MECHANICAL ENGINEERING

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. The department offers undergraduate tracks in biomechanical engineering and aerospace engineering. 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, and biomechanics. 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 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 small teams 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
The Mechanical Engineering department office is located in 223 Latrobe Hall. The teaching and research facilities of the department are located in Latrobe, Clark, Krieger, Wyman, Maryland, Malone, and Hackerman Halls.

The thermal-fluids teaching laboratory in Krieger Hall supports courses in Thermodynamics, Fluid Mechanics, and Thermal Processes. The undergraduate laboratories at the Wyman Park Building support courses in Design and CAD, Electronics and Instrumentation, Mechanics-Based Design, Robot Sensors and Actuators, Mechatronics, and Dynamical Systems. The Senior Design laboratories are used by seniors to construct and test their prototypes in the yearlong design project course.

The many research laboratories within Mechanical Engineering support a variety of focus areas including: turbulence, oceanographic fluid dynamics, turbomachinery, microfluidics, locomotion (sea, land, and air), mechanisms of deformation and damage, impact dynamics, additive manufacturing, polymer mechanics, mechanics of soft tissues, biophotonics, cellular mechanics, bioMEMS, robot and protein kinematics, haptics, medical robots, underwater robots, and autonomous vehicles.

Financial Aid
Scholarships and other forms of financial aid for undergraduates are described under Admissions and Finances (http://e-catalog.jhu.edu/undergrad-students/admissions-and-finances). Selected undergraduates may be employed as laboratory assistants on research projects.

Financial aid in the form of partial tuition coverage is provided to select master’s students. All master’s students will receive partially-covered health insurance, but most master’s students will be responsible for full tuition and other costs.

For Ph.D. students, financial aid is available through departmental fellowships and research assistantships that cover tuition, health insurance, dental and vision coverage, a one-time matriculation fee and a salary. Research assistantships support graduate students who work with professors on their research contracts and grants.

Competitively-awarded teaching assistant positions that pay a few hundred to a few thousand dollars per semester may be available, but are not guaranteed.

Applications for graduate study must be received by October 15 (Ph.D. only) for the Spring semester and December 15 (both Ph.D. and M.S.E.) for the Fall semester for consideration.

Undergraduate Programs
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 tracks 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 (http://me.jhu.edu/undergraduate-studies/academic-advising-undergraduate).

For details and an explanation of ABET requirements, visit 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) and the department’s undergraduate advising manuals (http://me.jhu.edu/undergraduate-studies/academic-advising-undergraduate).

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.

Our primary objective is to 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

- an ability to apply both analysis and synthesis in the engineering design process, resulting in designs that meet desired needs.
- an ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.
- an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must be socially, economically, and environmentally acceptable.
- an ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics.
- an ability to recognize the impact of engineering solutions in global, economic, and societal contexts.

Humanities (18 credits)

Six humanities and/or social science electives, of which one must specifically teach writing (either AS.220.105, AS.060.100, AS.060.113 or AS.060.114). See the Distribution tab in the Requirements for a Bachelor's Degree section for two exceptions to the rule that each H/S distribution course be at least 3 credits. Visit http://e-catalog.jhu.edu/undergrad-students/academic-policies/requirements-for-a-bachelors-degree/ for information.

Required Engineering Courses (50 credits)

(Grades below C are not accepted)

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<td>EN.530.107 MechE Undergraduate Seminar I</td>
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<tr>
<td>EN.530.108 MechE Undergraduate Seminar II</td>
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</tr>
<tr>
<td>EN.530.111 Intro to MechE Design and CAD</td>
<td>2</td>
</tr>
<tr>
<td>EN.530.115 MechE Freshman Lab I</td>
<td>1</td>
</tr>
<tr>
<td>EN.500.114 Gateway Computing: Matlab (AP Computer Science not accepted)</td>
<td>3</td>
</tr>
<tr>
<td>EN.560.201 Statics &amp; Mechanics of Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.560.202 Mechanical Engineering Dynamics</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.212 MechE Dynamics Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.215 Mechanics-Based Design</td>
<td>3</td>
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<tr>
<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>
</tr>
<tr>
<td>EN.530.232 Mechanical Engineering Thermodynamics Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.241 Electronics &amp; Instrumentation</td>
<td>4</td>
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<tr>
<td>or EN.520.230 Mastering Electronics</td>
<td></td>
</tr>
<tr>
<td>EN.520.230 is the alternate effective Fall 2017.</td>
<td></td>
</tr>
<tr>
<td>EN.530.254 Manufacturing Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.327 Introduction to Fluid Mechanics</td>
<td>3</td>
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<tr>
<td>EN.530.329 Introduction to Fluid Mechanics Laboratory</td>
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<td>EN.530.334 Heat Transfer</td>
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<td>EN.530.335 Heat Transfer Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.343 Design and Analysis of Dynamical Systems</td>
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</tr>
<tr>
<td>EN.530.344 Design and Analysis of Dynamical Systems Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.352 Materials Selection</td>
<td>4</td>
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<tr>
<td>EN.660.361 Engineering Business and Management</td>
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</table>

Mechanical Engineering Electives (9 credits)

(Grades below C are not accepted)

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

Technical Electives (9 credits)

(Grades below C are not accepted)

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.
A student may specialize in biomechanics 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):

Any five of the courses listed below are required. A sixth course from this list, though not required is highly recommended.

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<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>EN.530.418</td>
<td>Aerospace Structures &amp; Materials</td>
<td>3</td>
</tr>
<tr>
<td>or EN.530.619</td>
<td>Aerospace Structures &amp; Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.424</td>
<td>Dynamics of Robots and Spacecraft</td>
<td>3</td>
</tr>
<tr>
<td>or EN.530.624</td>
<td>Dynamics of Robots and Spacecraft (Graduate)</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.425</td>
<td>Mechanics of Flight</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.427</td>
<td>Intermediate Fluid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.432</td>
<td>Jet &amp; Rocket Propulsion</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.470</td>
<td>Space Vehicle Dynamics &amp; Control</td>
<td>3</td>
</tr>
<tr>
<td>AS.171.321</td>
<td>Introduction to Space, Science, and Technology</td>
<td>3</td>
</tr>
<tr>
<td>AS.270.318</td>
<td>Remote Sensing of the Environment</td>
<td>3</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>AS.171.118</td>
<td>Stars and the Universe: Cosmic Evolution</td>
<td>3</td>
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</table>

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 (*).

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>EN.510.435</td>
<td>Mechanical Properties of Biomaterials</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.410</td>
<td>Biomechanics of the Cell</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.426</td>
<td>Biofluid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.436</td>
<td>Bioinspired Science and Technology</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.439</td>
<td>Comparative Biomechanics</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.530.474</td>
<td>Effective and Economic Design for Biomedical Instrumentation</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.530.475</td>
<td>Locomotion I: Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.480</td>
<td>Image Processing and Data Visualization</td>
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<td>EN.530.495</td>
<td>Microfabrication Laboratory</td>
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<tr>
<td>EN.530.672</td>
<td>Biosensing &amp; BioMEMS</td>
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<tr>
<td>EN.540.405/605</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>
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<tr>
<td>EN.580.221</td>
<td>Molecules and Cells</td>
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<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 I</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.424</td>
<td>Systems Bioengineering Lab II</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.451</td>
<td>Cell and Tissue Engineering Lab</td>
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<tr>
<td>EN.580.452</td>
<td>Cell and Tissue Engineering Lab</td>
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</tr>
<tr>
<td>EN.580.456</td>
<td>Introduction to Rehabilitation Engineering</td>
<td>3</td>
</tr>
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</table>

Prerequisite: AS.030.101 Introductory Chemistry I

Students may not use the satisfactory/unsatisfactory option for required courses, including Humanities and Social Studies. Exceptions can be considered and approved by their faculty advisors. Further, the Department of Mechanical Engineering requires that grades of C- or better be obtained in all required engineering, mathematics, and science courses (i.e. grades of D, D+ or F will not be accepted). The department
will accept D or D+ grades only up to a maximum of 10 credits for Humanities and Social Sciences courses.

**Sample Program**

<table>
<thead>
<tr>
<th>First Year</th>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
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<tr>
<td></td>
<td>AS.110.108 Calculus I</td>
<td>4</td>
<td>AS.110.109 Calculus II (For Physical Sciences and Engineering)</td>
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<td>AS.030.101 Introductory Chemistry I</td>
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<td>Humanities/Social Sciences Elective</td>
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<td>EN.530.107 MechE Undergraduate Seminar I</td>
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<td>EN.530.108 MechE Undergraduate Seminar II</td>
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<tr>
<td></td>
<td>EN.530.111 Intro to MechE Design and CAD</td>
<td>2</td>
<td>EN.530.124 Intro to Mechanics II</td>
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<td></td>
<td>EN.530.115 MechE Freshman Lab I</td>
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<td>EN.500.114 Gateway Computing: Matlab</td>
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<td>EN.530.123 Introduction to Mechanics I</td>
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<td>Humanities/Social Sciences Elective</td>
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<td>Humanities/Social Sciences Elective: Writing Intensive (AS.060.100, AS.060.113, AS.060.114, or AS.220.105)</td>
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<tr>
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<td>AS.110.202 Calculus III</td>
<td>4</td>
<td>EN.530.202 Mechanical Engineering Dynamics</td>
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<td>EN.560.201 Statics Mechanics of Materials</td>
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<td>EN.530.212 MechE Dynamics Laboratory</td>
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<td>EN.530.231 Mechanical Engineering Thermodynamics</td>
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<td>EN.530.215 Mechanics-Based Design</td>
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<td>EN.530.232 Mechanical Engineering Thermodynamics: Laboratory</td>
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<td>EN.530.216 Mechanics-Based Design Laboratory</td>
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<td>AS.171.102 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 General Physics Laboratory II</td>
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<td>EN.553.291 Linear Algebra and Differential Equations</td>
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<th>Third Year</th>
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<tr>
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<td>EN.530.254 Manufacturing Engineering</td>
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<td>EN.530.334 Heat Transfer</td>
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<td>EN.530.327 Introduction to Fluid Mechanics</td>
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<td>EN.530.335 Heat Transfer Laboratory</td>
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<th>Fourth Year</th>
<th>Fall</th>
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<th>Spring</th>
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<td></td>
<td>EN.530.329 Introduction to Fluid Mechanics</td>
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<td>EN.530.343 Design and Analysis of Dynamical Systems</td>
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<td>EN.530.352 Materials Selection</td>
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<td>EN.530.344 Design and Analysis of Dynamical Systems Laboratory</td>
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<td>Statistics Elective</td>
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<td>Mechanical Engineering Elective</td>
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<td>Technical Elective</td>
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<td>Mechanical Engineering Elective</td>
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<td>Humanities/Social Sciences Elective</td>
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<td>Technical Elective</td>
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<tr>
<td></td>
<td>Humanities/Social Sciences Elective</td>
<td>3</td>
<td>Technical Elective</td>
<td>3</td>
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<tr>
<td></td>
<td>Technical Elective</td>
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<td>Humanities/Social Sciences Elective</td>
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<td></td>
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Total Credits: 122

**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:

1. An ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply both analysis and synthesis in the engineering design process, resulting in designs that meet desired needs.
3. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
4. An ability to communicate effectively with a range of audiences.
5. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
6. An ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.
7. An ability to function effectively on teams that establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty.

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, 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 Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
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</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></td>
</tr>
<tr>
<td>or AS.110.212</td>
<td>Honors Linear Algebra</td>
<td></td>
</tr>
</tbody>
</table>

Mathematics elective

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.560.348</td>
<td>Probability &amp; Statistics in Civil Engineering</td>
<td>3-4</td>
</tr>
<tr>
<td>or EN.553.31</td>
<td>Probability &amp; Statistics</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.553.291</td>
<td>Linear Algebra and Differential Equations</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.212</td>
<td>Honors Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>or AS.110.201</td>
<td>Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>&amp; AS.110.302</td>
<td>and Differential Equations and Applications</td>
<td></td>
</tr>
</tbody>
</table>

### Basic Science (16-17 credits)
(Grades below C- are not accepted)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.030.101</td>
<td>Introductory Chemistry 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>AS.173.112</td>
<td>General Physics Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.123</td>
<td>Introduction to Mechanics I</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.124</td>
<td>Intro to Mechanics II</td>
<td>2</td>
</tr>
</tbody>
</table>

Another basic science elective

### Humanities (18 credits)
Six humanities and/or social science electives, of which one must specifically teach writing (either AS.220.105, AS.060.100, AS.060.113 or AS.060.114). See the Distribution tab in the Requirements for a Bachelor's Degree section for two exceptions to the rule that each H/S distribution course be at least 3 credits. Visit http://e-catalog.jhu.edu/undergrad-students/academic-policies/requirements-for-a-bachelors-degree/ for information.

### Introductory Engineering and Computing

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.530.107</td>
<td>MechE Undergraduate Seminar I</td>
<td>0.5</td>
</tr>
<tr>
<td>EN.530.108</td>
<td>MechE Undergraduate Seminar II</td>
<td>0.5</td>
</tr>
<tr>
<td>EN.500.114</td>
<td>Gateway Computing: Matlab</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.111</td>
<td>Intro to MechE Design and CAD</td>
<td>2</td>
</tr>
<tr>
<td>EN.530.115</td>
<td>MechE Freshman Lab I</td>
<td>1</td>
</tr>
</tbody>
</table>

Alternate introductory courses are available. If EN.530.107/108, EN.530.111, EN.530.115, and EN.530.123/124 are not taken, students must take one course from the engineering course lists below:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.500.101</td>
<td>What Is Engineering?</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.137</td>
<td>Introduction To Electrical &amp; Computer Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.570.108</td>
<td>Introduction to Environmental Engineering and Design</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.202</td>
<td>Bme In The Real World</td>
<td>1</td>
</tr>
</tbody>
</table>

### Other Required Engineering Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.560.201</td>
<td>Statics &amp; Mechanics of Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.202</td>
<td>Mechanical Engineering Dynamics</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.212</td>
<td>MechE Dynamics Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.215</td>
<td>Mechanics-Based Design</td>
<td>3</td>
</tr>
<tr>
<td>or EN.530.405</td>
<td>Mechanics of Advanced Engineering Structures</td>
<td></td>
</tr>
<tr>
<td>EN.530.216</td>
<td>Mechanics Based Design Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.231</td>
<td>Mechanical Engineering Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.232</td>
<td>Mechanical Engineering Thermodynamics Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.327</td>
<td>Introduction to Fluid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.329</td>
<td>Introduction to Fluid Mechanics Laboratory</td>
<td>1</td>
</tr>
</tbody>
</table>

### Capstone Design (8 credits)
(Grades below C- are not accepted)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.530.403</td>
<td>MechE Senior Design Project I</td>
<td>4</td>
</tr>
<tr>
<td>&amp; EN.530.404</td>
<td>MechE Senior Design Project II</td>
<td></td>
</tr>
</tbody>
</table>

### Engineering Science Electives (12 credits)
(Grades below C- are not accepted)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.530.291</td>
<td>Linear Algebra and Differential Equations</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.212</td>
<td>Honors Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>or AS.110.201</td>
<td>Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>&amp; AS.110.302</td>
<td>and Differential Equations and Applications</td>
<td></td>
</tr>
</tbody>
</table>

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 (3 credits)
(Grades below C- are not accepted)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.530.304</td>
<td>Mechanics of Materials and Structures</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.413</td>
<td>Structural Mechanics and Materials</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.414</td>
<td>Mechanics of Fluids and Materials</td>
<td>1</td>
</tr>
</tbody>
</table>

One additional elective course 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.060.100 Introduction to Expository Writing, or 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)

++ Appropriate choices from the social sciences and philosophy may be also used to fulfill this requirement. Because of the importance of computer languages in modern technical society, students may take computer language courses at any level.

* AP Computer Science credits are not accepted for the Gateway Computing requirement.

Fluid mechanics courses may be chosen from courses such as:

- EN.530.425 Mechanics of Flight 3
- EN.530.426 Biofluid Mechanics 3
- EN.530.427 Intermediate Fluid Mechanics 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.530.430 Applied Finite Element Analysis 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 Humanities and Social Science credits. 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. One course can be either EN.601.107 Intro to Java, EN.601.220 Intermediate Programming or EN.601.226 Data Structures

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

- EN.530.410 Biomechanics of the Cell 3
- EN.530.426 Biofluid Mechanics 3
- EN.530.436 Bioinspired Science and Technology 3
- EN.530.439 Comparative Biomechanics 3
- EN.530.441 Introduction to Biophotonics 3
- EN.530.443 Fundamentals, Principles and Applications of Microfluidic Systems 3
- EN.530.445 Introduction to Biomechanics 3
- EN.530.446 Experimental Methods in Biomechanics 3
- EN.530.448 Biosolid Mechanics 3
- EN.530.473 Molecular Spectroscopy and Imaging 3
- EN.530.474 Effective and Economic Design for Biomedical Instrumentation 3
- EN.530.475 Locomotion I: Mechanics 3
- EN.530.480 Image Processing and Data Visualization 3
- EN.530.485 Physics and Feedback in Living Systems 3
- EN.530.495 Microfabrication Laboratory 4
- EN.530.672 Biosensing & BioMEMS 3
- EN.540.440 Micro/Nanotechnology. The Science and Engineering of Small Structures 3
- EN.580.221 Molecules and Cells 4
- EN.580.421 Systems Bioengineering I 4
- EN.580.423 Systems Bioengineering Lab I 2
- EN.580.451 Cell and Tissue Engineering Lab 3
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.

**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 Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.030.101 Introductory Chemistry I</td>
<td>3</td>
<td>Humanities/Social Sciences Elective (2)</td>
<td>3</td>
</tr>
<tr>
<td>Humanities/Social Sciences Elective (1) - Writing</td>
<td>3</td>
<td>EN.530.108 MechE Undergraduate Seminar II</td>
<td>0.5</td>
</tr>
<tr>
<td>EN.530.107 MechE Undergraduate Seminar I</td>
<td>.5</td>
<td>EN.530.124 Intro to Mechanics II</td>
<td>2</td>
</tr>
<tr>
<td>EN.530.111 Intro to MechE Design and CAD</td>
<td>2</td>
<td>EN.500.114 Gateway Computing: Matlab</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.115 MechE Freshman Lab I</td>
<td>1</td>
<td>Basic Science Elective</td>
<td>4</td>
</tr>
<tr>
<td>If EN.530.107, 111, and 115 are not taken, then take Intro to Engineering and Lab I options</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EN.530.123 Introduction to Mechanics I</td>
<td>3</td>
<td>If EN.530.123 is not taken, then another intro to mechanics or physics course</td>
<td></td>
</tr>
</tbody>
</table>

**Total Credits:** 16.5

**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>EN.530.212 MechE Dynamics Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>AS.173.112 General Physics Laboratory II</td>
<td>1</td>
<td>EN.530.215 Mechanics-Based Design</td>
<td>3</td>
</tr>
</tbody>
</table>

**Total Credits:** 16.5

**Third Year**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.530.327 Introduction to Fluid Mechanics</td>
<td>3</td>
<td>Engineering Science elective (fluids)</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.329 Introduction to Fluid Mechanics Laboratory</td>
<td>1</td>
<td>Engineering Science elective (solids/fluids)</td>
<td>3</td>
</tr>
<tr>
<td>Technical Elective (2)</td>
<td>3</td>
<td>Technical Elective</td>
<td>3</td>
</tr>
<tr>
<td>Humanities/Social Sciences Elective (3)</td>
<td>3</td>
<td>Mathematics Elective</td>
<td>4</td>
</tr>
<tr>
<td>Statistics Elective</td>
<td>3</td>
<td>Humanities/Social Sciences Elective (4)</td>
<td>3</td>
</tr>
<tr>
<td>Engineering Science elective (solids)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Credits:** 16

**Fourth Year**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.530.403 MechE Senior Design Project I</td>
<td>4</td>
<td>EN.530.404 MechE Senior Design Project II</td>
<td>4</td>
</tr>
<tr>
<td>Engineering Mechanics elective (solids, fluids, dynamics)</td>
<td>3</td>
<td>Technical Elective (4)</td>
<td>4</td>
</tr>
<tr>
<td>Engineering Science elective (materials/dynamics)</td>
<td>3</td>
<td>Technical Elective (5)</td>
<td>4</td>
</tr>
<tr>
<td>Engineering Mechanics elective (solids, fluids, dynamics)</td>
<td>3</td>
<td>Humanities/Social Sciences Elective (6)</td>
<td>3</td>
</tr>
<tr>
<td>Humanities/Social Sciences Elective (5)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Credits:** 15

**Total Credits: 128**

**The Combined Five-Year Bachelor's / Master's Program**

The Mechanical Engineering Department offers a concurrent five-year bachelor's/master's program for mechanical engineering and engineering mechanics majors. Applications to the B.S./M.S.E. program should be submitted by January 6 for consideration of spring admission and June 16 for possible fall admission, during applicant's junior (third) year.

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.

Graduate Programs
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. 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 .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 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.

Details on grade requirements and other departmental academic policy for the M.S.E. degree can be found on the Mechanical Engineering Graduate Advising page at http://me.jhu.edu/graduate-studies/academic-advising-graduate/.

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 second 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
Department Head
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' (snakelike) 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
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.
Jaafer 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.

Soojung 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, cavititation 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 instrumentation, 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.

Rui Ni
Assistant Professor: Experimental fluid mechanics, Turbulence and turbulent multiphase flow, Dusty flow and particle-laden flow, Environmental fluid dynamics, Lagrangian particle tracking, Physiological flow, Animal collective behaviors, and Complex system

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
Gregory L. Eyink

Michael Falk
Vice Dean of Undergraduate Education; Computational Materials Science, Structural Materials, and Optoelectronic and Magnetic Materials

Somnath Ghosh
Michael G. Callas Chair Professor, Civil Engineering: Computational Mechanics Modeling with a focus on multi-scale structure-materials analysis and simulations, multi-physics modeling and simulation of multi-functional materials, materials characterization, process modeling, emerging fields like Integrated Computational Materials Engineering (ICME).

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

Gregory Hager
Mandell Bellmore Professor, Computer Science: computer vision, robotics, medical robotics, human-machine systems

Todd Hufnagel
Professor; X-ray scattering, metallic glasses, mechanical properties of materials, phase transformations, electron microscopy

Robert Ivkov
Associate Professor, Radiation Oncology and Molecular Radiation Sciences: Development, characterization, and use of nanomaterials to target cancer; Selective heating with magnetic nanoparticles.

Enrique Mallada
Assistant Professor, Electrical & Computer Engineering: Networked dynamics and distributed systems; power networks.

Cynthia Moss
Professor, Psychological and Brain Sciences: mechanisms of sensorimotor integration, scene perception, spatial attention, and memory.

Daniel Naiman

Harirhar Rajaram
Professor, Environmental Health and Engineering: Fluid mechanics and transport phenomena in earth and environmental systems.

Mark Robbins
Joint, Part-Time, and Research Appointments: Professor (Physics and Astronomy): Connecting and contrasting atomistic and macroscopic descriptions of non-equilibrium processes including friction, adhesion, large-strain mechanical deformation, fracture, heat flow, fluid flow, and boundary conditions at interfaces between different materials. Techniques include molecular simulations, continuum calculations and multiscale modeling approaches that bridge the two.

Alexander Spector
Research Professor, Biomedical Engineering: Computational models of cell mechanics (electromechanics) and biophysics.

Dan Stoianovici
Joint, Part-Time, and Research Appointments: Professor (Brady Urological Institute): urology, medical robotics.

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

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

Rene Vidal
Joint, Part-Time, and Research Appointments: Associate Professor (Biomedical Engineering): biomedical image analysis, computer vision, machine learning, dynamical systems, signal processing.

Timothy Wehls
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.

June Wicks
Assistant Professor, Earth and Planetary Sciences: Planetary interiors and evolution; building equation of state and phase diagram models of matter at extreme conditions; kinetics of phase transitions at extreme conditions

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.

Nathan Scott
Associate Teaching Professor: Principles and practice of engineering design education.

Professor emeritus
Cila Herman
Professor Emeritus: experimental heat transfer and fluid mechanics, optical measurement techniques, image processing. Thermoacoustic 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; microelectro-mechanical systems (MEMS), microsample testing.

Research Scientist
Alan Brandt

Research Professor
Mehran Armand
Research Professor, Applied Physics Laboratory: Robotics, biomechanics, orthopaedic surgery, and computer-assisted surgery.

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
Stephen Belkoff
Associate Research Professor, Johns Hopkins Department of Orthopaedic Surgery: Vertebroplasty, soft tissue characterization, trauma biomechanics, mechanism of injury, mechanics of fracture fixation, and joint reconstruction.

Liben Chen
Associate Research Scholar

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

Jicai Lu
Associate Research Professor

Jung-Hee Seo
Associate Research Professor

Liming Voo
Associate Research Professor (Applied Physics Laboratory).

Assistant Research Professor
Jin Seob Kim
Assistant Research Professor

John Thomas
Assistant Research Professor

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

Adjunct Professors
William Blake
Adjunct Professor

Thomas Dragone
Adjunct Professor, Orbital Sciences Corporation

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

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

Adjunct Assistant Professors
Xiaofeng Liu
Adjunct Assistant Professor, San Diego State University

Jian Sheng
Adjunct Assistant Professor (Texas Tech University)

Assistant Research Scientist
Yizeng Li
Assistant Research Scientist

Kuangwen Shieh
Assistant Research Scientist

Kourosh Shoele
Assistant Research Scientist

Adam Sierakowski
Assistant Research Scientist, MARCC

Xiawa Wu
Assistant Research Scientist

Jing Yang
Assistant Research Scientist

Adjunct Research Scientist
Satish Rao
Adjunct Research Scientist, UES Inc.

David Smallwood
Adjunct Research Scientist

Adjunct Associate Research Scientist
Edwin Malkiel
Adjunct Associate Research Scientist.

Lecturers
Jin Seob Kim
Lecturer

Alissa Murphy
Lecturer

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.
Fellow-by-Courtesy
Tihomir Hristov
Associate Research Scientist.

Doctor of the University
G. Paul Neitzel
Doctor of the University: hydrodynamic stability of unsteady flows and flows driven by surface-tension effects, vortex breakdown, and bioreactor fluid mechanics, to permanent noncoalescence and nonwetting, including optical levitation and translation of droplets above solid surfaces.

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

Courses
EN.530.107. MechE Undergraduate Seminar I. NA 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Marra
Area: Engineering
NA.

EN.530.108. MechE Undergraduate Seminar II. NA 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 2 of a year-long sequence.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Marra
Area: Engineering
NA.

EN.530.111. Intro to MechE 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.
Prerequisites: NA
Corequisites: EN.530.115
Instructor(s): S. Marra
Area: Engineering
NA.

EN.530.115. MechE 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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): S. Marra
Area: Engineering
NA.

EN.530.116. MechE Freshman Lab II. 1.0 Credit.
Hands-on laboratory in which students continue to develop their engineering design skills. Laboratory topics include engines and motors, microcontrollers, and sensors. A 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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): S. Marra
Area: Engineering
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Thomas
Area: Engineering, Natural Sciences
NA.

EN.530.124. Intro to Mechanics II. 2.0 Credits.
This course offers an in-depth study of the fundamental elements of classical mechanics, statics, mechanics of materials, fluid mechanics, and thermodynamics. Part 2 of a year-long sequence. Restricted to Mechanical Engineering, Engineering Mechanics, Civil Engineering, Undecided Engineering Majors, or permission of instructor.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Belkoff
Area: Engineering, Natural Sciences
NA.
EN.530.156. Mini-Term: Manufacturing Engineering. 1.0 Credit.
The course presents a modern, all-inclusive look at manufacturing processes. This course is focused on manufacturing processes as an objective science rather than a descriptive art. Quantitative and engineering-oriented approach provides numerical problem exercises, homework & case study, labs, quizzes and final exam. Students should have experience with design, software for drafting.
Prerequisites: NA
Corequisites: NA
Instructor(s): Y. Ronzhes
Area: Engineering
NA.

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.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. \((\text{EN.530.201 OR EN.560.201}) \text{ AND (AS.171.101 OR AS.171.107 OR AS.171.105 OR (EN.530.103 OR EN.530.123) AND (EN.530.104 OR EN.530.124)) AND AS.110.109; grade of C- or higher required for EN.530.201 OR EN.560.201}\)
Corequisites: NA
Instructor(s): D. Kraemer; S. Bailey; S. Belkoff; S. Marra
Area: Engineering
NA.

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

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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: EN.530.215
Instructor(s): S. Marra
Area: Engineering
NA.

EN.530.231. Mechanical Engineering Thermodynamics. 3.0 Credits.
Prerequisites: (AS.171.102 OR AS.171.108);AS.110.109
Corequisites: EN.530.232
Instructor(s): G. Tryggyason
Area: Engineering
NA.

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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): S. Marra
Area: Engineering, Natural Sciences
NA.

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: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;AS.171.102 OR AS.171.108 OR AS.171.106/(EN.550.291 OR EN.553.291) OR (AS.110.201 AND AS.110.302) OR (AS.110.212 AND AS.110.302)
Corequisites: NA
Instructor(s): D. Kraemer
Area: Engineering
NA.
EN.530.254. Manufacturing Engineering. 3.0 Credits.
An introduction to the grand spectrum of the manufacturing processes and technologies 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. Open only to Mechanical Engineering and Engineering Mechanics sophomore and junior majors; other majors only by permission of instructor. Pre-requisite: students must have completed basic shop training and 3D printer training with the WSE Manufacturing shop before class begins. Visit https://wsemanufacturing.jhu.edu/selfservice/ to arrange training.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;EN.530.111 OR EN.530.414 or permission of instructor.
Corequisites: NA
Instructor(s): Y. Ronzhes
Area: Engineering
NA.

EN.530.310. Reverse Engineering and Diagnostics. 3.0 Credits.
We will disassemble, inspect, diagnose, reverse engineer, repair (if needed) and test the subsystems of the first modern tractor, the iconic Ford N series (9N, 2N or 8N). The systems include power, cooling, electrical, ignition, hydraulic, transmission, steering, fuel, control (governor) and braking. The course is not about tractor repair, but upon successful completion, you will know the tractor’s design and function, inside and out and you will be empowered with the confidence to understand and diagnose mechanical systems. Lessons learned will be applicable to other areas of mechanical engineering and will be particularly helpful for Senior Design. We will analyze (reverse engineer) the tractor. For example, given the engine delivers 28 HP at the PTO, how big does the PTO shaft need to be? How big is it? Over/under designed? How was it manufactured? How else could it have been manufactured. What size engine delivers 28 HP? What fuel consumption is needed? What cooling capacity is needed? Answering such questions will prepare students to ask appropriate questions in senior design. How big/strong do we need to make it? We will also have a functioning N-series tractor that will be ‘sabotaged’ each week for students to test their logic skills at diagnosing the cause of the malfunction. Course goals include developing diagnostic skills, learning to read electrical and hydraulic schematics and assembly drawings, developing engineering intuition and applying theoretical knowledge to practical problems. No mechanical experience is needed. Students with the least ‘hands on’ background will have the most to benefit, but even BAJA members have much to gain.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): S. Belkoff
Area: Engineering
NA.

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.550.291 or AS.110.306
Corequisites: NA
Instructor(s): R. Mittal
Area: Engineering
NA.

EN.530.329. Introduction to Fluid Mechanics Laboratory. 1.0 Credit.
This course is the complementary laboratory course and a required co-requisite 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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): S. Marra
Area: Engineering
NA.

EN.530.334. Heat Transfer. 3.0 Credits.
Prerequisites: EN.530.231AND EN.530.327
Corequisites: NA
Instructor(s): A. Prosperetti; R. Mittal; S. Hur
Area: Engineering
NA.

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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: EN.530.334
Instructor(s): N. Scott; S. Marra
Area: Engineering
NA.
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: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

Corequisites: NA
Instructor(s): N. Cowan; S. Marra
Area: Engineering
NA.

EN.530.344. Design and Analysis of Dynamical Systems Laboratory. 1.0 Credit.

Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

Corequisites: EN.530.343
Instructor(s): S. Marra
Area: Engineering
NA.

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
Corequisites: NA
Instructor(s): K. Hemker
Area: Engineering
NA.

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.550.291 OR (AS.110.201 AND AS.110.302)
Corequisites: NA
Instructor(s): D. Kraemer
Area: Engineering, Quantitative and Mathematical Sciences
NA.

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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): N. Scott
Area: Engineering
NA.

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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): N. Scott; S. Bailey
Area: Engineering
NA.
EN.530.404. MechE Senior 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
Corequisites: NA
Instructor(s): N. Scott
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. 
Prerequisites: NA
Corequisites: NA
Instructor(s): J. El-Awady
Area: Engineering, Natural Sciences
NA.

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. 
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Sun
Area: Engineering, Natural Sciences
NA.

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. 
Prerequisites: NA
Corequisites: NA
Instructor(s): D. Stoianovici
Area: Engineering
NA.

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. 
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Kang
Area: Engineering
NA.

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. 
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Dragone
Area: Engineering
NA.
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. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module. OR (AS.171.101 AND AS.171.102) OR (AS.171.107 AND AS.171.108) OR (EN.530.103 AND EN.530.104) OR (EN.530.123 AND EN.530.124)) AND (AS.110.106 OR AS.110.108) AND AS.110.109 AND (AS.110.202 OR AS.110.211) AND (EN.550.291 OR AS.110.302) AND (EN.530.241 OR EN.530.230 OR (EN.520.132 AND EN.520.345))
Corequisites: NA
Instructor(s): D. Kraemer; N. Cowan
Area: Engineering
NA.

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: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): J. Brown
Area: Engineering
NA.

EN.530.422. 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Kim
Area: Engineering
NA.

EN.530.425. Mechanics of Flight. 3.0 Credits.
Elements of flight dynamics: aerodynamics forces, gliding, cruising, turning, ascending, descending, stability, etc. Review of the pertinent fluid mechanic principles. Application to two-dimensional airfoils and theory of lift. Three-dimensional airfoils. Effects of compressibility. Subsonic and supersonic flight.
Prerequisites: NA
Corequisites: NA
Instructor(s): R. Ni
Area: Engineering
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): R. Mittal
Area: Engineering
NA.

EN.530.427. Intermediate Fluid Mechanics. 3.0 Credits.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Meneveau
Area: Engineering
NA.

EN.530.430. Applied Finite Element Analysis. 3.0 Credits.
This course will introduce finite element methods for analysis of solid, structure and biomechanics problems. Following topics will be covered.
• Computational solution vs. other solution approaches • Definition of a mechanics problem: governing equations, constitutive equations, boundary and initial conditions. • Procedure to converting a mechanical problem into a computational solution problem. • Understanding and making choices of finite element types to suit problem type. • Finite element solution choices and their application. • Finite element analysis using commercial software ABAQUS. • FE model verification and validation, solution understanding uncertainty. The course will include homework assignments, 2 exams, and a term project. The term project will involve applying FEA to an engineering problem or a research problem, interpretation of results and documenting them in a short report.
Prerequisites: Prerequisite: EN.550.291 OR AS.110.302, and matrix analysis / algebra and programming recommended.
Corequisites: NA
Instructor(s): L. Voo
Area: Engineering
NA.

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 are 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 spaceflight. Laminar viscous flow. Boundary layers. Turbulence. Compressible flows. Projects using computational tools, design of pipe network.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Katz
Area: Engineering
NA.
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.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Kang
Area: Engineering, Natural Sciences
NA.

EN.530.439. Comparative Biomechanics. 3.0 Credits.
Comparative Biomechanics refers to the mechanics of biological organisms, including both humans and many non-human organisms. This course introduces the biomechanical principles of organism morphology, function, and interactions with their environment, as well as how these principles have inspired useful engineering devices. There is an emphasis on both the diversity of natural and artificial biomechanical systems and the underlying unifying principles. Many interesting topics will be discussed. Some examples include: Why can a mouse falling from a skyscraper walk away with little injury, but a horse will smash? Why do horses walk at low speeds but run at higher speeds? Can T-Rex run? Why do larger animals become more erect in their leg posture? How do geckos adhere to almost any surface? Can we learn from it to create a spider man? How can fleas jump to hundreds times of their body height? How does a chameleon shoot out its tongue to catch bugs? Why do British archers use the yew trees to make long bows? What other functions can muscles serve besides doing work? Why do animals need lungs for ventilation and a heart for blood circulation? How do dogs get fresh air into their nest underground? How can giraffes drink by bending their head down to the ground without blowing their brains out, with a large blood pressure required to pump blood up when their head is up? Why do many tiny organisms have hairs? How do water striders walk on water and how do Jesus Christ lizards run on water? Can humans run on water? Students from ME and other departments are welcome. Students are assumed to be familiar with introductory physics. Although this is an upper lever undergraduate and graduate course, freshman and sophomore undergraduate students with sufficient physics background may take it with instructor approval. Closely-related course: EN.530.475/675. Locomotion I: Mechanics. Visit https://li.me.jhu.edu/teaching for more information.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Li
Area: Engineering
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Hur
Area: Engineering, Quantitative and Mathematical Sciences
NA.

EN.530.443. Fundamentals, Principles and Applications of Microfluidic Systems. 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
Corequisites: NA
Instructor(s): I. Barman
Area: Engineering
NA.

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 will 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Belkoff
Area: Engineering
NA.
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.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): S. Belkoff
Area: Engineering, Natural Sciences
NA.

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 of 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 course in statics and mechanics.
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Nguyen
Area: Engineering
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): K. Hemker
Area: Engineering
NA.

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
Prerequisites: NA
Corequisites: NA
Instructor(s): D. Gayme
Area: Engineering
NA.

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 of 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): B. Shapiro; M. Ozimek
Area: Engineering
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): I. Barman
Area: Engineering
NA.
EN.530.474. Effective and Economic Design for Biomedical Instrumentation. 3.0 Credits.
This course is to introduce students to the design, practice, and devices used in biomedical research. The class will be divided into two parts: lecture and lab. In the lectures, students will learn the physics behind the device, the specific requirements of biomedical instruments, and the engineering principles to construct the devices. Lab sessions will focus on designing and building a prototype device. This course aims to forge collaboration between biomedical researchers and mechanical engineers. The goal is to make the devices accessible to the biomedical research community as well as the general public. Economical availability will be one of the critical elements in the device design. Students will be encouraged to build the devices within a healthy budget. PREREQUISITES: Introductory Physics, Programming, and CAD Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): Y. Chen
Area: Engineering
EN.530.475. Locomotion I: Mechanics. 3.0 Credits.
We will study the mechanics of locomotion of both animals and machines, particularly bio-inspired robots. Locomotion emerges from effective physical interaction with an environment; therefore, the ability to generate appropriate forces (besides sensing, control, and planning) is essential to successful locomotion. From this mechanics view, we will discuss why animals move well in almost any environment, how they inspired some highly successful machines, and yet why most robots still struggle in modestly complex environments and how to improve them by better understanding the mechanics of locomotion. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Many interesting topics will be discussed, such as: How can kangaroos hop faster than their muscles allow? Why do race walkers use a peculiar hip movement? How do animals inspire prosthetic feet that helped Blade Runner compete with abled athletes, and highly efficient and dynamically stable running and walking robots like those built by Boston Dynamics? Why do legs work better than wheels on sand? How do sidewinders crawl up sandy dunes without triggering avalanches? How do cockroaches rapidly go through dense vegetation on the forest floor? Why do migrating birds fly in a V-formation? How exactly do bumblebees fly, given that engineers predicted they should not be able to, and how do this help engineers build robotic bees? Do Speedo's sharkskin swimsuits really reduce drag? Students from ME and other departments are welcome. Freshmen and sophomores with sufficient physics background may take with instructor approval. Students should have a strong understanding of Newtonian mechanics. Recommended course background: B or higher in EN.530.202 Dynamics or EN.560.202 Dynamics. Closely-related courses: EN.530.439/639. Comparative Biomechanics; EN.530.676. Locomotion II: Dynamics.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Li
Area: Engineering
NA.
EN.530.476. Locomotion II: Dynamics.
This 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): Y. Chen
Area: Engineering, Quantitative and Mathematical Sciences
NA.
EN.530.477. Applied Computational Modeling in Aerodynamics and Heat Transfer. 3.0 Credits.
Introduction to fundamental principles and applications of the computational modeling in fluid dynamics and heat transfer. Emphasis is on basics of finite-difference methods and hands-on experience in code development as well as the use of a commercial software package (ANSYS CFX) for modeling and simulation. Students will also learn about meshing strategies, post-processing, and critical analysis of simulation results. The concept of numerical errors and the validation and verification will also be emphasized. Recommended Background: (1) Undergraduate or introductory level course in fluid dynamics or heat transfer or transport phenomena or classical mechanics. (2) Basic expertise in writing computer codes (MATLAB or C++ or Fortran or Python).
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Seo
Area: Engineering, Quantitative and Mathematical Sciences
NA.
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 about the mechanics of locomotion of both animals and machines, particularly bio-inspired robots. Locomotion emerges from effective physical interaction with an environment; therefore, the ability to generate appropriate forces (besides sensing, control, and planning) is essential to successful locomotion. From this mechanics view, we will discuss why animals move well in almost any environment, how they inspired some highly successful machines, and yet why most robots still struggle in modestly complex environments and how to improve them by better understanding the mechanics of locomotion. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Many interesting topics will be discussed, such as: How can kangaroos hop faster than their muscles allow? Why do race walkers use a peculiar hip movement? How do animals inspire prosthetic feet that helped Blade Runner compete with abled athletes, and highly efficient and dynamically stable running and walking robots like those built by Boston Dynamics? Why do legs work better than wheels on sand? How do sidewinders crawl up sandy dunes without triggering avalanches? How do cockroaches rapidly go through dense vegetation on the forest floor? Why do migrating birds fly in a V-formation? How exactly do bumblebees fly, given that engineers predicted they should not be able to, and how do this help engineers build robotic bees? Do Speedo's sharkskin swimsuits really reduce drag? Students from ME and other departments are welcome. Freshmen and sophomores with sufficient physics background may take with instructor approval. Students should have a strong understanding of Newtonian mechanics. Recommended course background: B or higher in EN.530.202 Dynamics or EN.560.202 Dynamics. Closely-related courses: EN.530.439/639. Comparative Biomechanics; EN.530.676. Locomotion II: Dynamics.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Li
Area: Engineering
NA.
EN.530.483. Applied Computational Modeling in Aerodynamics and Heat Transfer. 3.0 Credits.
This course examines the critical roles that physical principles and stability and facilitate adaptation in the presence of a changing world. 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): Y. Chen
Area: Engineering, Quantitative and Mathematical Sciences
NA.
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.
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Cowan
Area: Engineering
NA.
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, photosist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services. Seniors only or Permission Required. Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): A. Andreou; J. Wang
Area: Engineering, Natural Sciences NA.

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 strongly encouraged to present a research poster at the Johns Hopkins University's DREAMS Undergraduate Research Day. Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA NA.

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 strongly encouraged to present a research poster at the Johns Hopkins University's DREAMS Undergraduate Research Day. Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA NA.

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.) Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA NA.

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. Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA NA.

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. Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA NA.

EN.530.597. Research - Summer. 1.0 - 3.0 Credits.
NA
Prerequisites: You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Corequisites: NA
Instructor(s): Staff
Area: NA NA.

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

EN.530.602. Master's Essay 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 Essay. Note that "essay" is the official term for a thesis at Johns Hopkins University. Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA NA.
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 and/or Python.
Prerequisites: NA
Corequisites: NA
Instructor(s): M. Kobilarov
Area: NA

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): R. Hurley
Area: NA

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, geomaterials or biomechanics.
Prerequisites: NA
Corequisites: NA
Instructor(s): R. Hurley
Area: Engineering

EN.530.608. Experimental Fluid Dynamics. 3.0 Credits.
This course will serve as a virtual tour to many experimental facilities and techniques following the history of fluid dynamics research. Stories of several interesting debates will be told to show that iterations of experimental facilities based on the physics of fluid can lead to major new discoveries that brought a long-lasting impact on the entire field. The course will also focus on the unique opportunities and challenges in this decade thanks to the rapid advance of digital cameras, lasers, computed tomography, fluorescence imaging, as well as diagnostic tools based on X-ray, MRI, and gamma radiation. The course is designed for graduate students at all levels that are interested in fluid dynamics.
Prerequisites: NA
Corequisites: NA
Instructor(s): R. Ni
Area: NA

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Sun
Area: NA

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Nguyen
Area: NA
EN.530.613. MechE Master's Design Project I. 3.0 Credits.
This course is intended to give graduate students some practice and experience in the art of engineering design in conjunction with undergraduate students taking MechE Senior Design Project I. 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: C- or higher in both 530.403 and 530.404 MechE Senior Design Project I/II. Students from other universities may ask to be considered if they have taken a course like MechE Senior Design Project i.e. two semesters, design-build-test, ideally with industry connection.
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Scott; S. Bailey
Area: Engineering
NA.

EN.530.614. Master's Design Project II. 3.0 Credits.
This course is intended to give graduate students some practice and experience in the art of engineering design in conjunction with undergraduate students taking MechE Senior Design Project II. 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: C- or higher in both 530.403 and 530.404 MechE Senior Design Project I/II. Students from other universities may ask to be considered if they have taken a course like MechE Senior Design Project i.e. two semesters, design-build-test, ideally with industry connection.
Prerequisites: NA
Corequisites: NA
Instructor(s): N. Scott; S. Bailey
Area: Engineering
NA.

EN.530.616. Introduction to Linear Systems Theory. 3.0 Credits.
A beginning graduate course in multi-input multi-output, linear, time-invariant systems. Topics include state-space and input-output representations; solutions and their properties; multivariable poles and zeros; reachability, observability and minimal realizations; stability; system norms and their computation; linearization techniques. Students cannot take EN.530.616 if they have already taken the equivalent courses EN.520.601 OR EN.580.616.
Prerequisites: Students cannot take EN.530.616 if they have already taken EN.520.601 OR EN.580.616.
Corequisites: NA
Instructor(s): N. Cowan
Area: NA
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Kang
Area: NA
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Dragone
Area: NA
NA.

EN.530.621. Fluid Dynamics I. 3.0 Credits.
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Zaki
Area: NA
NA.
EN.530.622. Fluid Dynamics II. 3.0 Credits.
Kinematics. Stress. Conservation of mass, momentum, and energy.
**Prerequisites:** NA
**Corequisites:** NA
**Instructor(s):** J. Katz
**Area:** NA

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.
**Prerequisites:** NA
**Corequisites:** NA
**Instructor(s):** J. Kim
**Area:** NA

EN.530.625. Turbulence. 3.0 Credits.
**Prerequisites:** NA
**Corequisites:** NA
**Instructor(s):** C. Meneveau
**Area:** NA

EN.530.627. Intermediate Fluid Mechanics (graduate). 3.0 Credits.
**Prerequisites:** NA
**Corequisites:** NA
**Instructor(s):** C. Meneveau
**Area:** NA

EN.530.629. Simulation and Analysis of Ocean Wave Energy Systems. 3.0 Credits.
Aspects of the simulation of a dynamic system are covered in this project-based course. Open-source software packages are used to simulate the hydrodynamics and rigid-body dynamics of an ocean wave-energy conversion project. Topics include: wave-energy converter types (buoyancy, hydrostatic pressure, potential energy, etc.), multi-body coupled dynamics, hydrodynamics, and energy conversion. Prerequisites: dynamics, fluid mechanics, computer programming (any language).
**Prerequisites:** NA
**Corequisites:** NA
**Instructor(s):** D. Kraemer
**Area:** NA

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.
**Prerequisites:** NA
**Corequisites:** NA
**Instructor(s):** N. Daphalapurkar
**Area:** NA

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.
**Prerequisites:** NA
**Corequisites:** NA
**Instructor(s):** J. Seo
**Area:** NA

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
**Prerequisites:** NA
**Corequisites:** NA
**Instructor(s):** Y. Chen
**Area:** NA

EN.530.634. 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
**Prerequisites:** NA
**Corequisites:** NA
**Instructor(s):** Y. Chen
**Area:** NA
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.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Kang
Area: NA

EN.530.639. Comparative Biomechanics. 3.0 Credits.
Comparative Biomechanics refers to the mechanics of biological organisms, including both humans and many non-human organisms. This course introduces the biomechanical principles of organism morphology, function, and interactions with their environment, as well as how these principles have inspired useful engineering devices. There is an emphasis on both the diversity of natural and artificial biomechanical systems and the underlying unifying principles. Many interesting topics will be discussed. Some examples include: Why can a mouse falling from a skyscraper walk away with little injury, but a horse will smash? Why do horses walk at low speeds but run at higher speeds? Can T-Rex run? Why do larger animals become more erect in their leg posture? How do geckos adhere to almost any surface? Can we learn from it to create a spider man? How can fleas jump to hundreds times of their body height? How does a chameleon shoot out its tongue to catch bugs? Why do British archers use the yew trees to make long bows? What other functions can muscles serve besides doing work? Why do animals need lungs for ventilation and a heart for blood circulation? How do dogs get fresh air into their nest underground? How can giraffes drink using their long necks? Why do water striders walk on water and how do Jesus Christ lizards run on water? Can humans run on water? Students from ME and other departments are welcome. Students are assumed to be familiar with introductory physics. Although this is an upper lever undergraduate and graduate course, freshman and sophomore undergraduate students with sufficient physics background may take it with instructor approval. Closely-related course: EN.530.475/675. Locomotion I: Mechanics. Visit https://li.me.jhu.edu/teaching for more information.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Li
Area: NA

EN.530.641. Statistical Learning For Engineers. 3.0 Credits.
Graduate level introductory course on machine learning and reinforcement learning. Artificial intelligence (AI) is rapidly growing in virtually all science and engineering fields. Technologies related to machine learning are at the center of this trend. This course provides a fundamental and core knowledge on machine learning and reinforcement learning, which in turn prepares students so as to self-advance into the state-of-the-art AI technologies in a variety of fields. This course will discuss general aspects of machine and reinforcement learning, which is suitable for students in different fields of interest, though the primary applications include robotics engineering. Topics that will be covered include: core mathematics necessary, core principles for supervised and unsupervised learning (e.g., linear regression, logistic regression, Bayesian nets, EM, and so on), and for reinforcement learning (e.g., Markov decision process, dynamic programming, etc.). Homework assignments include both theoretical and computational components. Recommended Course Background: o Course background: Linear Algebra, Multivariate Calculus, Probability, Differential Equations; o Programming: Knowledge of Python (and Matlab)
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Kim
Area: NA

EN.530.642. Plasticity. 3.0 Credits.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. El-Awady
Area: NA

EN.530.643. Fundamentals, Principles and Applications of Microfluidic Systems. 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Hur
Area: NA
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 parameterization 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. Recommend Course Background: Undergraduate linear algebra and multivariable calculus.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Kim
Area: NA

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Kim
Area: NA

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. Please see the course home page here for additional information: https://dscl.lcsr.jhu.edu/courses/530-647-adaptive-systems-fall-2017. Audit registration not permitted.
Prerequisites: NA
Corequisites: NA
Instructor(s): L. Whitcomb
Area: NA

EN.530.653. Advanced Systems Modeling. 3.0 Credits.
This course covers the following topics at an advanced level: Newton's laws and 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, Langrange, 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 related the topics of this course to his or her research.
Prerequisites: NA
Corequisites: NA
Instructor(s): G. Chirikjian
Area: NA

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): G. Chirikjian
Area: NA

EN.530.655. Additive Manufacturing (Graduate). 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 in Materials Science equivalent to 530.352 Materials Selection.
Prerequisites: NA
Corequisites: NA
Instructor(s): K. Hemker
Area: NA

EN.530.656. Additive Manufacturing (Graduate). 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 in Materials Science equivalent to 530.352 Materials Selection.
EN.530.656. Deformation Mechanisms. 3.0 Credits.
An advanced course on the microscopic mechanisms that control the mechanical behavior of materials. Methods and techniques for measuring, understanding, and modeling: plasticity, creep, shear banding, and fracture will be addressed. Subjects to be covered include dislocation theory and strengthening mechanisms, high temperature diffusion and grain boundary sliding, shear localization, void formation, ductile rupture, and brittle fracture.
Prerequisites: NA
Corequisites: NA
Instructor(s): K. Hemker
Area: NA
NA.

EN.530.663. Robot Motion Planning. 3.0 Credits.
This course provides a graduate-level introduction to robot motion planning. Topics include geometric representation of rigid bodies, configuration space of robots, graph search algorithms, shortest-path motion, and various approaches to motion planning problems (e.g., combinatorial and sampling-based motion planning algorithms, and potential field method). The emphasis is both on mathematical aspects of motion planning (which provides fundamentals in understanding the state-of-the-art planning techniques) and computational implementation of algorithms.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Kim
Area: NA
NA.

EN.530.664. Energy Systems Analysis (graduate). 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 EN.530.464.
Prerequisites: NA
Corequisites: NA
Instructor(s): D. Gayme
Area: NA
NA.

EN.530.674. Effective and Economic Design for Biomedical Instrumentation. 4.0 Credits.
This course is to introduce students to the design, practice, and devices used in biomedical research. The class will be divided into two parts: lecture and lab. In the lectures, students will learn the physics behind the device, the specific requirements of biomedical instruments, and the engineering principles to construct the devices. Lab sessions will focus on designing and building a prototype device. This course aims to forge collaboration between biomedical researchers and mechanical engineers. The goal is to make the devices accessible to the biomedical research community as well as the general public. Economical availability will be one of the critical elements in the device design. Students will be encouraged to build devices within a healthy budget. PREREQUISITES: Introductory Physics, Programming, and CAD
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): Y. Chen
Area: Engineering
NA.

EN.530.675. Locomotion I: Mechanics. 3.0 Credits.
We will study the mechanics of locomotion of both animals and machines, particularly bio-inspired robots. Locomotion emerges from effective physical interaction with an environment; therefore, the ability to generate appropriate forces (besides sensing, control, and planning) is essential to successful locomotion. From this mechanics view, we will discuss why animals move well in almost any environment, how they inspired some highly successful machines, and yet why most robots still struggle in modestly complex environments and how to improve them by better understanding the mechanics of locomotion. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Many interesting topics will be discussed, such as: How can kangaroos hop faster than their muscles allow? Why do race walkers use a peculiar hip movement? How do animals inspire prosthetic feet that helped Blade Runner compete with abled athletes, and highly efficient and dynamically stable running and walking robots like those built by Boston Dynamics? Why do legs work better than wheels on sand? How do sidewinders crawl up sandy dunes without triggering avalanches? How do cockroaches rapidly go through dense vegetation on the forest floor? Why do migrating birds fly in a V-formation? How exactly do bumblebees fly, given that engineers predicted they should not be able to, and how do this help engineers build robotic bees? Do Speedo’s sharkskin swimsuits really reduce drag? Students from ME and other departments are welcome. Freshmen and sophomores with sufficient physics background may take with instructor approval. Students should have a strong understanding of Newtonian mechanics. Recommended course background: B or higher in EN.530.202 Dynamics or EN.560.202 Dynamics. Closely-related courses: EN.530.439/639. Comparative Biomechanics; EN.530.676. Locomotion II: Dynamics.
Prerequisites: NA
Corequisites: NA
Instructor(s): C. Li
Area: Engineering
NA.
EN.530.676. Locomotion II: Dynamics. 3.0 Credits.
Graduate course on mechanics and control in locomotion. Topics include modeling (e.g. Lagrangian mechanics), dynamical systems theory (nonholonomic systems, limit-cycle behavior, Poincaré analysis, and Floquet theory), design (control synthesis, mechanical design), and data-driven modeling from animal locomotor control experiments.
Prerequisites: A graduate course in linear systems theory (e.g. EN.520.601). Suggested background (not required): 530.475/675.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Seo
Area: NA
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): M. Kobilarov
Area: NA
NA.

EN.530.681. 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): K. Hemker
Area: NA
NA.

EN.530.683. Applied Computational Modeling in Aerodynamics and Heat Transfer. 3.0 Credits.
Introduction to fundamental principles and applications of the computational modeling in fluid dynamics and heat transfer. Emphasis is on basics of finite-difference methods and hands-on experience in code development as well as the use of a commercial software package (ANSYS CFX) for modeling and simulation. Students will also learn about meshing strategies, post-processing, and critical analysis of simulation results. The concept of numerical errors and the validation and verification will also be emphasized. Recommended Background: (1) Undergraduate or introductory level course in fluid dynamics or heat transfer or transport phenomena or classical mechanics. (2) Basic expertise in writing computer codes (MATLAB or C++ or Fortran or Python).
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Seo
Area: Engineering, Quantitative and Mathematical Sciences
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Brown
Area: NA
NA.

EN.530.707. Robot System Programming. 4.0 Credits.
This course seeks to introduce students to open-source software tools that are available today for building complex experimental and fieldable robotic systems. The course is grouped into sections, each of which building on the previous in increasing complexity and specificity: tools and frameworks supporting robotics research, robotics-specific software frameworks, integrating complete robotic systems, and culminates with an independent project of the student's own design using small mobile robots or other robots in the lab. Students will need to provide a computer (with at least a few GB of memory and a several tens of GB of disk space) running Ubuntu (https://www.ubuntu.com or one of its variants such as Xubuntu) and ROS (http://ros.org/). Students should have an understanding of intermediate programming in C/C++ (including data structures and object-oriented programming). Familiarity with Linux programming. Familiarity with software version control systems such as Git, and linear algebra. Students should see the course homepage http://dscl.lcsr.jhu.edu/ME530707_2018 for more information and to get started with the course. Required Course Prerequisite/Corequisite: EN.530.646 and EN.600.436. Registration only by permission of the instructor. Please contact Prof. Louis Whitcomb at llw@jhu.edu. Please put ‘530.707 Robot System Programming’ in the subject line of your email.
Prerequisites: NA
Corequisites: NA
Instructor(s): L. Whitcomb
Area: NA
NA.

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Katz
Area: NA
NA.
EN.530.715. Mesoscale Simulations of Defects in Metals. 3.0 Credits.
This course focuses on coarse-grained simulations of defects and plasticity in crystalline materials. Topics of interest include modeling dislocation plasticity, diffusion of point defects, grain and twin boundaries, precipitates, etc. under different loading and boundary conditions.
Prerequisites: Either EN.530.605, EN.510.604, or waiver from the instructor. Student must also have background in programming using MATLAB, C, C++, FORTRAN or an equivalent coding language.
Corequisites: NA
Instructor(s): J. El-Awady
Area: NA

EN.530.717. Machine Learning for Solid Mechanics and Materials Engineering. 3.0 Credits.
Machine learning (ML) and principles of informatics are playing an increasing role in many aspects of solid mechanics and materials engineering. ML techniques enable the extraction of relationships from a large amount of seemingly uncorrelated data and can expedite the process of predicting deformation in solids and the discovery/design of materials. This course provides an introductory overview for graduate students on ML and principles of informatics as well as provide a survey of applications of ML in solid mechanics and materials engineering.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. El-Awady
Area: NA

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): T. Zaki
Area: NA

EN.530.730. Finite Element Methods. 3.0 Credits.
Variational methods and mathematical foundations, Direct and Iterative solvers, 1-D Problems formulation and boundary conditions, Trusses, 2-D/3D Problems, Triangular elements, QUAD4 elements, Higher Order Elements, Element Pathology, Improving Element Convergence, Dynamic Problems.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Cheng
Area: NA

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): K. Ramesh
Area: NA

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

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 including: linear algebra and matrix theory, ordinary differential equations, Laplace and Fourier transforms, as well as an introduction to partial differential equations.
Prerequisites: NA
Corequisites: NA
Instructor(s): D. Gayme
Area: NA

EN.530.766. Numerical Methods. 3.0 Credits.
Comprehensive introduction to the finite-difference method and associated numerical techniques for solving partial differential equations (PDEs) encountered in Engineering and Physics. Homework assignments and Project require substantial computer programming.
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Seo
Area: NA

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.
Prerequisites: NA
Corequisites: NA
Instructor(s): R. Mittal
Area: NA

EN.530.777. Multiphase Flow. 3.0 Credits.
An introduction to basic contemporary ideas concerning gas, liquid, and solid-fluid two-phase flows.
Prerequisites: NA
Corequisites: NA
Instructor(s): G. Tryggvason
Area: NA
EN.530.800. Independent Study. 3.0 - 20.0 Credits.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

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

EN.530.802. PhD Graduate Research. 3.0 - 20.0 Credits.
Sec. 01 Hur Sec. 02 Meneveau Sec. 03 Stoianovici Sec. 04 El-Awady Sec. 05 Fridman Sec. 06 Ramesh Sec. 07 Taylor Sec. 08 Staff Sec. 09 Nguyen Sec. 10 Zaki Sec. 11 Hemker Sec. 12 Chirikjian Sec. 13 Whitcomb Sec. 14 Gayme Sec. 15 Kobilarov Sec. 16 Wang Sec. 17 Sun Sec. 18 Cowan Sec. 19 Katz Sec. 20 Vidal Sec. 21 Mittal Sec. 22 Belkoff Sec. 23 Iordachita Sec. 24 Armand Sec. 25 Ghosh Sec. 26 Barman Sec. 27 Hurley Sec. 28 Scott Sec. 29 Kang Sec. 30 Li Sec. 31 Kraemer Sec. 32 Marra Sec. 33 Brown Sec. 34 Chen Sec. 35 Ivkov Sec. 36 Tryggvason Sec. 37 Ni
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

EN.530.803. Mechanical Engineering Seminar. 1.0 Credit.
Open to Mechanical Engineering PhD students in the first three years.
Prerequisites: NA
Corequisites: NA
Instructor(s): R. Mittal
Area: NA
NA.

EN.530.804. Mechanical Engineering Seminar. 1.0 Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): R. Mittal
Area: NA
NA.

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

EN.530.808. Graduate Seminar in Fluid Mechanics. 1.0 Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Katz
Area: NA
NA.

EN.530.809. Mechanics of Materials and Structures Graduate Seminar. 1.0 Credit.
Cross-listed with Mechanical Engineering.
Prerequisites: NA
Corequisites: NA
Instructor(s): R. Hurley
Area: NA
NA.

EN.530.810. Mechanics and Materials Graduate Seminar. 1.0 Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): S. Kang
Area: NA
NA.

EN.530.897. Research-Summer. 3.0 - 20.0 Credits.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): Staff
Area: NA
NA.

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

Cross Listed Courses

General Engineering

EN.500.114. Gateway Computing: Matlab. 3.0 Credits.
This course introduces fundamental programming concepts and techniques, and is intended for all who plan to develop computational artifacts or intelligently deploy computational tools in their studies and careers. Topics covered include the design and implementation of algorithms using variables, control structures, arrays, functions, files, testing, debugging, and structured program design. Elements of object-oriented programming, algorithmic efficiency and data visualization are also introduced. Students deploy programming to develop working solutions that address problems in engineering, science and other areas of contemporary interest that vary from section to section.
Course homework involves significant programming. Attendance and participation in class sessions are expected.
Prerequisites: Students may not have earned credit in: EN.500.112 OR EN.500.113 OR EN.510.202 OR EN.520.123 OR EN.530.112 OR EN.580.200 OR EN.601.107
Corequisites: NA
Instructor(s): D. Giovanis
Area: Engineering
NA.

EN.500.602. Seminar: Environmental and Applied Fluid Mechanics. 1.0 Credit.
NA
Prerequisites: NA
Corequisites: NA
Instructor(s): J. Katz
Area: NA
NA.
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. Birobotics 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.
Prerequisites: NA
Corequisites: NA
Instructor(s): L. Whitcomb; P. Kazanzides
Area: NA

EN.520.340. Introduction to Mechatronics. 3.0 Credits.
Introduction to Mechatronics is mostly hands-on, interdisciplinary design class consisting of lectures about key topics in mechatronics, and lab activities aimed at building basic professional competence. After completing the labs, the course will be focused on a final mini-project for the remainder of the semester. This course will encourage and emphasize active collaboration with classmates. Each team will plan, design, manufacture and/or build, test, and demonstrate a robotic system that meets the specified objectives.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): I. Sekyonda
Area: NA

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: EN.520.214 OR EN.530.343 OR EN.580.222
Corequisites: NA
Instructor(s): E. Mallada Garcia
Area: Engineering
NA.

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. Seniors 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.
Corequisites: NA
Instructor(s): A. Andreou; J. Wang
Area: Engineering, Natural Sciences
NA.

EN.520.773. Advanced Topics In Microsystem 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.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Corequisites: NA
Instructor(s): J. Wang
Area: NA
NA.

Civil Engineering
EN.560.201. Statics & Mechanics of Materials. 3.0 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.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module; AS.171.101 OR AS.171.107 OR (EN.530.123 AND EN.530.124) or instructor permission.
Corequisites: NA
Instructor(s): R. Sangree
Area: Engineering
NA.
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

Prerequisites: NA
Corequisites: NA
Instructor(s): E. Haase
Area: Engineering, Natural Sciences
NA.

Center for Leadership Education

EN.660.361. Engineering Business and Management. 3.0 Credits.
When engineers become working professionals, especially if they become managers, they must juggle knowledge of and tasks associated with operations, finance, ethics, strategy, team citizenship leadership and projects. While engineers’ success may depend on their direct input — the sweat of their own brow — managers’ success depends on their ability to enlist the active involvement of others: direct reports, other managers, other team members, other department employees, and those above them on the organizational chart. You will learn these concepts and skills in this course. In this course, you will learn about teamwork and people management, and gain an introduction to strategy, finance, and project management. You will practice writing concise persuasive analyses and action plans and verbally defending your ideas. Cross-listed with Mechanical Engineering. Please note that this course will not be available in the spring.

Prerequisites: NA
Corequisites: NA
Instructor(s): I. Izenberg; M. Agronin
Area: Engineering
NA.