concepts of constitutive relations: frame invariance, material
symmetry, and dissipation. The second half of the class will be devoted
to elasticity, both classical and finite elasticity, and solution methods for
boundary value problems.
Instructor(s): K. Ramesh.
An overview of the area of the mechanics of solids and materials, with
the intent of providing the foundation for graduate students interested
in research that involves these disciplines. The course is based on
the principles of continuum mechanics, and covers the fundamental
concepts of elasticity, plasticity, and fracture as applied to materials.
One objective is to get graduate students to the point that they can
understand significant fractions of research seminars and papers
in this area. This mathematically rigorous course emphasizes the
setup and solution of boundary value problems in mechanics, and
attempts to integrate the primary behaviors with deformation and failure
mechanisms in materials. Special topics covered may include (depending
on the interests of the student body) wave propagation, viscoelasticity,
geomechanics or biomechanics.
Instructor(s): J. El-Awady
Area: Engineering.

EN.530.610. Statistical Mechanics in Biological Systems. 3.0 Credits.
Application of equilibrium and nonequilibrium concepts in statistical
mechanics to biology is presented in some detail. Topics include many-
body dynamics and equilibrium ensembles, thermodynamics and phase
transitions, free energy functionals, computer simulations of biological
systems, nonequilibrium model such as the Langevin equation and the
Fokker-Planck equation, kinetic models of biochemical networks, Markov
models of stochastic systems and pattern formation in nonequilibrium
systems. Emphasis will be on quantitative understanding of biological
problems.
Instructor(s): S. Sun.

EN.530.612. Computational Solid Mechanics. 3.0 Credits.
This course teaches in-depth and hands-on understanding of numerical
methods for solid mechanics problems. The course begins with a review
of the fundamental concepts of the finite element method for linear
boundary value problems (BVP) and initial boundary value problems
(IBVP) in solid mechanics. Then more advance methods for nonlinear
BVPs are presented and applied to problems of material inelasticity and
finite elasticity. Topics covered include the strong and weak statements
of the BVP, weighted residual methods, time integration, Newton-type
methods for nonlinear problems, and error estimation and convergence.
Instructor(s): T. Nguyen.

EN.530.618. Fabricatology - Advanced Materials Processing. 3.0 Credits.
The “Fabricatology” is a course that students can learn how to make
desired shapes, structures, and surfaces across various length scales.
It will introduce rich scientific and engineering knowledge related to
fabrication at multiple length scales and the generated materials and
mechanical systems can be utilized for studying diverse topics including
energy harvesting, metamaterials, wetting, and information storage.
From this course, students can learn principles and technologies to
control shapes at various length scales and processes to control internal
structures or surface properties for desired properties/functions. They
will be also introduced to exciting recent development in the field so
that they can have a comprehensive knowledge about the subject.
Recommended Course Background: coursework in introduction to
materials chemistry or engineering materials.
Instructor(s): S. Kang.

EN.530.619. Aerospace Structures and Materials. 3.0 Credits.
A graduate-level introduction to the design of aircraft and spacecraft
structures and components. This course will build on skills learned
in EN.530.215 Mechanics Based Design and EN.530.352 Materials
Selection. Recommended Course Background: EN.530.352 (or knowledge
of materials selection) or instructor permission.
Instructor(s): T. Dragone.

EN.530.621. Fluid Dynamics I. 3.0 Credits.
Kinematics. Stress. Conservation of mass, momentum, and energy.
Newtonian fluids. The Navier-Stokes equations. Inviscid flows. Laminar
flows. Compressible flows. Introduction to non-Newtonian fluids.
Instructor(s): T. Zaki.

EN.530.622. Fluid Dynamics II. 3.0 Credits.
Kinematics. Stress. Conservation of mass, momentum, and energy.
Newtonian fluids. The Navier-Stokes equations. Inviscid flows. Laminar
flows. Compressible flows. Introduction to non-Newtonian fluids.
Instructor(s): J. Katz.

EN.530.624. Dynamics of Robots and Spacecraft (Graduate). 3.0 Credits.
An introduction to Lagrangian mechanics with application to robot and
spacecraft dynamics and control. Topics include rigid body kinematics,
efficient formulation of equations of motion, stability theory, and
Hamilton’s principle.
Instructor(s): J. Kim.

EN.530.625. Turbulence. 3.0 Credits.
Fundamental equations of fluid mechanics, Reynolds averaging, and the
closure problem. Scaling and self-preservation in boundary-free and wall-
bounded shear flows. Isotropic turbulence and spectral theories. Vorticity
dynamics, intermittency, and cascade models. Turbulence modeling:
one- and two-equation models, Reynolds stress modeling, and large-eddy
simulations.
Instructor(s): C. Meneveau.

EN.530.626. Statistical Mechanics and Extreme Value Distributions. 3.0
Credits.
The course will explore a collection of statistical mechanics minimal
models and approaches that are been used in several topics of materials
science and engineering. An introduction to the basics of statistical
mechanics will be followed by focus on specific models, one each week
or so. While lectures will focus on the basic theory and applications of the
model, the homework sets will guide the students to develop a code of
the model in Python or Matlab, test its accuracy, and investigate specific
aspects of the model’s predictions. Through the study of these models,
statistical properties and distributions will be explored in situ, as well as
their connections to extreme value statistics. In the span of the semester,
it is expected to investigate models of thermodynamic phase transitions,
fracture of brittle, disordered solids, crystal plasticity, amorphous solid
plasticity, percolation, rigidity percolation, jamming of repulsive spheres,
crowd dynamics.
Instructor(s): S. Papanikolaou.

EN.530.628. Nonlinear Dynamical Systems - Mechanics and Biology. 3.0
Credits.
Nonlinear dynamical systems theory are discussed in the context of
mechanics, engineering and biological problems. Concepts such as
stability, bifurcations, limit cycles and chaos are illustrated using simple
analytic theories as well as practical examples. Emphasis are placed on
developing intuition using analytic approaches and simple numerical
calculations. The course is appropriate for graduate students with
foundational knowledge of solid and fluid mechanics, and some notions
of statistical mechanics and biological concepts.
Instructor(s): D. Gayme; S. Sun.
EN.530.630. Applied Finite Element Analysis. 3.0 Credits.
This course will introduce finite element methods for analysis of solids, structures and heat transfer problems. Following topics will be considered. Procedure to defining a mechanics problem: governing equations, constitutive equations, boundary and initial value problems. Theory and implementation of the finite element methods for static analysis using linear elasticity. Finite element analysis (FEA) using ABAQUS software. Verification and validation, understanding uncertainty. Introduction to other FEA topics: structural elements, dynamic analysis, heat transfer and thermodynamics using ABAQUS. The course will include assignments and a term project. The term project is mandatory for graduate students and will involve applying FEA to an engineering problem or a research problem, interpretation of results and documenting a term paper. Recommended Course Background: Course(s) in Linear Algebra, Differential Equations required; matrix analysis / algebra and programming.
Instructor(s): N. Daphalapurkar.

EN.530.632. Convection. 3.0 Credits.
This course begins with a review of the phenomenological basis of the constitutive models for energy and mass flux. Then, using the transport theorem, general conservation and balance laws are developed for mass, species, energy, and entropy. Scaling analysis is used to determine when simplifications are justified, and simplified cases are solved analytically. Experimental results and correlations are given for more complex situations. Free, mixed, and forced internal and external convection are studied, and convection with a phase change is also explored.
Instructor(s): J. Seo.

EN.530.633. Mechanics of the Biological Systems and Biophysical Methodologies. 3.0 Credits.
Introduction to the following topics and tools used in these subfields: 1. The hierarchical structure of biological systems. 2. The dynamical nature of the biological systems. 3. Quantitative characterization of biological behaviors. 4. The modern tools used to measure biophysical parameters
Recommended Course Background: Introductory Physics, Calculus, and Linear Algebra
Instructor(s): Y. Chen.

EN.530.635. Guidance and Control of Flight Vehicles. 3.0 Credits.
This course introduces the fundamental concepts of guidance and control of rockets and will highlight methodologies often employed in industry. The topics covered include: aerodynamic control, review of flight control principles (transfer functions, block diagram reduction, root locus, frequency domain methods), nonlinear representation of an airframe, linearization of an airframe, flight control design of a rocket, three-loop autopilot design, and fundamentals of tactical guidance (proportional navigation guidance theory, zero effort miss). Recommended Course Background: EN.530.343: Design and Analysis of Dynamic Systems or equivalent knowledge if the course was not previously taken. Co-listed with EN.530.436
Instructor(s): K. Phillips.

EN.530.636. Bioinspired Science and Technology. 3.0 Credits.
Nature has been a source of inspiration for scientists and engineers and it receives particular attention recently to address many challenges the human society encounter. The course will study novel natural materials/structures with unique properties, the underlying principles, and the recent development of the bio-inspired materials and systems. From this course, students can learn about ingenious and sustainable strategies of organisms, open eyes about various phenomena in nature, and get inspiration for opening new directions of science and technology.
Instructor(s): N. Cowan; S. Kang.

EN.530.637. Energy and the Environment. 3.0 Credits.
This course focuses on advanced topics related to energy and thermodynamics. The objective of this course is to provide a thorough understanding of the environmental impacts related to energy conversion systems. The use of the second law of thermodynamics is introduced to quantify the performance of energy conversion systems. Topics such as global warming, alternative energy sources (solar, wind power, geothermal, tides, etc.) and new technology (fuel cells and hydrogen economy) and resources and sustainable development are addressed. A section of the course is devoted to current trends in nuclear energy generation and environmental issues associated with it.
Instructor(s): C. Herman.

EN.530.642. Plasticity. 3.0 Credits.
Instructor(s): S. Papanikolaou.

EN.530.643. Fundamentals of Microscale Phenomena. 3.0 Credits.
This course will introduce fundamental physical and chemical principles involved in unique microscale phenomena. Topics to be covered include issues associated with being in micrometers in science and engineering, fluid mechanics in micro systems, diffusion, surface tension, surfactants, and interfacial forces, Interfacial hydrodynamics, Mechanical properties of materials in microscale. Students will learn about applications, enabled by the discussed principles. Required Pre-Requisites: Knowledge of fluid mechanics and thermodynamics. Recommended Pre-Requisites: heat transfer. Suggested: advanced knowledge of fluid mechanics plus knowledge of cell and tissue engineering.
Instructor(s): S. Hur.

EN.530.645. Kinematics. 3.0 Credits.
A theoretical treatment of the kinematics of mechanisms, machines, and robotic manipulators intended for (though not restricted to) graduate students. Topics include parameterizations of spherical motion - Euler angles, Rodrigues parameters, unit quaternions, the matrix exponential; analysis of planar and spatial linkages; robot kinematics - forward and inverse kinematics, singularities, elementary topological issues; theory of wrenches and twists; research issues in robot kinematics - redundancy resolution, grasping and rolling contact, steering of nonholonomic systems. Other advanced topics will be covered as time permits. Recommended Course Background: Undergraduate linear algebra and multivariable calculus.
Instructor(s): G. Chirikjian.
EN.530.646. Robot Devices, Kinematics, Dynamics, and Control. 4.0 Credits.
Graduate-level introduction to the mechanics of robotic systems with emphasis on the mathematical tools for kinematics and dynamics of robot arms and mobile robots. Topics include the geometry and mathematical representation of rigid body motion, forward and inverse kinematics of articulated mechanical arms, trajectory generation, manipulator dynamics, actuation, and design issues, manipulator control, and additional special topics. Recommended course background: multivariable integral and differential calculus, classical physics, linear algebra, ordinary differential equations. Programming: Knowledge of the Matlab programming language including data input/output, 1-D and 2-D arrays, and user-defined function calls. Students with experience with these language elements in other programming languages (C, C++, Python, Java, etc.) should be able to self-tutor themselves in the Matlab language as part of the programming exercises.
Instructor(s): N. Cowan.

EN.530.647. Adaptive Systems. 4.0 Credits.
Graduate-level introduction to adaptive identification and control. Emphasis on applications to mechanical systems possessing unknown parameters (e.g., mass, inertia, friction). Topics include stability of linear and nonlinear dynamical systems, Lyapunov stability, input-output stability, adaptive identification, and direct and indirect adaptive control. Required Prerequisites: Calculus I, II, and III; Physics I and II; Linear Algebra; Differential Equations; Graduate linear systems theory such as EN.520.601 Introduction to Linear Systems Theory is required prerequisite. Audit registration not permitted.
Instructor(s): L. Whitcomb.

EN.530.649. System Identification. 3.0 Credits.
This course will cover several fundamental approaches system identification, including spectral, prediction error, subspace, and “online” (adaptive) identification methods. The emphasis will be on LTI systems, but some time will be devoted to system identification for classes of nonlinear dynamical systems, such as those that are linear in parameters.
Instructor(s): N. Cowan.

EN.530.653. Advanced Systems Modeling. 3.0 Credits.
This course covers the following topics at an advanced level: Newton’s laws of kinematics of systems of particles and rigid bodies; Lagrange’s equations for single- and multi-degree-of-freedom systems composed of point masses; normal mode analysis and forced linear systems with damping, the matrix exponential and stability theory for linear systems; nonlinear equations of motion; manipulator dynamics: Newton-Euler formulation, Lagrange, Kane’s formulation of dynamics, computing torques with O(n) recursive manipulator dynamics: Luh-Walker-Paul, Hollerbach, O(n) dynamics simulation: Rodrigues-Jain-Kreutz, Saha, Fixman. There is also an individual course project that each student must do which relates the topics of this course to his or her research.
Instructor(s): G. Chirikjian.

EN.530.654. Advanced Systems Modeling II. 3.0 Credits.
A continuation of EN.530.653, this course covers the following topics at an advanced level: Newton’s laws of kinematics of systems of particles and rigid bodies; Lagrange’s equations for single- and multi-degree-of-freedom systems composed of point masses; normal mode analysis and forced linear systems with damping, the matrix exponential and stability theory for linear systems; nonlinear equations of motion; structure, passivity, PD control, noise models and stochastic equations of motion; manipulator dynamics: Newton-Euler formulation, Lagrange, Kane’s formulation of dynamics, computing torques with O(n) recursive manipulator dynamics: Luh-Walker-Paul, Hollerbach, O(n) dynamics simulation: Rodrigues-Jain-Kreutz, Saha, Fixman. There is also an individual course project that each student must do which relates the topics of this course to his or her research.
Instructor(s): G. Chirikjian.
EN.530.672. Biosensing & BioMEMS. 3.0 Credits.
The course discusses the principles of biosensing and introduces micro- and nano-scale devices for fluidic control and molecular/cellular manipulation, measurements of biological phenomena, and clinical applications.
Instructor(s): J. Wang.

EN.530.675. Locomotion I: Mechanics. 3.0 Credits.
This is a course on the mechanics of locomotion in animals and machines (particularly bio-inspired and biomimetic robots). Locomotion emerges from effective physical interaction of an animal or a machine with the surrounding environment; therefore, the ability to generate appropriate forces (besides appropriate sensing and control) is essential to successful locomotion. From a mechanics point of view, we will discuss why animals move amazingly well in almost any environment, how they have inspired some highly successful machines, and yet why the majority of robots still struggle in environments that are only modestly complex and how they may be improved by better understanding the mechanics of locomotion. Primary focus will be on terrestrial locomotion, but aerial and aquatic locomotion will be also discussed, all with numerous examples. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Students from ME and other departments are welcome. A strong understanding of Newtonian mechanics is required. Visit http://li.me.jhu.edu/teaching for more information. Recommended Course Background: B+ or higher in EN.530.202 Dynamics or EN.560.202 Dynamics
Instructor(s): C. Li
Area: Engineering.

EN.530.676. Locomotion in Mechanical and Biological Systems. 3.0 Credits.
This is a course on the mechanics of locomotion in animals and machines (particularly bio-inspired and biomimetic robots). It will introduce you to the breadth of diverse topics within the field of animal and robot locomotion. We will discuss why animals move amazingly well in all kinds of environments, how they have inspired some highly successful machines, and yet why the majority of robots still struggle in environments that are only modestly complex. Terrestrial, aerial, and aquatic locomotion will be discussed, with numerous examples. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Students from ME and other departments are welcome. Please visit http://li.me.jhu.edu/teaching for updated information.
Instructor(s): N. Cowan.

EN.530.678. Nonlinear Control and Planning in Robotics. 3.0 Credits.
The course starts with a brief introduction to nonlinear systems and covers selected topics related to model-based trajectory planning and feedback control. Focus is on applications to autonomous robotic vehicles modeled as underactuated mechanical systems subject to constraints such as obstacles in the environment. Topics include: nonlinear stability, stabilization and tracking, systems with symmetries, differential flatness, backstepping, probabilistic roadmaps, stochastic optimization. Recommended Course Background: multi-variable/differential calculus, AS.110.302, AS.110.201, undergraduate linear control, basic probability theory.
Instructor(s): M. Kobilarov.

EN.530.671. TEM: Practice and Applications. 3.0 Credits.
A lab and lecture course covering the practical aspects of transmission electron microscopy. Electron diffraction, image formation, and analytical techniques are explained, and students are given an opportunity to gain hands-on microscopy experience.
Instructor(s): K. Hemker.

EN.530.682. Haptic Applications. 4.0 Credits.
An introduction to the required theoretical and practical background in the design and development of haptic applications. Haptic technology enables users to touch and/or manipulate virtual or remote objects in simulated environments or tele-operation systems. This course aims to cover the basics of haptics through lectures, lab assignments, a term project, and readings on current topics in haptics. Through lab assignments, students learn to create haptic-enabled virtual environments using software development toolkits and a haptic device. Students will be required to complete a project with approval of the instructor. Recommended course background: ME, CS, and ECE graduate and senior undergraduate students who are being enthusiastic to learn about haptics and knowledgeable in basic C++ programming. Students with experience with other programming languages (Python, Java, etc.) should be able to self-tutor themselves to complete lab assignments.
Instructor(s): M. Zadeh.

EN.530.684. Orientation Mapping of Crystalline Materials. 3.0 Credits.
Recent advances in instrumental capabilities are fast making it routine to acquire large 2D and 3D datasets and maps of crystalline materials. SEM-based orientation imaging microscopy (OIM) and transmission Kikuchi diffraction (TKD) and TEM-based precession-assisted crystal orientation mapping (PACOM) provide the means to characterize intra- and inter-granular details such as grain: orientation, size, shape, neighborhoods and GND distributions. This course will cover the science that underpins these technologies and provide practical experience in gathering, filtering, quantifying and displaying such information. It is motivated by the fact that emergent advances based on the practice of Integrated Materials Science and Engineering (ICMSE) and the Materials Genome Initiative (MGI) are predicated on the availability of physics-based, multi-scale models that are based on such detailed quantitative experimental observations of polycrystalline materials.
Instructor(s): K. Hemker.

EN.530.686. Mechanics of Locomotion. 3.0 Credits.
This is a course on the mechanics of locomotion in animals and machines (particularly bio-inspired and biomimetic robots). It will introduce you to the breadth of diverse topics within the field of animal and robot locomotion. We will discuss why animals move amazingly well in all kinds of environments, how they have inspired some highly successful machines, and yet why the majority of robots still struggle in environments that are only modestly complex. Terrestrial, aerial, and aquatic locomotion will be discussed, with numerous examples. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Students from ME and other departments are welcome. Please visit http://li.me.jhu.edu/teaching for updated information. Co-listed with EN.530.486
Instructor(s): C. Li.
EN.530.691. Haptic Interface Design for Human-Robot Interaction. 3.0 Credits.
This course provides an introduction to haptic interface design and analysis for human-robot interaction involving virtual environments, augmented reality, and teleoperation. Topics include human touch perception, haptic-focused mechatronic design, system modeling and analysis (kinematic and dynamic), human-in-the-loop feedback control, and haptic feedback evaluation. Recommended: coursework or knowledge of Dynamics and knowledge of feedback control, mechatronics, and Matlab.
Instructor(s): J. Brown.

EN.530.707. Robot System Programming. 4.0 Credits.
Graduate-level introduction to adaptive identification and control.
Emphasis on applications to mechanical systems possessing unknown parameters (e.g., mass, inertia, friction). Topics include stability of linear and nonlinear dynamical systems, Lyapunov stability, input-output stability, adaptive identification, and direct and indirect adaptive control.
Audit registration not permitted. Required Prerequisites: Multivariable Calculus, Classical Physics, Linear Algebra, Differential Equations, and EN.520.601 Introduction to Linear Systems Theory.
Instructor(s): L. Whitcomb.

EN.530.710. Optical Measurement Techniques. 3.0 Credits.
Optic-based techniques are being utilized as measurement and data transmission tools in a growing number of applications. The objective of this course is to introduce graduate students with limited background in optics (but with background in graduate-level mathematics) to the fundamentals of optics and their implementation. Topics covered include reflection, refraction, fluorescence, phosphorescence and diffraction of light; review of geometric optics, lenses, lens systems (microscope, telescope), mirrors, prisms; aberrations, astigmatism, coma, and methods to correct them; light as an electromagnetic wave; Fourier optics; spectral analysis of optical systems; coherent and incoherent imaging, holography, interferometry, diffraction grating; lasers, polarization, light detectors; elements of non-linear optics, birefringence; optical fibers, data transmission, and networking.
Instructor(s): J. Katz.

EN.530.726. Hydrodynamic Stability. 3.0 Credits.
Hydrodynamic linear stability theory is developed and applied to a variety of flow problems using analytical techniques and numerical methods. Necessary and sufficient conditions for flow stability are derived. Canonical examples are used to introduce various concepts including, e.g. temporal and spatial analyses, asymptotic and transient flow response, convective and absolute instability, global methods, and direct stability analysis.
Instructor(s): T. Zaki.

EN.530.732. Fracture Of Materials. 3.0 Credits.
An advanced examination of fracture mechanisms in ductile and brittle materials. Both the mechanics and the materials aspects are covered with importance placed on the synthesis of the two approaches. Topics include linear elastic fracture mechanics, ductile fracture, the J-integral, atomistic aspects of fracture in polycrystalline materials, fracture in ceramics and polymers, influence of the material microstructure on fracture toughness and ductility in FCC and BCC materials.
Instructor(s): K. Ramesh.

EN.530.748. Stress Waves, Impacts and Shockwaves. 3.0 Credits.
Instructor(s): K. Ramesh.

EN.530.761. Mathematical Methods of Engineering I. 3.0 Credits.
This course is a fast-paced overview of some fundamental topics in applied mathematics: analytic functions, matrix theory, vector analysis, ordinary differential equations, Bessel functions, fundamental properties of the delta distribution, elements of partial differential equations, two-sided and one-sided Fourier transforms, Laplace transform. Mechanical Engineering graduate students only.
Instructor(s): D. Gayme.

EN.530.766. Numerical Methods. 3.0 Credits.
Elementary introduction to numerical methods for the solution of fundamental problems in engineering. Computer assignments requiring programming.
Instructor(s): R. Mittal.

EN.530.767. Computational Fluid Dynamics. 3.0 Credits.
Advanced introduction to finite-difference and finite-volume approaches to modeling incompressible flows. Computer project requiring programming.
Instructor(s): R. Mittal.

EN.530.772. Non-Linear Finite Elements. 3.0 Credits.
This course will discuss state of the art theoretical developments and modeling techniques in nonlinear computational mechanics, for problems with geometric and material nonlinearities. Large deformation of elastic-plastic and visco-plastic materials, contact-friction and other heterogeneous materials like composites and porous materials will be considered. A wide variety of applications in different disciplines, e.g., metal forming, composite materials, polycrystalline materials will be considered. Co-listed with EN.560.772.
Instructor(s): S. Ghosh.

EN.530.790. Advanced Finite Element Methods and Multi-Scale Methods. 3.0 Credits.
Adaptive Methods: p-, h-, and r-Adaptivity, Error Indicators, Residual, Global and Local Projection, Strategies for Adaptive Analysis; Element Instabilities and Locking: Babuska Brezzi (BB) Condition; Reduced and Selective Integration Techniques; Stiffness Matrix Rank and Rank Deficiency, Spurious Singular Modes; Hourglassing; Mixed and Hybrid Finite Element Methods; Mixed Variational Principles; Hu-Washizu Stabilization, Assumed Stress Hybrid Method; Conclusions. Multi-Scale Methods: Homogenization and Multiscale Models; Concurrent Multiscale Analysis of Composites, Multilevel Model for Damage Analysis in Composites. Computer project.
Instructor(s): S. Ghosh.

EN.530.800. Independent Study. 3.0 - 20.0 Credits.
Instructor(s): Staff.

EN.530.801. PhD Graduate Research. 3.0 - 20.0 Credits.
Instructor(s): Staff.

EN.530.802. PhD Graduate Research. 3.0 - 20.0 Credits.
Department approval required to enroll in 01.
Instructor(s): Staff.

EN.530.803. Mechanical Engineering Seminar. 1.0 Credit.
Instructor(s): S. Sun.

EN.530.804. Mechanical Engineering Seminar. 1.0 Credit.
Instructor(s): S. Sun.

EN.530.807. Graduate Research Seminar in Fluid Mechanics. 1.0 Credit.
Instructor(s): J. Katz.

EN.530.808. Graduate Seminar in Fluid Mechanics. 1.0 Credit.
Instructor(s): J. Katz.
EN.530.809. Mechanics of Materials and Structures Graduate Seminar. 1.0 Credit.
Cross-listed with Mechanical Engineering.
Instructor(s): S. Kang.

EN.530.810. Mechanics and Materials Graduate Seminar. 1.0 Credit.
Instructor(s): J. El-Awady.

EN.530.897. Research-Summer. 3.0 - 20.0 Credits.
Instructor(s): Staff.

EN.530.899. Independent Study-Summer. 1.0 - 3.0 Credits.
Instructor(s): Staff.

Cross Listed Courses

General Engineering
EN.500.602. Seminar: Environmental and Applied Fluid Mechanics. 1.0 Credit.
Instructor(s): J. Katz.

EN.500.745. Seminar in Computational Sensing and Robotics. 1.0 Credit.
Seminar series in robotics. Topics include: Medical robotics, including computer-integrated surgical systems and image-guided intervention. Sensor based robotics, including computer vision and biomedical image analysis. Algorithmic robotics, robot control and machine learning. Autonomous robotics for monitoring, exploration and manipulation with applications in home, environmental (land, sea, space), and defense areas. Biobotics and neuromechanics, including devices, algorithms and approaches to robotics inspired by principles in biomechanics and neuroscience. Human-machine systems, including haptic and visual feedback, human perception, cognition and decision making, and human-machine collaborative systems. Cross-listed Mechanical Engineering, Computer Science, Electrical and Computer Engineering, and Biomedical Engineering.
Instructor(s): L. Whitcomb, P. Kazanzides.

Electrical Computer Engineering
EN.520.353. Control Systems. 3.0 Credits.
Modeling, analysis, and an introduction to design for feedback control systems. Topics include state equation and transfer function representations, stability, performance measures, root locus methods, and frequency response methods (Nyquist, Bode).
Prerequisites: Prereqs: EN.530.343 AND EN.520.214
Instructor(s): E. Mallada Garcia
Area: Engineering.

EN.520.495. Microfabrication Laboratory. 4.0 Credits.
This laboratory course is an introduction to the principles of microfabrication for microelectronics, sensors, MEMS, and other synthetic microsystems that have applications in medicine and biology. Course comprises of laboratory work and accompanying lectures that cover silicon oxidation, aluminum evaporation, photoresist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services. Students only or Perm. Req’d. Co-listed as EN.580.495 & EN.530.495
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): A. Andreou, J. Wang
Area: Engineering, Natural Sciences.

EN.520.773. Advanced Topics In Microsysnem Fabrication. 4.0 Credits.
Graduate-level course on topics that relate to microsystem integration of complex functional units across different physical scales from nano to micro and macro. Course comprises of laboratory work and accompanying lectures that cover silicon oxidation, aluminum evaporation, photoresist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services. Topics will include emerging fabrication technologies, micro-electromechanical systems, nanolithography, nanotechnology, soft lithography, self-assembly, and soft materials. Discussion will also include biological systems as models of microsystem integration and functional complexity. Perm. Required.
Instructor(s): A. Andreou, J. Wang.

Civil Engineering
EN.560.201. Statics & Mechanics of Materials. 4.0 Credits.
Basic principles of classical mechanics applied to the equilibrium of particles and rigid bodies at rest, under the influence of various force systems. In addition, the following topics are studied: free body concept, analysis of simple structures, friction, centroids and centers of gravity, and moments of inertia. Includes laboratory experience. Co-listed with EN.530.201.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
AS.171.101 OR AS.171.107 or instructor permission.
Instructor(s): R. Sangree
Area: Engineering.

Biomedical Engineering
EN.580.451. Cell and Tissue Engineering Lab. 3.0 Credits.
Cell and tissue engineering is a field that relies heavily on experimental techniques. This laboratory course will consist of three six experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Students will learn basic cell culture procedures and specialized techniques related to faculty expertise in cell engineering, microfluidics, gene therapy, microfabrication and cell encapsulation. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. Co-listed with EN.530.451. Senior and Graduate students only; others, instructor permission required. Fall semester only. Lab Fee: $100
Instructor(s): E. Haase
Area: Engineering, Natural Sciences.

Entrepreneurship and Management
EN.660.361. Engineering Business and Management. 3.0 Credits.
An introduction to the business and management aspects of the engineering profession, project management, prioritization of resource allocation, intellectual property protection, management of technical projects, and product/production management. Preference will be given to Mechanical Engineering students. No audits. Recommended Course Background: EN.660.105
Instructor(s): I. Izenberg, M. Agronin
Area: Engineering, Natural Sciences.
EN.660.461. Engineering Business and Management. 3.0 Credits.
An introduction to the business and management aspects of the engineering profession, project management, prioritization of resource allocation, intellectual property protection, management of technical projects, and product/production management. Preference will be given to Mechanical Engineering students. No audits. Recommended Course Background: EN.660.105
Instructor(s): I. Izenberg; M. Agronin
Area: Engineering.