

# EN.530 (MECHANICAL ENGINEERING)

## Courses

### EN.530.107. MechE Undergraduate Seminar I. 0.5 Credits.

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.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

### EN.530.108. MechE Undergraduate Seminar II. 0.5 Credits.

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.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

### EN.530.111. Intro to MechE Design and CAD. 2 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.

**Corequisite(s):** EN.530.115

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

### EN.530.115. MechE Freshman Lab I. 1 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.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

### EN.530.116. MechE Freshman Lab II. 1 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. The ePortfolio tag(s) on this course signify that there are one or more assignments offered in the course that provide students with the opportunity to be assessed for proficiency in completion of the relevant ePortfolio requirement(s).

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

EN Foundational Abilities: Conceiving of and Realizing Projects ePortfolio (FA6eP)

### EN.530.123. Introduction to Mechanics I. 3 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.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

### EN.530.124. Introduction to Mechanics II. 2 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.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

### EN.530.202. Mechanical Engineering Dynamics. 3 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.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); (EN.530.201 OR EN.560.201 ) AND ( AS.171.101 OR AS.171.107 OR AS.171.105 OR ( (EN.530.103 OR EN.530.123) AND EN.530.104 ) ) AND (AS.110.109 OR AS.110.107); grade of C- or higher required for EN.530.201 OR EN.560.201

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.204. Manufacturing Engineering Theory. 2 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. Students should have knowledge of engineering drawing software like SolidWorks, AutoCAD, or Pro-E.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.205. Manufacturing Engineering Laboratory. 1 Credit.**

This course is the laboratory that supports EN.530.204 Manufacturing Engineering Theory. While concurrent enrollment with EN.530.204 is suggested, it is not required.

**Prerequisite(s):** 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.530.204

**EN.530.212. MechE Dynamics Laboratory. 1 Credit.**

This is the laboratory component to EN.530.202 MechE Dynamics.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>);EN.530.202

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.215. Mechanics-Based Design. 3 Credits.**

Stresses and strains in three dimensions, transformations. Combined loading of components, failure theories. Buckling of columns. Stress concentrations. Introduction to the finite element method. Design of fasteners, springs, gears, bearings, and other components.

**Prerequisite(s):** EN.530.201 OR EN.560.201

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.216. Mechanics Based Design Laboratory. 1 Credit.**

This is the laboratory that supports EN.530.215 Mechanics Based Design.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

**Corequisite(s):** EN.530.215

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.231. Mechanical Engineering Thermodynamics. 3 Credits.**

Properties of pure substances, phase equilibrium, equations of state. First law, control volumes, conservation of energy. Second law, entropy, efficiency, reversibility. Carnot and Rankine cycles. Internal combustion engines, gas turbines. Ideal gas mixtures, air-vapor mixtures. Introduction to combustion.

**Prerequisite(s):** All pre-requisite courses must be graded C- or higher before course registration. (AS.171.102 OR AS.171.108 OR AS.171.106) can be taken at the same time OR prior to enrolling in EN.530.231.;All pre-requisite courses must be graded C- or higher before course registration. AS.110.109 AND ((EN.530.123 AND EN.530.124) OR (AS.171.101 OR AS.171.107 OR AS.171.105))

**Corequisite(s):** EN.530.232 must be taken at the same time as EN.530.231.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.232. Mechanical Engineering Thermodynamics Laboratory. 1 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.

**Prerequisite(s):** EN.530.232 Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

**Corequisite(s):** Students must take both EN.530.231 and EN.530.232 in the same semester.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.530.241. Electronics & Instrumentation. 3 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.

**Prerequisite(s):** AS.171.102 OR AS.171.108 OR AS.171.106;EN.553.291 OR (AS.110.201 AND AS.110.302) OR (AS.110.212 AND AS.110.302) can be taken prior to or at the same time as EN.530.241.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.243. Electronics and Instrumentation Laboratory. 1 Credit.**

This is the laboratory that supports EN.530.241 Electronics and Instrumentation.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

**Corequisite(s):** EN.530.241 Electronics and Instrumentation or instructor approval

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.254. Manufacturing Engineering. 3 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. Students must have completed the WSE Manufacturing Basic Shop training prior to registering for this class. Students should have knowledge of engineering drawing software like SolidWorks, AutoCAD, or Pro-E.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); EN.530.111 OR EN.530.414 or permission of instructor.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.310. Reverse Engineering and Diagnostics. 3 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.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

Distribution Area: Engineering

**EN.530.327. Introduction to Fluid Mechanics. 3 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.

**Prerequisite(s):** All pre-requisite courses must be graded C- or higher before course registration. AS.110.302 OR EN.553.291. These courses can be taken prior to enrolling in EN.530.327, or at the same time as EN.530.327.; All pre-requisite courses must be graded C- or higher before course registration. EN.530.202 must be taken prior to enrolling in EN.530.327.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.329. Introduction to Fluid Mechanics Laboratory. 1 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.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

**Corequisite(s):** Students must take both EN.530.327 and EN.530.329 in the same term.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.334. Heat Transfer. 3 Credits.**

Steady and unsteady conduction in one, two, and three dimensions. Elementary computational modeling of conduction heat transfer. External and internal forced convection. Performance and design of heat exchangers. Boiling and condensation. Black-body and gray-body radiation, Stefan-Boltzmann law view factors and some applications.

**Prerequisite(s):** EN.530.231 AND EN.530.327

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.335. Heat Transfer Laboratory. 1 Credit.**

This is the laboratory that supports EN.530.334 Heat Transfer.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

**Corequisite(s):** EN.530.334

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.343. Design and Analysis of Dynamical Systems. 3 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.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); AS.110.108 AND AS.110.109 AND (AS.110.202 OR AS.110.211) AND (EN.553.291 OR (AS.110.302 AND AS.110.201) OR (AS.110.306 AND AS.110.201)) and C- or better EN.530.202 or EN.560.202. MechE Majors must also have taken EN.530.241

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.344. Design and Analysis of Dynamical Systems Laboratory. 1 Credit.**

This is the laboratory that supports EN.530.343 Design and Analysis of Dynamical Systems.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

**Corequisite(s):** EN.530.343

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.352. Materials Selection. 4 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.

**Prerequisite(s):** All pre-requisite courses must be graded C- or higher before course registration. EN.530.215

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.381. Engineering Design Process. 3 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.

**Prerequisite(s):** 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.

Distribution Area: Engineering

**EN.530.403. MechE Senior Design Project I. 4 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.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.404. MechE Senior Design Project II. 4 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.

**Prerequisite(s):** EN.530.403

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

Writing Intensive

**EN.530.405. Mechanics of Advanced Engineering Structures. 3 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 value problems that occur in engineering structures, energy methods and foundations of the finite element method.

Distribution Area: Engineering, Natural Sciences

**EN.530.409. Introduction to Mechanobiology. 3 Credits.**

Introduction to mechanobiology, an emerging multidisciplinary field that encompasses the study of mechanisms by which cells sense and respond to mechanical signals. Mechanical signals regulate a wide range of biological behaviors, including cell differentiation, migration, polarization, and etc. This course covers how these forces influence tissue development, adaptation, regeneration, and aging, with a focus on cardiovascular and pulmonary systems, cancer, and tissue engineering. We will discuss both theoretical and empirical foundations alongside engineering methodologies for the application, quantification, and elucidation of mechanobiological mechanisms. The implications for human health and the progression of disease will be highlighted.

**Prerequisite(s):** (EN.530.123 AND EN.530.124) OR AS.171.101 OR AS.171.105 OR AS.171.107

Distribution Area: Engineering

**EN.530.410. Biomechanics of the Cell. 3 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.

Distribution Area: Engineering, Natural Sciences

**EN.530.411. Composite Materials. 3 Credits.**

Rarely a single material suffice to provide the desired performance for particular applications and we typically resort to a combination of materials (or composite materials). Apart from that a single material may also have defects in its microstructure which influences response. This course describes how to deal with the mechanics aspect of the composite materials. Based on concepts of stress, strain definition for a continuum, this course is oriented towards developing a fundamental understanding of composite materials. At the end of this course, a successful student will be able to:

- Evaluate effective properties of a composite material with inclusions of different shapes and put bounds on the homogenized values.
- Evaluate effective properties of laminates.
- Comprehend concepts of strength and failure criterion in composites and apply to design.
- Comprehend wave propagation relation in composites.
- Appreciate the principles of homogenization used to scale up from micro/meso to that of the continuum level representation.

Distribution Area: Engineering

**EN.530.414. Computer-Aided Design. 3 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.

Distribution Area: Engineering

**EN.530.418. Aerospace Structures. 3 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.

**Prerequisite(s):** EN.530.352 or instructor permission

Distribution Area: Engineering

**EN.530.420. Robot Sensors/Actuators. 4 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.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); ((AS.171.101 AND AS.171.102) OR (AS.171.107 AND AS.171.108) OR (AS.171.101 AND AS.171.108) OR (AS.171.107 AND AS.171.102) OR (EN.530.123 AND EN.530.124)) AND ((AS.110.106 OR AS.110.108) AND (AS.110.107 OR AS.110.109) AND (AS.110.202 OR AS.110.211) AND (EN.553.291 OR AS.110.302) AND ((EN.530.241 AND EN.530.243) OR (EN.520.230 AND EN.520.231)))

Distribution Area: Engineering

**EN.530.421. Mechatronics. 3 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.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); EN.530.420 OR EN.520.240 OR EN.520.340 or permission of the instructor.  
Distribution Area: Engineering

**EN.530.423. Design of Marine Robots. 3 Credits.**

This class will introduce the design of marine robotic systems, with a particular emphasis on Autonomous Underwater Vehicles (AUVs). This class is intended to give the student a broad view of the applications, design, and operation of marine robots. Students will be introduced to the ocean as an operating environment, establish mission sets, vehicle subsystems, design strategies, and performance metrics. Students will be introduced to the fundamentals of underwater acoustics, especially as it pertains to underwater sensing, navigation, and communication. Operations of AUV will be explored, along with analysis of different types of operations such as ship-based, under-ice, shore-launched, and docking-based operations. Emphasis will be given to the conceptual design phase of robot design, and the development and use of parametric approaches to performance evaluation. Finally, multiplatform survey systems will be analyzed, and we will explore the challenges associated with designing AUV that might operate on other ocean worlds, such as Europa and Enceladus.

**Prerequisite(s):** (EN.530.124 AND AS.171.102 AND AS.110.202) AND (EN.530.241 OR EN.520.230) plus proficiency with MATLAB..  
Distribution Area: Engineering

**EN.530.424. Dynamics of Robots and Spacecraft. 3 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.

Distribution Area: Engineering

**EN.530.425. Mechanics of Flight. 3 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. Boundary layers. Effects of compressibility. Subsonic and supersonic flight.

Distribution Area: Engineering

**EN.530.427. Intermediate Fluid Mechanics. 3 Credits.**

Linear and angular momentum in integral form, applications to turbomachines. The Navier-Stokes equations. Inviscid flow. Laminar viscous flow. Boundary layers. Turbulence. Compressible flows. Projects using computational tools, design of pipe network.

Distribution Area: Engineering

**EN.530.429. Musculoskeletal Biomechanics. 3 Credits.**

This course will apply fundamental principles of engineering to the analysis of the human musculoskeletal system. Most of the course will focus on bone and soft tissue mechanics, joint mechanics, and joint kinematics. Various sports related injuries will be discussed. Additional topics will include biomaterials, implant mechanics, fracture, and wear. Recommended Course Background: EN.530.201 and EN.530.202 or instructor permission.

Distribution Area: Engineering

**EN.530.430. Applied Finite Element Analysis. 3 Credits.**

This Applied Finite Element Analysis course offers an extensive exploration of the practical applications of finite element analysis (FEA) using Creo Simulate and Ansys. Using Simulate, students will learn to perform linear static structural and thermal analyses of parts and assemblies. Students will also learn to represent preloaded bolts, create both solid and thin shell meshes, and improve the reliability of FEA results through convergence studies. Creo Simulate's integration with the Creo Parametric, a computer-aided design (CAD) tool, provides several advantages. First, the integration enables remarkable efficiency in performing analyses. Simulate also seamlessly manipulates the CAD model in running design optimizations. Additionally, CAD models can be generated from the results of Generative Design studies. Ansys is an industry standard FEA program. In the Ansys portion of the course, students will revisit the most common types of analyses, making some comparisons back to the results from Creo Simulate. Next, students will learn to partition CAD geometry into mesh-able volumes and construct high quality hexahedral meshes. Finally, students perform a broad array of other simulation types that include transient structural, nonlinear materials, explicit dynamics, and computational fluid dynamics. Throughout the course, students will have opportunities to apply the techniques covered in ways that align with their personal interests, other courses, or career ambitions. CAD experience preferred but not required. Course work or knowledge of matrix analysis/algebra recommended.

Distribution Area: Engineering

**EN.530.431. Biomechanics of Development. 3 Credits.**

Embryo development is an extraordinary journey, shaped not solely by gene expression, but also by the profound influence of mechanical principles. This course will familiarize students with the pivotal role of mechanical cues in cell differentiation, migration, and tissue morphogenesis, providing insight into the mechanical basis of congenital anomalies. Additionally, we will explore instrumentation, methodologies, and tools employed in developmental studies. Throughout the course, students will actively engage in surveying and reviewing research literature, addressing simple biomechanical problems, proposing solutions to biomechanical challenges, and choosing specific developing tissues for in-depth discussions.

Distribution Area: Engineering

**EN.530.432. Jet & Rocket Propulsion. 3 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 space flight, chemical rocket components, and combustion involving liquid and solid fuels.

Distribution Area: Engineering

**EN.530.435. Guidance and Control of Flight Vehicles. 3 Credits.**

This course introduces the fundamental concepts of guidance and control of rockets and will highlight methodologies often employed in industry. The topics covered include: aerodynamic control, review of flight control principles (transfer functions, block diagram reduction, root locus, frequency domain methods), nonlinear representation of an airframe, linearization of an airframe, flight control design of a rocket, three-loop autopilot design, and fundamentals of tactical guidance (proportional navigation guidance theory, zero effort miss).

**Prerequisite(s):** EN.530.343

Distribution Area: Engineering

**EN.530.436. Bioinspired Science and Technology. 3 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.

Distribution Area: Engineering, Natural Sciences

**EN.530.438. Aerospace Materials. 3 Credits.**

Aircraft materials have come a long way from the early days of bamboo, muslin and bailing wire, and this course will accentuate processing-structure-property-performance relations in a variety of metallic alloys, ceramics and composites. Materials with applications in aeronautics, space and hypersonics will be emphasized, and topics will include: Al and Ti alloys, Co and Ni-based superalloys, refractory alloys; ceramic, metal and polymer-based composites; thermal protection systems; and dielectric windows and radomes.

**Prerequisite(s):** EN.530.352

Distribution Area: Engineering

**EN.530.441. Introduction to Biophotonics. 3 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.

Distribution Area: Engineering

**EN.530.443. Fundamentals, Design Principles and Applications of Microfluidic Systems. 3 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

**Prerequisite(s):** All pre-requisite courses must be graded C- or higher before course registration. EN.530.327 AND EN.530.231

Distribution Area: Engineering, Quantitative and Mathematical Sciences

**EN.530.448. Biosolid Mechanics. 3 Credits.**

This class will introduce fundamental concepts of statics and solid mechanics and apply them to study the mechanical behavior bones, blood vessels, and connective tissues such as tendon and skin. Topics to be covered include the structure and mechanical properties of tissues, such as bone, tendon, cartilage and cell cytoskeleton; concepts of small and large deformation; stress; constitutive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity; and experimental methods for measuring mechanical properties, Recommended Course Background: AS.110.201 and AS.110.302, as well as a class in statics and mechanics.

Distribution Area: Engineering

**EN.530.455. Additive Manufacturing. 3 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.

Distribution Area: Engineering

**EN.530.465. Spacecrafts, Submarines, and Glaciers: Solid Mechanics in Extreme Environments. 3 Credits.**

In this course, students will explore the mechanics of solids in the context of designing and operating spacecrafts and submarines, as well as understanding deformation and failure in glaciers. This course covers the fundamentals of solid mechanics, including three-dimensional stress, strain, deformation, and failure, and their application in extreme environments. Through such real-world examples, students will gain a strong foundation in the mechanics of solids and their unique applications. Students will learn about some aspects of spacecraft structural design to overcome unique challenges, including the effects of extreme temperatures, radiation, and vacuum environments on materials and structures. Students will also learn about the structural design of submarines, including behavior under high pressure as well as failure induced by implosion or crushing. The final part of the course will focus on glacier mechanics, including the behavior of ice under different loads and temperatures and the mechanics of ice sheets and icebergs. Students will learn about the use of mechanics principles in understanding glacier dynamics and the design of structures such as ice dams and ice walls. Through real-world examples, students will gain a strong foundation in the mechanics of solids and structures, as well as an understanding of the challenges and opportunities presented by designing and operating structures in extreme environments.

Distribution Area: Engineering

**EN.530.468. Locomotion Mechanics: Fundamentals. 3 Credits.**

This upper level undergraduate and graduate class will discuss fundamental 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. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Sample topics include: How can kangaroos hop faster and fleas jump higher 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? Why do Boston Dynamics' robots move so well in most modest environments, and why does it still fail in complex terrain? Why do horses walk at low speeds but run at higher speeds? Can T-Rex run or must they walk? Why do larger animals become more erect in their leg posture? Why can a mouse falling from a skyscraper walk away with little injury, but a horse will smash? How can our muscles serve as energy-saving springs, force transmitting struts, and even energy-damping brakes? Why do migrating birds fly in a V-formation? Do Speedo's sharkskin swimsuits really reduce drag? Students from ME, Robotics, and other programs are all welcome. Freshmen and sophomores with sufficient physics background may take with instructor approval. Students should have a strong understanding of Newtonian mechanics. Nearly all these fundamental studies of interesting biological locomotion phenomena have led to engineering devices that use the same physics principles to move in complex environments, with performance approaching that of animals. Recommended background: Earned B or higher in EN.530.202 (or EN.560.202) Dynamics or equivalent.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.530.469. Locomotion Mechanics: Recent Advances. 3 Credits.**

This upper level undergraduate and graduate class will discuss recent advances in the mechanics of animal and bio-inspired robot locomotion in complex environments. All of the topics covered are from cutting edge research over the last 20 years, with many still being active research areas. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Sample topics include: How do geckos adhere to and climb over almost any surfaces? How do all kinds of animals use tails in novel ways to quickly maneuver in the air and on the ground? How do sandfish lizards burrow into and swim under sand? How do sidewinder snakes crawl up steep sand dunes without triggering an avalanche? How do large ants colonies dig and live in narrow tunnels without trapping themselves in traffic jams? Why do legged and snake robots struggle on sand and rubble, whereas insects, lizards, and snakes traverse similar terrain at ease? Why do insects rotate their wings while flapping to fly? How do soft-bodied worms move and how can we make better soft robots? How do cockroaches survive after squeezing through gaps with pressure several hundreds of their body weight? How do water striders walk on water and why can't we do it? All these fundamental studies of interesting biological locomotion phenomena have led to bio-inspired robots that use the same physics principles to move in complex environments, with performance approaching that of animals. Students from ME, Robotics, and other programs are all welcome. Freshmen and sophomores with sufficient physics background may take with instructor approval. Students should have a strong understanding of Newtonian mechanics. Recommended background: B or higher in EN.530.202 Dynamics or EN.560.202 Dynamics. Closely-related courses: EN.530.468/668 Locomotion Mechanics: Fundamentals EN.530.676 Locomotion Dynamics and Control Visit <https://li.me.jhu.edu/teaching> for more information.

Distribution Area: Engineering

**EN.530.470. Space Vehicle Dynamics & Control. 3 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.

Distribution Area: Engineering

**EN.530.474. Effective and Economic Design for Biomedical Instrumentation. 4 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

**Prerequisite(s):** 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.

Distribution Area: Engineering

**EN.530.480. Image Processing and Data Visualization. 3 Credits.**

The course will be divided into two parts. In the first part, students will learn the basics of image processing, including handling noisy background, creating 2D/3D filters, Fourier domain operations, and building processing pipelines. In the second part, students will learn the importance of data visualization, as well as the skills to use the aids such as virtual reality goggles and haptic devices to help scientists gain insights for data interpretation. Recommended experience programming in Matlab.

Distribution Area: Engineering, Quantitative and Mathematical Sciences

**EN.530.483. Applied Computational Modeling in Aerodynamics and Heat Transfer. 3 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).

Distribution Area: Engineering, Quantitative and Mathematical Sciences

**EN.530.493. Fabrication of Biomaterials, Engineered Tissues and Food. 4 Credits.**

Students will learn how to manufacture biocompatible or cell-encapsulated materials for various purposes, including applications in regenerative medicine, individualized drug screening and animal-free meat production.

**Prerequisite(s):** Students who have taken or are enrolled in EN.530.693 are not eligible to take EN.530.493.

Distribution Area: Engineering

**EN.530.501. Undergraduate Research. 1 - 3 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.

**Prerequisite(s):** You must request Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms.

**EN.530.511. Group Undergraduate Research. 1 - 3 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.

**Prerequisite(s):** You must request Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms.

**EN.530.526. Undergrad Independent Study. 1 - 3 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.

**Prerequisite(s):** You must request Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms.

**EN.530.527. Independent Study. 1 - 3 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.

**Prerequisite(s):** You must request Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms.

**EN.530.566. Independent Research - DAVINCI Venus Mission. 1 Credit.**

Continuing work on the NASA DAVINCI VFOx instrument to investigate oxygen in the atmosphere of Venus. Student should propose work to be done, with faculty approval.

**Prerequisite(s):** You must request Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms.;AS.270.366

**EN.530.597. Research - Summer. 1 - 3 Credits.**

This course is taken by students seeking to conduct undergraduate-level research during the summer for academic credit.

**Prerequisite(s):** You must request Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms.

**EN.530.599. Independent Study. 1 - 4 Credits.**

Independent Study is the result of creating a course of study focused on topics beyond coursework or expands on a topic in which further study is desired.

**Prerequisite(s):** You must request Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms.

**EN.530.603. Applied Optimal Control. 3 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.

**EN.530.604. Mechanical Properties of Materials. 3 Credits.**

An introduction to the properties and mechanisms that control the mechanical performance of materials. Topics include mechanical testing, tensor description of stress and strain, isotropic and anisotropic elasticity, plastic behavior of crystals, dislocation theory, mechanisms of microscopic plasticity, creep, fracture, and deformation and fracture of polymers. Recommended Course Background: EN.510.601

**Prerequisite(s):** Students who have taken EN.510.604 are not eligible to take EN.530.604.

**EN.530.605. Mechanics of Solids and Materials. 3 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.

**EN.530.606. Mechanics of Solids and Materials II. 3 Credits.**

An overview of the area of the mechanics of solids and materials, with the intent of providing the foundation for graduate students interested in research that involves these disciplines. The course is based on the principles of continuum mechanics, and covers the fundamental concepts of elasticity, plasticity, and fracture as applied to materials. One objective is to get graduate students to the point that they can understand significant fractions of research seminars and papers in this area. This mathematically rigorous course emphasizes the setup and solution of boundary value problems in mechanics, and attempts to integrate the primary behaviors with deformation and failure mechanisms in materials. Special topics covered may include (depending on the interests of the student body) wave propagation, viscoelasticity, geomechanics or biomechanics.

Distribution Area: Engineering

**EN.530.607. Introduction to Wind Energy. 3 Credits.**

This project-based course will provide an introduction to wind energy engineering.

**EN.530.610. Quantitative Cell Mechanics. 3 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.

**EN.530.611. Composite Materials. 3 Credits.**

Rarely a single material suffice to provide the desired performance for particular applications and we typically resort to a combination of materials (or composite materials). Apart from that a single material may also have defects in its microstructure which influences response. This course describes how to deal with the mechanics aspect of the composite materials. Based on concepts of stress, strain definition for a continuum, this course is oriented towards developing a fundamental understanding of composite materials. At the end of this course, a successful student will be able to:

- Evaluate effective properties of a composite material with inclusions of different shapes and put bounds on the homogenized values.
- Evaluate effective properties of laminates.
- Comprehend concepts of strength and failure criterion in composites and apply to design. Comprehend wave propagation relation in composites.
- Appreciate the principles of homogenization used to scale up from micro/meso to that of the continuum level representation.

**EN.530.616. Introduction to Linear Systems Theory. 3 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 course EN.520.601. No audit option, but contact the instructor if you want to informally sit in on the course. Recommended course background are undergraduate courses in linear algebra, differential equations, and an undergraduate level course in control systems. Students cannot take EN.530.616 if they have already taken EN.520.601.

**Prerequisite(s):** Recommended course background are undergraduate courses in linear algebra, differential equations, and an undergraduate level course in control systems. Students cannot take EN.530.616 if they have already taken EN.520.601

**EN.530.618. Fabricatology - Advanced Materials Processing. 3 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.

**EN.530.619. Aerospace Structures. 3 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.

**EN.530.621. Fluid Dynamics I. 3 Credits.**

Kinematics. Stress. Conservation of mass, momentum, and energy. Newtonian fluids. The Navier-Stokes equations. Inviscid flows. Laminar viscous flows. Vorticity. Instability. Turbulence. Boundary layers. External flows. Compressible flows. Introduction to non-Newtonian fluids.

**EN.530.622. Fluid Dynamics II. 3 Credits.**

Kinematics. Stress. Conservation of mass, momentum, and energy. Newtonian fluids. The Navier-Stokes equations. Inviscid flows. Laminar viscous flows. Vorticity. Instability. Turbulence. Boundary layers. External flows. Compressible flows. Introduction to non-Newtonian fluids.

**EN.530.623. Design of Marine Robots. 3 Credits.**

This class will introduce the design of marine robotic systems, with a particular emphasis on Autonomous Underwater Vehicles (AUVs). This class is intended to give the student a broad view of the applications, design, and operation of marine robots. Students will be introduced to the ocean as an operating environment, establish mission sets, vehicle subsystems, design strategies, and performance metrics. Students will be introduced to the fundamentals of underwater acoustics, especially as it pertains to underwater sensing, navigation, and communication.

Operations of AUV will be explored, along with analysis of different types of operations such as ship-based, under-ice, shore-launched, and docking-based operations. Emphasis will be given to the conceptual design phase of robot design, and the development and use of parametric approaches to performance evaluation. Finally, multiplatform survey systems will be analyzed, and we will explore the challenges associated with designing AUV that might operate on other ocean worlds, such as Europa and Enceladus.

Distribution Area: Engineering

**EN.530.624. Dynamics of Robots and Spacecraft (Graduate). 3 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.

**EN.530.625. Turbulence. 3 Credits.**

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

**EN.530.626. Trajectory Generation for Space Systems. 3 Credits.**

This course will provide an introduction to trajectory design techniques for aerospace and spacecraft robotic systems. We will place a heavy emphasis on optimization-based techniques and study optimal control formulations for solving trajectory optimization and model predictive control problems. Applications of interest will include interplanetary trajectory optimization, rocket entry-descent-landing, asteroid proximity operations, and planetary rover path planning. A strong emphasis will be placed on practical applications through coding implementations in Python and evaluation in simple simulation environments. Finally, a course project will be included to allow students to gain further experience on an algorithm or application of their choice.

**EN.530.627. Intermediate Fluid Mechanics (graduate). 3 Credits.**

Linear and angular momentum in integral form, applications to turbomachines. The Navier-Stokes equations. Inviscid flow. Laminar viscous flow. Boundary layers. Turbulence. Compressible flows. Projects using computational tools, design of pipe network.

**EN.530.632. Convection. 3 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.

**EN.530.635. Guidance and Control of Flight Vehicles. 3 Credits.**

This course introduces the fundamental concepts of guidance and control of rockets and will highlight methodologies often employed in industry. The topics covered include: aerodynamic control, review of flight control principles (transfer functions, block diagram reduction, root locus, frequency domain methods), nonlinear representation of an airframe, linearization of an airframe, flight control design of a rocket, three-loop autopilot design, and fundamentals of tactical guidance (proportional navigation guidance theory, zero effort miss).

Distribution Area: Engineering

**EN.530.637. Energy Meteorology. 3 Credits.**

Renewable energy is growing rapidly in the United States and around the world to provide sustainably-generated electricity, and many renewable energy generators are influenced by the weather. Transmission and power demand are also vulnerable to weather. Traditional energy sources also interact with weather. By studying interactions between the atmosphere and energy generators, transmission lines, and demand centers, we gain an understanding of processes that shape local weather and climate worldwide. In-class activities and weekly homework assignments give you opportunities to work with real-world data as you would at an energy development company. Weekly quizzes challenge your specialist vocabulary and scientific understanding. Presentations on papers and class projects (graduate students) enable you to develop and exercise important scientific communication skills. Several guest speakers will share their insights of the renewable and traditional energy industries.

**EN.530.638. Aerospace Materials. 3 Credits.**

Aircraft materials have come a long way from the early days of bamboo, muslin and bailing wire, and this course will accentuate processing-structure-property-performance relations in a variety of metallic alloys, ceramics and composites. Materials with applications in aeronautics, space and hypersonics will be emphasized, and topics will include: Al and Ti alloys, Co and Ni-based superalloys, refractory alloys; ceramic, metal and polymer-based composites; thermal protection systems; and dielectric windows and radomes.

**EN.530.641. Statistical Learning For Engineers. 3 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, Bayes 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. No Audits Recommended Course Background: o Course background: Linear Algebra, Multivariate Calculus, Probability, Differential Equations; Programming: Knowledge of Python (and Matlab)

**EN.530.642. Plasticity. 3 Credits.**

The theory of the inelastic behavior of metallic materials. Experimental background and fundamental postulates for the plastic stress-strain relations. Mechanisms of plastic flow; single-crystal and polycrystalline plasticity. Boundary value problems. Variational principles, uniqueness and the upper and lower bound theorems of limit analysis. Slip line theory. Dynamic plasticity and wave phenomena. Finite strain plasticity and instability.

**EN.530.643. Fundamentals, Design Principles and Applications of Microfluidic Systems. 3 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.

**EN.530.645. Kinematics. 3 Credits.**

A theoretical treatment of the kinematics of mechanisms, machines, and robotic manipulators intended for (though not restricted to) graduate students. Topics include parameterizations of spherical motion - Euler angles, Rodrigues parameters, unit quaternions, the matrix exponential; analysis of planar and spatial linkages; robot kinematics - forward and inverse kinematics, singularities, elementary topological issues; theory of wrenches and twists; research issues in robot kinematics - redundancy resolution, grasping and rolling contact, steering of nonholonomic systems. Other advanced topics will be covered as time permits. Recommend Course Background: Undergraduate linear algebra and multivariable calculus.

**EN.530.646. Robot Devices, Kinematics, Dynamics, and Control. 4 Credits.**

Graduate-level introduction to the mechanics of robotic systems with emphasis on the mathematical tools for kinematics and dynamics of robotic systems. Topics include the geometry and mathematical representation of rigid body motion, manipulator kinematics including forward and inverse kinematics of articulated robot arms, differential kinematics, manipulator dynamics and control. Additional special topics such as trajectory generation, actuation, and design issues will be considered as time permits.

**EN.530.647. Adaptive Systems and Control. 4 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 or EN.530.616 Introduction to Linear Systems Theory is a required prerequisite. Please see the course home page here for additional information: 647-adaptive-systems-and-control-spring-2024" target="\_blank"><https://dscl.lcsr.jhu.edu/530-647-adaptive-systems-and-control-spring-2024>. Audit registration not permitted.

**EN.530.648. Biosolid Mechanics. 3 Credits.**

This class will introduce fundamental concepts of statics and solid mechanics and apply them to study the mechanical behavior bones, blood vessels, and connective tissues such as tendon and skin. Topics to be covered include the structure and mechanical properties of tissues, such as bone, tendon, cartilage and cell cytoskeleton; concepts of small and large deformation; stress; constitutive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity; and experimental methods for measuring mechanical properties, Recommended Course Background: AS.110.201 and AS.110.302, as well as a class in statics and mechanics.

**EN.530.655. Additive Manufacturing (Graduate). 3 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 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.

**EN.530.663. Robot Motion Planning. 3 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.

**EN.530.666. Magnetically Actuated and MRI Compatible Robots. 3 Credits.**

In many futuristic science fiction scenes, complex surgical procedures are conducted autonomously and non-invasively, leading to incredible patient outcomes and recovery times. While robots have been employed to assist surgeons in performing complex procedures, current state-of-the-art mechanical manipulator based surgical robots are still a long way from the envisioned. Removing the mechanical manipulator could lead to ultra-minimally invasive procedures, like the closing of a hole in the heart or repairing a hernia with just a pin prick for access. Magnetic fields are safe, can penetrate inside the human body, provide exquisite 3D imaging using magnetic resonance imaging (MRI), and provide a means of transmitting power and manipulating magnetic objects. With appropriately designed control algorithms and external hardware, simple medical tools such as needles, forceps, and scissors can become wireless end-effectors of electromagnetic actuation systems. The primary goal of this course is to acquaint the students with the fundamentals of robot design, development, magnetic control, and MRI imaging and other areas of research that lead to the development of MRI compatible and magnetically actuated robotic systems. We will also cover additional topics specific to medical robotics such as medical image guidance focusing on MRI. The course will include two team projects, where students will learn to design, develop, build, and control medical robots. The class will be held synchronously in person with asynchronous accommodations.

**EN.530.668. Locomotion Mechanics: Fundamentals. 3 Credits.**

This upper level undergraduate and graduate class will discuss fundamental 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. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Sample topics include: How can kangaroos hop faster and fleas jump higher 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? Why do Boston Dynamics' robots move so well in most modest environments, and why does it still fail in complex terrain? Why do horses walk at low speeds but run at higher speeds? Can T-Rex run or must they walk? Why do larger animals become more erect in their leg posture? Why can a mouse falling from a skyscraper walk away with little injury, but a horse will smash? How can our muscles serve as energy-saving springs, force transmitting struts, and even energy-damping brakes? Why do migrating birds fly in a V-formation? Do Speedo's sharkskin swimsuits really reduce drag? Students from ME, Robotics, and other programs are all welcome. Freshmen and sophomores with sufficient physics background may take with instructor approval. Students should have a strong understanding of Newtonian mechanics. Nearly all these fundamental studies of interesting biological locomotion phenomena have led to engineering devices that use the same physics principles to move in complex environments, with performance approaching that of animals. Recommended background: Earned B or higher in EN.530.202 (or EN.560.202) Dynamics or equivalent.

Distribution Area: Engineering

**EN.530.669. Locomotion Mechanics: Recent Advances. 3 Credits.**

This upper level undergraduate and graduate class will discuss recent advances in the mechanics of animal and bio-inspired robot locomotion in complex environments. All of the topics covered are from cutting edge research over the last 20 years, with many still being active research areas. General principles and integration of knowledge from engineering, biology, and physics will be emphasized. Sample topics include: How do geckos adhere to and climb over almost any surfaces? How do all kinds of animals use tails in novel ways to quickly maneuver in the air and on the ground? How do sandfish lizards burrow into and swim under sand? How do sidewinder snakes crawl up steep sand dunes without triggering an avalanche? How do large ants colonies dig and live in narrow tunnels without trapping themselves in traffic jams? Why do legged and snake robots struggle on sand and rubble, whereas insects, lizards, and snakes traverse similar terrain at ease? Why do insects rotate their wings while flapping to fly? How do soft-bodied worms move and how can we make better soft robots? How do cockroaches survive after squeezing through gaps with pressure several hundreds of their body weight? How do water striders walk on water and why can't we do it? All these fundamental studies of interesting biological locomotion phenomena have led to bio-inspired robots that use the same physics principles to move in complex environments, with performance approaching that of animals. Students from ME, Robotics, and other programs are all welcome. Freshmen and sophomores with sufficient physics background may take with instructor approval. Students should have a strong understanding of Newtonian mechanics. Recommended background: B or higher in EN.530.202 Dynamics or EN.560.202 Dynamics. Closely-related courses: EN.530.468/668 Locomotion Mechanics: Fundamentals EN.530.676 Locomotion Dynamics and Control Visit <https://li.me.jhu.edu/teaching> for more information. Distribution Area: Engineering

**EN.530.672. Biosensing & BioMEMS. 3 Credits.**

The course discusses the principles of biosensing and introduces micro- and nano-scale devices for fluidic control and molecular/cellular manipulation, measurements of biological phenomena, and clinical applications.

**EN.530.673. Introduction to Molecular and Atomistic Modeling and Simulation. 3 Credits.**

The course provides an introduction of how material behaves at the molecular and atomistic levels, when they are subjected to changes in pressure and temperature. The behavior of materials at the molecular/atomistic level defines the global/continuum behavioral response of the material subjected to some loading conditions. The course relates concepts of physics to engineering concepts of deformation in materials/structures. At the end of this course, a successful student will be able to:

- Perform simple molecular dynamics simulations on materials.
- Appreciate suitability and limitation of molecular/atomistic simulations.
- Comprehend how molecular and atomistic modeling and simulation are related to define the global/continuum description of materials/structures.
- Comprehend concepts of interatomic potentials used to represent different types of bonds in materials.
- Understand concepts of wave/particle duality and the role of electrons in the description of properties of a material.
- Develop the ability to understand literature in the area of molecular/atomistic modeling and simulation.

For molecular simulations, LAMMPS code (Sandia Labs) will be used by the students and Matlab/Python for post processing. It's an open source software, so students can install it in their laptops. However, for purpose of running simulations, ARCH will be used. For electronic contributions, Quantum Espresso code will be utilized, which is also open source. ARCH already has both the software installed in it, so the students will be given temporary access to it to run their codes.

**EN.530.674. Effective and Economic Design for Biomedical Instrumentation. 4 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

**Prerequisite(s):** 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. Distribution Area: Engineering

**EN.530.676. Locomotion Dynamics & Control. 3 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.

**Prerequisite(s):** A graduate course in linear systems theory (e.g. EN.520.601, EN.530.616) or mathematical methods of engineering (e.g. EN.530.761), or permission from the instructor.

**EN.530.678. Nonlinear Control and Planning in Robotics. 3 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.

**EN.530.679. Modern Tools and Applications in Experimental Solid Mechanics. 3 Credits.**

This course provides students with an introduction to experimental solid mechanics, equipping them with the fundamental knowledge required to design, set up, and interpret laboratory tests to determine the strength, stiffness, fracture toughness, and strains and stresses in solids under quasi-static and dynamic loads. The course is divided into a series of modules, with each module containing a lecture and accompanying laboratory exercises in which students set up and execute experiments and analysis. Module topics include: the basics of experimental measurements, noise, and errors; strain gages; photoelasticity; digital image correlation; impact testing and high-speed imaging; fracture toughness measurements. By the end of the course, students will be able to formulate, design, and execute experiments to characterize the elastic, plastic, and dynamic response of a variety of materials, and compare their measurements with theoretical predictions. Recommended Course Background: knowledge of statics, mechanics and materials, and mechanics based design  
Distribution Area: Engineering

**EN.530.683. Applied Computational Modeling in Aerodynamics and Heat Transfer. 3 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).

Distribution Area: Engineering, Quantitative and Mathematical Sciences

**EN.530.684. Orientation Mapping of Crystalline Materials. 3 Credits.**

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

**EN.530.690. Introduction to Aero/Hydro Acoustics. 3 Credits.**

This introductory course aims to introduce senior undergraduate and graduate students to the real-world problems of aeroacoustics and hydroacoustics, such as jet noise, airframe noise, automobile aerodynamic noise, echo-sounding, sonars, and ocean acoustic tomography. This course uses analytical and computational methods to help students understand the fundamental physics of sound that originates, propagates, and scatters in gases and liquids.

Distribution Area: Engineering

**EN.530.691. Haptic Interface Design for Human-Robot Interaction. 3 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.

**EN.530.692. Flexible Robotic System Modeling. 3 Credits.**

Recent advancements in robotics highlight two crucial concepts: “soft robots” and “uncertainty / stochasticity”, both of which are implied by the term “flexible” in the course. Examples include continuum/hyper-redundant robots used in the medical applications. This course will explore techniques for modeling these flexible robotic systems, with a particular emphasis on the geometric descriptions necessary for such modeling. Key topics will include kinematics and dynamics of a rigid body, Gaussian distribution and probability, differential geometry, introductory Lie group theory, the general theory of elastic rods, and stochastic equations of motion. Additional topics will be covered as time permits.

**EN.530.693. Fabrication of Biomaterials, Engineered Tissues and Food. 4 Credits.**

Students will learn how to manufacture biocompatible or cell-encapsulated materials for various purposes, including applications in regenerative medicine, individualized drug screening and animal-free meat production.

**Prerequisite(s):** Students who have taken or are enrolled in EN.530.493 are not eligible to take EN.530.693.

Distribution Area: Engineering

**EN.530.694. Scanning Electron Microscopy 101: Fundamentals of Nanocharacterization and Nanofabrication. 3 Credits.**

Over half a century after its formal birth, scanning electron microscope (SEM) has now become a routine instrument that is employed in physical and biological sciences, manufacturing engineering, archeology, forensic science, and more broader fields. SEM typically work as a superb magnifier but actually far beyond that. When a focused electron beam scans over a sample, a variety of signals arise and bring forth information about surface topography, element composition, crystallographic orientation, electronic bands, and so on, all of which can be imaged with micron to sub-nanometer resolution. Recent integration with in situ measurement tools and Focused Ion Beam system further transform SEM into a powerful platform of materials characterization and fabrication. This course is intended as a guidebook for junior scientists and engineers in all fields who have been or will be a SEM user. The basic science and practical experience covered in this course will help them understand what can be achieved from and how to make the best use of the versatile instrument.

**EN.530.696. Learning-Based Control for Robotics. 3 Credits.**

Model-based methods provide a powerful framework for controlling challenging robotic systems; however, imperfect models often lead to poor performance during real-world deployment. Machine learning methods provide one means of addressing deficient models, either through explicitly learning a model of the system dynamics or computing a control policy directly from data. In this course, we will explore the intersection between optimal control and machine learning, covering both model-free and model-based methods for learning-based control. We will start with a review of dynamic programming and its relationship to reinforcement learning. We will then explore the three primary means of incorporating learning into controller synthesis: learning value functions, control policies, and dynamics models. The course will culminate in a discussion of model-based reinforcement learning and adaptive optimal control. We will also discuss advanced topics such as learning Lyapunov functions and contraction metrics from data, iterative learning control, and techniques for adaptive nonlinear model predictive control. No Audits allowed. Recommended Course Background: Course work in 1) differential equations 2) multi-variable calculus 3) linear algebra 4) undergraduate linear control 5) graduate-level introductory robotics course such as EN.530.646 Robot Devices, Kinematics, Dynamics and Control and 5) MATLAB and/or Python programming.

**EN.530.707. Robot System Programming. 4 Credits.**

This course seeks to introduce students to open-source software tools that are available today for building robotic systems. The project-based course covers the following frameworks: Robot Operating System (2), Gazebo (Ignition) simulation, Orocos Real-Time Toolkit (RTT) and Orocos Kinematics and Dynamics Library (KDL). A different interface is covered each week with hand-on lectures and assignments. These include: topics, services, actionlib, launch files, transformation manager, URDF, dynamic simulation, simulation plugins, control loops design, kinematics and dynamics implementations. Student must bring a Linux laptop with ROS2 to each lecture and have intermediate programming skill level in C/C++. Familiarity with Linux, GIT and CMake is also recommended. Contact the instructor by email for approval and inquire about operating system and software versions. Required Course Prerequisite/Corequisite: EN.530.646 and EN.601.436/663. No audit option.

**EN.530.712. Computational Solid Mechanics. 3 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.

**Prerequisite(s):** EN.530.606 Mechanics of Solids and Materials II or equivalent AND EN.530.761 Mathematical Methods for Engineers or equivalent or permission of instructor.

**EN.530.721. Medical Robotics System Design. 3 Credits.**

The evolution of medical robotics is a new and exciting development. Medical robotics brings together many disparate areas of research such as development and modeling of robotic systems, design, control, safety in medical robotics, regulatory and ethics, haptics (sense of touch), ergonomics, and last but not the least, medicine. The primary goal of this course is to acquaint the students with the fundamentals of robot design, development, and control and different areas of research that lead to the development of medical robotic systems. We will also cover additional topics specific to medical robotics such as medical image guidance. The course will include a project, where students will learn to design, develop, build, and control a medical robot.

**Prerequisite(s):** EN.530.646

**EN.530.738. Micromechanics of Heterogeneous and Granular Materials. 3 Credits.**

This graduate-level course provides an introduction to the mechanical behavior of heterogeneous and granular materials from a microscopic point of view. The goal of the course is to provide a foundation for graduate students interested in performing research related to the micromechanics of heterogeneous materials and granular materials. The course employs the principles of continuum mechanics and discusses topics including inclusion and defect theory for materials (e.g., Eshelby's inclusion and inhomogeneity problems, strain fields around cracks and voids) and homogenized properties (e.g., average stresses and strains, homogenization and interaction assumptions, bounds on moduli) for heterogeneous materials with defects and voids. The course also applies the principles of continuum mechanics to homogenization of microscale behavior in granular materials (forces and packing structure) for the calculation of macroscale fields (stresses and strains). The course involves the solution of boundary value problems as well as reading and discussion of recent papers in the field.

**EN.530.748. Stress Waves, Impacts and Shockwaves. 1 Credit.**

Elastic waves in unbounded media. Elastic waveguides. Waves in elastic-plastic and nonlinear elastic materials. Analysis of impact on materials and structures. Impact on various scales, from planetary to microscopic. Shock waves. Impact signatures in materials (time permitting).

**EN.530.761. Mathematical Methods of Engineering I. 3 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.

**EN.530.766. Numerical Methods. 3 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.

**EN.530.767. Computational Fluid Dynamics. 3 Credits.**

Advanced introduction to finite-difference and finite-volume approaches to modeling incompressible flows. Computer project requiring programming.

**EN.530.777. Multiphase Flow. 3 Credits.**

An introduction to basic contemporary ideas concerning gas, liquid, and solid-fluid two-phase flows.

**EN.530.800. Independent Study. 3 - 20 Credits.**

Graduate students pursue research problems with a faculty supervisor. Although the research is under the direct supervision of a faculty member, students are encouraged to pursue the research as independently as possible.

**EN.530.801. PhD Graduate Research. 3 - 20 Credits.**

This course is taken by PhD students who are conducting graduate research in Mechanical Engineering.

**EN.530.803. Mechanical Engineering Graduate Seminar. 1 Credit.**

This seminar features talks on current research of interest to graduate students in Mechanical Engineering by guest speakers from both Johns Hopkins University and other educational institutions.

**EN.530.807. Graduate Research Seminar in Fluid Mechanics. 1 Credit.**

This research seminar features talks on graduate student research in Mechanical Engineering in a variety of fluid mechanics study.

**EN.530.809. Mechanics of Materials and Structures Graduate Seminar. 1 Credit.**

This research seminar features talks on graduate student research in Mechanical Engineering in a variety of mechanics and materials study.

**EN.530.820. MSE All-Course - Graduate Research. 3 - 10 Credits.**

This course will provide a Mechanical Engineering graduate-level research experience to those pursuing an "all-course" master's degree, which will help a student engage in research on a specific topic and/or in specific research group under faculty supervision. Prior to course registration, students will submit a research proposal for approval by the research supervisor and the student's faculty advisor. In case the faculty advisor is the same as the research supervisor, the proposal should be submitted to the ME Director of Graduate Studies for approval. The research will be the equivalent of at least three credits, or approximately 120 hours of work in a typical semester.

**EN.530.821. Master's Essay - Research and Writing. 3 - 10 Credits.**

This course will be taken by Mechanical Engineering students when doing research and/or writing for the Master's Essay.

**EN.530.822. Master's Essay - Co-Op. 3 - 10 Credits.**

This course will be taken by Mechanical Engineering students when working in a cooperative environment for writing the Master's Essay. Note that "essay" is the official term for a thesis at Johns Hopkins University.

**EN.530.823. MSE Graduate Research. 3 - 10 Credits.**

This course will provide a Mechanical Engineering graduate-level research experience to those pursuing either an "all-course" or an "essay" master's degree, which will help a student engage in research on a specific topic and/or in a specific research group under faculty supervision. Prior to course registration, students will submit a research proposal for approval by the research supervisor and the student's faculty advisor. In case the faculty advisor is the same as the research supervisor, the proposal should be submitted to the Mechanical Engineering department's Director of Graduate Studies for approval. The research will be the equivalent of at least three credits, or approximately 120 hours of work in a typical semester.

**EN.530.897. Graduate Research - Summer. 3 - 20 Credits.**

This is a placeholder "course" that recognizes graduate students as conducting research full-time during the summer, with the express benefit of saving such students from being assessed "FICA" or Social Security tax on their summer stipends and pay.