EN.530 (MECHANICAL ENGINEERING)

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.
Area: Engineering

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.
Area: Engineering

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
Area: Engineering

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 458083 in the Search box to locate the appropriate module.
Area: Engineering

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.
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.
Area: Engineering

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.
Area: Engineering, Natural Sciences

EN.530.124. Intro 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.
Area: Engineering, Natural Sciences

EN.530.156. Mini-Term: Manufacturing Engineering. 1 Credit.
The course presents a modern, all-inclusive look at manufacturing processes. This course is focused on manufacturing processes as an objective science rather than a descriptive art. Quantitative and engineering-oriented approach provides numerical problem exercises, homework & case study, labs, quizzes and final exam. Students should have experience with design, software for drafting.
Area: Engineering

EN.530.202. Mechanical Engineering Dynamics. 4 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.;(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; grade of C- or higher required for EN.530.201 OR EN.560.201
Area: Engineering

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 458083 in the Search box to locate the appropriate module.
Corequisite(s): EN.530.202
Area: Engineering

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
Area: Engineering

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 458083 in the Search box to locate the appropriate module.
Corequisite(s): EN.530.215
Area: Engineering

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): (AS.171.102 OR AS.171.108);AS.110.109
Corequisite(s): EN.530.232
Area: Engineering

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.530.231There 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 458083 in the Search box to locate the appropriate module.
Area: Engineering, Natural Sciences

EN.530.241. Electronics & Instrumentation. 4 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): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;AS.171.102 OR AS.171.108 OR AS.171.106;(EN.550.291/EN.553.291) OR (AS.110.201 AND AS.110.302) OR (AS.110.212 AND AS.110.302); students may take the required courses concurrently with EN.530.241.
Area: Engineering

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 458083 in the Search box to locate the appropriate module.;EN.530.111 OR EN.530.414 or permission of instructor.
Area: Engineering

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 458083 in the Search box to locate the appropriate module.
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): EN.530.329;(EN.530.202[OR EN.560.202) AND (AS.110.302 OR EN.550.291 OR AS.110.306)
Area: Engineering

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.530.327There 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 458083 in the Search box to locate the appropriate module.
Area: Engineering

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
Area: Engineering

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 458083 in the Search box to locate the appropriate module.
Corequisite(s): EN.530.334
Area: Engineering

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 458083 in the Search box to locate the appropriate module.;AS.110.108[AND AS.110.109 AND (AS.110.202 OR AS.110.211) AND (EN.550.291 OR (AS.110.302[AND AS.110.201) OR (AS.110.306 AND AS.110.201)) and C- or better or concurrent enrollment in 530.202 or 560.202. MechE Majors must also have taken 530.241
Area: Engineering

EN.530.344. Design and Analysis of Dynamical Systems Laboratory. 1 Credit.
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.
Corequisite(s): EN.530.343
Area: Engineering

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): EN.530.215
Area: Engineering

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.
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 458083 in the Search box to locate the appropriate module.
Area: Engineering

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
Area: Engineering
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 values problems that occur in engineering structures, energy methods and foundations of the finite element method.
Area: Engineering, Natural Sciences

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.
Area: Engineering, Natural Sciences

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.
Area: Engineering

EN.530.417. 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.
Area: Engineering

EN.530.418. Aerospace Structures & Materials. 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.
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 458083 in the Search box to locate the appropriate module.; ((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.530.103 AND EN.530.104) OR (EN.530.123 AND EN.530.124)) AND ((AS.110.106 OR AS.110.108) AND AS.110.109 AND (AS.110.202 OR AS.110.211) AND (EN.550.291 OR AS.110.302) AND (EN.530.241 OR (EN.520.230 AND EN.520.231)))
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 458083 in the Search box to locate the appropriate module.;EN.530.420 OR EN.520.240 OR EN.520.340 or permission of the instructor.
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.
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.
Area: Engineering

EN.530.426. Biofluid Mechanics. 3 Credits.
Objective: To introduce fundamental concepts associated with the fluid mechanics of biological systems, including physiological flows and organisms living in fluids.
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.
Area: Engineering

EN.530.430. Applied Finite Element Analysis. 3 Credits.
This course will introduce finite element methods for analysis of solid, structure and biomechanics problems. Following topics will be covered. • Computational solution vs. other solution approaches• Definition of a mechanics problem: governing equations, constitutive equations, boundary and initial conditions. • Procedure to converting a mechanical problem into a computational solution problem.• Understanding and making choices of finite element types to suit problem type.• Finite element solution choices and their application. • Finite element analysis using commercial software ABAQUS. • FE model verification and validation, solution understanding uncertainty. The course will include homework assignments, 2 exams, and a term project. The term project will involve applying FEA to an engineering problem or a research problem, interpretation of results and documenting them in a short report.
Prerequisite(s): EN.550.291 OR AS.110.302
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.
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.
Area: Engineering, Natural Sciences

EN.530.439. Comparative Biomechanics. 3 Credits.
Comparative Biomechanics refers to the mechanics of biological organisms, including both humans and many non-human organisms. This course introduces the biomechanical principles of organism morphology, function, and interactions with their environment, as well as how these principles have inspired useful engineering devices. There is an emphasis on both the diversity of natural and artificial biomechanical systems and the underlying unifying principles.Many interesting topics will be discussed. Some examples include: Why can a mouse falling from a skyscraper walk away with little injury, but a horse will smash? Why do horses walk at low speeds but run at higher speeds? Can T-Rex run? Why do larger animals become more erect in their leg posture? How do geckos adhere to almost any surface? Can we learn from it to create a spider man? How can fleas jump to hundreds times of their body height? How does a chameleon shoot out its tongue to catch bugs? Why do British archers use the yew trees to make long bows? What other functions can muscles serve besides doing work? Why do animals need lungs for ventilation and a heart for blood circulation? How do prairie dogs get fresh air into their nest underground? How can giraffes drink by bending their head down to the ground without blowing their brains out, with a large blood pressure required to pump blood up when their head is up? Why do many tiny organisms have hairs? How do water striders walk on water and how do Jesus Christ lizards run on water? Can humans run on water? Students from ME and other departments are welcome.Students are assumed to be familiar with introductory physics. Although this is an upper lever undergraduate and graduate course, freshman and sophomore undergraduate students with sufficient physics background may take it with instructor approval.Closely-related course: EN.530.475/675. Locomotion I: Mechanics.Visit https://li.me.jhu.edu/teaching for more information.
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.
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): EN.530.327 AND EN.530.231
Area: Engineering, Quantitative and Mathematical Sciences

EN.530.445. Introduction to Biomechanics. 3 Credits.
An introduction to the mechanics of biological materials and systems. Both soft tissue such as muscle and hard tissue such as bone will be studied as will the way they interact in physiological functions. Special emphasis will be given to orthopedic biomechanics. Recommended Course Background: EN.530.215/EN.530.216 and Lab or equivalent. If you have not taken this course or an equivalent, please contact the instructor before registering to ensure you have the appropriate background knowledge to succeed in this course.
Area: Engineering

EN.530.446. Experimental Methods in Biomechanics. 3 Credits.
An introduction to experimental methods used in biomedical research. Standard experimental techniques will be applied to biological tissues, where applicable and novel techniques will be introduced. Topics include strain gauges, extensometers, load transducers, optical kinematic tracking, digital image correlation, proper experimental design, calibration and error analysis. Of particular emphasis will be maintaining native tissue temperature and hydration. Laboratory will include "hands- on" testing.
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.
Area: Engineering, Natural 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 concepts of small and large deformation, stress, constitutive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity, and experimental methods. Recommended Course Background: AS.110.201 and AS.110.302, as well as a class in statics and mechanics
Area: Engineering

EN.530.455. Additive Manufacturing. 3 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.
Area: Engineering

EN.530.464. Energy Systems Analysis. 3 Credits.
This course discusses the grid integration of renewable energy systems. The main emphasis is on grid level effects of renewable energy, particularly wind power systems. It begins with an introduction to basic power system concepts along with power flow analysis (and optimization). Then, important concepts for wind power systems are discussed. Following that, integration issues for wind power at the transmission level and solar cell integration at the distribution level are introduced. The last part of the course will focus on current research in these areas. Students will choose a system to research and present a project or literature review at the end of the term. Prior knowledge of optimization is helpful, but not required. Co-listed with EN530.664
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.
Area: Engineering

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: FundamentalsEN.530.676 Locomotion Dynamics and ControlVisit https://li.me.jhu.edu/teaching for more information.
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 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.
Area: Engineering

EN.530.473. Molecular Spectroscopy and Imaging. 3 Credits.
The overarching objective of this course is to understand, employ and innovate molecular spectroscopy and optical imaging tools. The emphasis will be to bridge the domain between molecular spectroscopy, which provides exquisite chemical information, and the imaging capabilities of microscopy to seamlessly traverse between structural and biochemical spaces. The course will build on the foundational principles of light-matter interactions and an understanding of light sources, geometrical and wave optics, and detectors. Using vibrational and fluorescence spectroscopy as the tools of choice, we will discuss the design and fabrication of molecular reporters that offer unprecedented sensitivity, specificity and multiplexing capabilities in imaging of live biological specimen. Finally, we will learn about spectral and image-processing algorithms that have fundamentally changed the nature and quantity of useful information and have directly lead to breakthroughs in super-resolution imaging and multi-modal image fusion. All through the course, the focus will be on the underlying concepts and physical insights as we navigate through a diverse array of biophotonics applications.
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.
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.
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).
Area: Engineering, Quantitative and Mathematical Sciences

EN.530.495. Microfabrication Laboratory. 4 Credits.
This laboratory course is an introduction to the principles of microfabrication for microelectronics, sensors, MEMS, and other synthetic microsystems that have applications in medicine and biology. Course comprised of laboratory work and accompanying lectures that cover silicon oxidation, aluminum evaporation, photoresist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services. Seniors only or Permission Required.
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.
Area: Engineering, Natural Sciences

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 Independent Academic Work using the Independent Academic Work 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 Independent Academic Work using the Independent Academic Work 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 Independent Academic Work using the Independent Academic Work 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 Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.530.597. Research - Summer. 1 - 3 Credits.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.530.599. Independent Study. 1 - 4 Credits.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.530.600. 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.530.602. 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.530.603. 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.530.605. 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.
Area: Engineering

EN.530.608. Experimental Fluid Dynamics. 3 Credits.
This course will serve as a virtual tour to many experimental facilities and techniques following the history of fluid dynamics research. Stories of several interesting debates will be told to show that iterations of experimental facilities based on the physics of fluid can lead to major new discoveries that brought a long-lasting impact on the entire field. The course will also focus on the unique opportunities and challenges in this decade thanks to the rapid advance of digital cameras, lasers, computed tomography, fluorescence imaging, as well as diagnostic tools based on X-ray, MRI, and gamma radiation. The course is designed for graduate students at all levels that are interested in fluid dynamics.

EN.530.609. 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.530.610. Statistical Mechanics in Biological Systems. 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.530.612. 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 AND EN.530.766 Numerical Methods or equivalent or permission of instructor.

EN.530.613. MechE Master's Design Project I. 3 Credits.
This course is intended to give graduate students some practice and experience in the art of engineering design in conjunction with undergraduate students taking MechE Senior Design Project I. Students working in teams of two to four will select a small-scale, industry-suggested design problem in the area of small production equipment, light machinery products, or manufacturing systems and methods. A solution to the problem is devised and constructed by the student group within limited time and cost boundaries. Preliminary oral reports of the proposed solution are presented at the end of the first semester. A final device, product, system, or method is presented orally and in writing at the end of the second semester. Facilities of the Engineering Design Laboratory (including machine shop time) and a specified amount of money are allocated to each student design team for purchases of parts, supplies, and machine shop time where needed.Recommended Course Background: C- or higher in both 530.403 and 530.404 MechE Senior Design Project I/II. Students from other universities may ask to be considered if they have taken a course like MechE Senior Design Project i.e. two semesters, design-build-test, ideally with industry connection.
Area: Engineering

EN.530.614. Master's Design Project II. 3 Credits.
This course is intended to give graduate students some practice and experience in the art of engineering design in conjunction with undergraduate students taking MechE Senior Design Project II. Students working in teams of two to four will select a small-scale, industry-suggested design problem in the area of small production equipment, light machinery products, or manufacturing systems and methods. A solution to the problem is devised and constructed by the student group within limited time and cost boundaries. Preliminary oral reports of the proposed solution are presented at the end of the first semester. A final device, product, system, or method is presented orally and in writing at the end of the second semester. Facilities of the Engineering Design Laboratory (including machine shop time) and a specified amount of money are allocated to each student design team for purchases of parts, supplies, and machine shop time where needed.Recommended Course Background: C- or higher in both 530.403 and 530.404 MechE Senior Design Project I/II. Students from other universities may ask to be considered if they have taken a course like MechE Senior Design Project i.e. two semesters, design-build-test, ideally with industry connection.

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 courses EN.520.601 OR EN.580.616. No audit option.
Prerequisite(s): Students cannot take EN.530.616 if they have already taken EN.520.601 OR EN.580.616.

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 and Materials. 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.530.624. 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.530.627. 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.530.629. Simulation and Analysis of Ocean Wave Energy Systems. 3 Credits.
Aspects of the simulation of a dynamic system are covered in this project-based course. Open-source software packages are used to simulate the hydrodynamics and rigid-body dynamics of an ocean wave-energy conversion project. Topics include: wave-energy converter types (buoyancy, hydrostatic pressure, potential energy, etc.), multi-body coupled dynamics, hydrodynamics, and energy conversion. Prerequisites: dynamics, fluid mechanics, computer programming (any language).

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

EN.530.636. 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.

EN.530.639. Comparative Biomechanics. 3 Credits.
Comparative Biomechanics refers to the mechanics of biological organisms, including both humans and many non-human organisms. This course introduces the biomechanical principles of organism morphology, function, and interactions with their environment, as well as how these principles have inspired useful engineering devices. There is an emphasis on both the diversity of natural and artificial biomechanical systems and the underlying unifying principles.Many interesting topics will be discussed. Some examples include: Why can a mouse falling from a skyscraper walk away with little injury, but a horse will smash? Why do horses walk at low speeds but run at higher speeds? Can T-Rex run? Why do larger animals become more erect in their leg posture? How do geckos adhere to almost any surface? Can we learn from it to create a spider man? How can fleas jump to hundreds times of their body height? How does a chameleon shoot out its tongue to catch bugs? Why do British archers use the yew trees to make long bows? What other functions can muscles serve besides doing work? Why do animals need lungs for ventilation and a heart for blood circulation? How do prairie dogs get fresh air into their nest underground? How can giraffes drink by bending their head down to the ground without blowing their brains out, with a large blood pressure required to pump blood up when their head is up? Why do many tiny organisms have hairs? How do water striders walk on water and how do Jesus Christ lizards run on water? Can humans run on water? Students from ME and other departments are welcome.Students are assumed to be familiar with introductory physics. Although this is an upper lever undergraduate and graduate course, freshman and sophomore undergraduate students with sufficient physics background may take it with instructor approval.Closely-related course: EN.530.475/675. Locomotion I: Mechanics.Visit https://li.me.jhu.edu/teaching for more information.

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.Recommended Course Background:o Course background: Linear Algebra, Multivariate Calculus, Probability, Differential Equations;o 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 Introduction to Linear Systems Theory is required prerequisite. Please see the course home page for additional information. Audit registration not permitted.

EN.530.653. Advanced Systems Modeling. 3 Credits.
This course covers the following topics at an advanced level: Newton's laws and kinematics of systems of particles and rigid bodies; Lagrange's equations for single- and multi-degree-of-freedom systems composed of point masses; normal mode analysis and forced linear systems with damping, the matrix exponential and stability theory for linear systems; nonlinear equations of motion: structure, passivity, PD control, noise models and stochastic equations of motion; manipulator dynamics: Newton-Euler formulation, Langrange, Kane's formulation of dynamics, computing torques with O(n) recursive manipulator dynamics: Luh-Walker-Paul, Hollerbach, O(n) dynamic simulation: Rodrigues-Jain-Kreutz, Saha, Fixman. There is also an individual course project that each student must do which related the topics of this course to his or her research.

EN.530.654. Advanced Systems Modeling II. 3 Credits.
A continuation of EN.530.653, this course covers the following topics at an advanced level:Newton's laws of kinematics of systems of particles and rigid bodies; Lagrange's equations forsingle- and multi-degree-of-freedom systems composed of point masses; normal mode analysis and forced linear systems with damping, the matrix exponential and stability theory for linear systems; nonlinear equations of motion; structure, passivity, PD control, noise models and stochastic equations of motion; manipulator dynamics: Newton-Euler formulation, Lagrange, Kane's formulation of dynamics, computing torques with O(n) recursive manipulator dynamics:Luh-Walker-Paul, Hollerbach, O(n) dynamics simulation: Rodriques-Jain-Kreutz, Saha, Fixman. There is also an individual course project that each student must do which relates the topics of this course to his or her research.

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.530.664. Energy Systems Analysis (graduate). 3 Credits.
This course discusses the grid integration of renewable energy systems. The main emphasis is on grid level effects of renewable energy, particularly wind power systems. It begins with an introduction to basic power system concepts along with power flow analysis (and optimization). Then, important concepts for wind power systems are discussed. Following that, integration issues for wind power at the transmission level and solar cell integration at the distribution level are introduced. The last part of the course will focus on current research in these areas. Students will choose a system to research and present a project or literature review at the end of the term. Prior knowledge of optimization is helpful, but not required. Co-listed with EN.530.464.

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.
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: FundamentalsEN.530.676 Locomotion Dynamics and ControlVisit https://li.me.jhu.edu/teaching for more information.
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.530.674. 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.
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.530.683. 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).
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-grantular 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.530.691. 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.530.707. Robot System Programming. 4 Credits.
This course seeks to introduce students to open-source software tools that are available today for building complex experimental and fieldable robotic systems. The course is grouped into sections, each of which building on the previous in increasing complexity and specificity: tools and frameworks supporting robotics research, robotics-specific software frameworks, integrating complete robotic systems, and culminates with an independent project of the student's own design using small mobile robots or other robots in the lab. Students will need to provide a computer (with at least a few GB of memory and a several tens of GB of disc space) running Ubuntu (https://www.ubuntu.com or one of its variants such as Xubuntu) and ROS (http://ros.org/). Students should have an understanding of intermediate programming in C/C++ (including data structures and object-oriented programming). Familiarity with Linux programming. Familiarity with software version control systems such as Git, and linear algebra. Students should see the course homepage https://dscl.lcsr.jhu.edu/home/courses/me530707-2019 for more information and to get started with the course. Required Course Prerequisite/Corequisite: EN.530.646 and EN.600.436. No audit option.

EN.530.710. Optical Measurement Techniques. 3 Credits.
Optic-based techniques are being utilized as measurement and data transmission tools in a growing number of applications. The objective of this course is to introduce graduate students with limited background in optics (but with background in graduate-level mathematics) to the fundamentals of optics and their implementation. Topics covered include reflection, refraction, fluorescence, phosphorescence and diffraction of light; review of geometric optics, lenses, lens systems (microscope, telescope), mirrors, prisms; aberrations, astigmatism, coma, and methods to correct them; light as an electromagnetic wave; Fourier optics; spectral analysis of optical systems; coherent and incoherent imaging, holography, interferometry, diffraction grating; lasers, polarization, light detectors; elements of non-liner optics, birefringence; optical fibers, data transmission, and networking.

EN.530.715. Mesoscale Simulations of Defects in Metals. 3 Credits.
This course focuses on coarse grained simulations of defects and plasticity in crystalline materials. Topics of interest include modeling dislocation plasticity, diffusion of point defects, grain and twin boundaries, precipitates, etc under different loading and boundary conditions.
Prerequisite(s): Either EN.530.605, EN.510.604, or waiver from the instructor. Student must also have background in programing using MATLAB, C, C++, FORTRAN or an equivalent coding language.

EN.530.717. Machine Learning for Solid Mechanics and Materials Engineering. 3 Credits.
Machine learning (ML) and principles of informatics are playing an increasing role in many aspects of solid mechanics and materials engineering. ML techniques enable the extraction of relationships from a large amount of seemingly uncorrelated data and can expedite the process of predicting deformation in solids and the discovery/design of materials. This course provides an introductory overview for graduate students on ML and principles of informatics as well as provide a survey of applications of ML in solid mechanics and materials engineering.

EN.530.726. Hydrodynamic Stability. 3 Credits.
Hydrodynamic linear stability theory is developed and applied to a variety of flow problems using analytical techniques and numerical methods. Necessary and sufficient conditions for flow stability are derived. Canonical examples are used to introduce various concepts including, e.g. temporal and spatial analyses, asymptotic and transient flow response, convective and absolute instability, global methods, and direct stability analysis.

EN.530.730. Finite Element Methods. 3 Credits.
Variational methods and mathematical foundations, Direct and Iterative solvers, 1-D Problems formulation and boundary conditions, Trusses, 2-D/ 3D Problems, Triangular elements, QUAD4 elements, Higher Order Elements, Element Pathology, Improving Element Convergence, Dynamic Problems.

EN.530.732. Fracture Of Materials. 3 Credits.
An advanced examination of fracture mechanisms in ductile and brittle materials. Both the mechanics and the materials aspects are covered with importance placed on the synthesis of the two approaches. Topics include linear elastic fracture mechanics, ductile fracture, the J-integral, atomistic aspects of fracture in polycrystalline materials, fracture in ceramics and polymers, influence of the material microstructure on fracture toughness and ductility in FCC and BCC materials.

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.
Prerequisite(s): EN.530.605 AND EN.530.606 OR Permission of the Instructor.

EN.530.748. Stress Waves, Impacts and Shockwaves. 3 Credits.
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.

EN.530.802. PhD Graduate Research. 3 - 20 Credits.
PhD Mechanical Engineering students conduct research toward the selection of their dissertation topic and completion of their dissertations to prepare for the defense and graduation. This course is taken every semester by all resident PhD Mechanical Engineering students.

EN.530.803. Mechanical Engineering Seminar. 1 Credit.
Open to Mechanical Engineering PhD students in the first three years.

EN.530.804. Mechanical Engineering Seminar. 1 Credit.

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

EN.530.808. Graduate Seminar in Fluid Mechanics. 1 Credit.

EN.530.809. Mechanics of Materials and Structures Graduate Seminar. 1 Credit.
Cross-listed with Mechanical Engineering.

EN.530.810. Mechanics and Materials Graduate Seminar. 1 Credit.

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.530.897. Research-Summer. 3 - 20 Credits.

EN.530.899. Independent Study-Summer. 1 - 3 Credits.

EN.535.606. Advanced Strength Of Materials. 3 Credits.
This course reviews stress and strain in three dimensions, elastic and inelastic material behavior, and energy methods. It also covers use of the strength of materials approach to solving advanced problems of torsion and bending of beams. Prerequisite(s): Fundamental understanding of stress and strain and axial, torsion, and bending effects in linear elastic solids.

EN.535.609. Topics in Data Analysis. 3 Credits.
This course will provide a survey of standard techniques for the extraction of information from data generated experimentally and computationally. The approach will emphasize the theoretical foundation for each topic followed by applications of each technique to sample experimental data. The student will be provided with implementations to gain experience with each tool to allow the student to then quickly adapt to other implementations found in common data analysis packages. Topics include uncertainty analysis, data fitting, feed-forward neural networks, probability density functions, correlation functions, Fourier analysis and FFT procedures, spectral analysis, digital filtering, and Hilbert transforms. Prerequisite(s): Projects will require some programming experience or familiarity with tools such as MATLAB.

EN.535.610. Computational Methods of Analysis. 3 Credits.
This course serves as an introduction to using MATLAB for typical engineering analyses and may serve as a valuable precursor to the more computationally intensive courses in the program that use MATLAB. Course topics include an introduction to script programming, solution of one- and two-dimensional definite integrals, solution of coupled sets of ordinary differential equations, typical data analysis (e.g., Fourier transforms, curve fitting, and signal processing), and matrix manipulation (e.g., solution of linear systems and eigenvalue extraction).

EN.535.612. Intermediate Dynamics. 3 Credits.
This course develops student’s ability to accurately model the dynamics of single and multi-body engineering systems undergoing motion in 3D space. The course begins with formulating the differential geometry and kinematics of curvilinear coordinates to permit kinematic descriptions of relative motion and rotation of rigid bodies and mechanisms subject to common engineering constraints such as substructure interconnections, dry friction, and rolling. Momentum and inertia properties of rigid body dynamics follow. Students are then introduced to analytical dynamics, where Lagrange’s equations and Kane’s method are derived and studied to facilitate efficient formulation of the equations of motion governing the dynamics of systems subject to conservative and non-conservative forces and engineering constraints. The course also concludes with gyroscopic dynamics with applications to inertial guidance and spacecraft attitude dynamics. Prerequisite(s): Mathematics through calculus and linear algebra.

EN.535.613. Structural Dynamics and Stability. 3 Credits.
This course introduces the propagation of elastic waves, and the loss of stability in engineering structures and systems. In the first part of the course, fundamental physical principles of elasticity and wave mechanics are reviewed and developed to provide students with the capability to model and analyze wave propagation, reflection, and refraction in isotropic and anisotropic engineering structures such as rods, beams, and plates. In the second part of the course, mechanical stability models are studied and applied in terms of dynamic behavior where the combined effects of vibration, gyroscopic motion, impact/shock, and buckling lead to new structural configurations or unstable motions that must often be avoided in design. Applications span nondestructive evaluation, composites, cables, aircraft/space structures, rotordynamics, aeroelasticity, civil engineering structures, and others. Prerequisite(s): Undergraduate or graduate course in vibrations.

EN.535.614. Fundamentals Acoustics. 3 Credits.
This course provides an introduction to the physical principles of acoustics and their application. Fundamental topics include the generation, transmission, and reception of acoustic waves. Applications covered are selected from underwater acoustics, architectural acoustics, remote sensing, and nondestructive testing. Prerequisite(s): Some familiarity with linear algebra, complex variables, and differential equations.

EN.535.621. Intermediate Fluid Dynamics. 3 Credits.
This course prepares the student to solve practical engineering flow problems and concentrates on the kinematics and dynamics of viscous fluid flows. Topics include the control volume and differential formulations of the conservation laws, including the Navier-Stokes equations. Students examine vorticity and circulation, dynamic similarity, and laminar and turbulent flows. The student is exposed to analytical techniques and experimental methods, and the course includes an introduction to computational methods in fluid dynamics. It also includes a programming project to develop a numerical solution to a practical fluid flow problem. Prerequisite(s): An undergraduate fluid mechanics course.

EN.535.622. Robot Motion Planning. 3 Credits.
This course investigates the motion planning problem in robotics. Topics include motion of rigid objects by the configurations space and retraction approaches, shortest path motion, motion of linked robot arms, compliant motion, coordinated motion of several objects, robust motion with error detection and recovery, and motion in an unknown environment

EN.535.623. Intermediate Vibrations. 3 Credits.
Course topics include transient and forced vibration of 1- and N-degree-of-freedom systems and an introduction to vibration of continuous systems. Hamilton's Principle and Lagrange's equations are used throughout the course to derive the equation(s) of motion. MATLAB is introduced and used to solve the equations of motion and plot the response of the system. This course also addresses common topics in applied vibrations such as the environmental testing, the shock response spectrum, random vibration, vibration isolation, and the design of tuned-mass damper systems. Prerequisite(s): An undergraduate vibrations course.

EN.535.625. 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.535.627. Computer-Aided Design. 3 Credits.
This course provides a wide-ranging exploration of computer-aided design (CAD) using Creo Parametric (a PTC CAD software, previously called Pro/ENGINEER). Topics include sketching, solid modeling, assembly modeling, detail drafting, geometric dimensioning and tolerancing, advanced modeling, sheet metal modeling, mechanism dynamics, and structural/thermal finite element analysis (FEA).

EN.535.628. Computer-Integrated Design and Manufacturing. 3 Credits.
This course emphasizes the computer automation of design and manufacturing systems. A survey of the automation techniques used for integration in modern design and manufacturing facilities is presented. Discussions are presented related to the system integration of computer-aided design (CAD), computeraided engineering (CAE), computer-aided manufacturing (CAM), robotics, material resource planning, tool management, information management, process control, and quality control. The current capabilities, applications, limitations, trends, and economic considerations are stressed.

EN.535.629. Energy Engineering. 3 Credits.
The course will focus on an analytical system performance technique known as Availability or Exergy Analysis, which is based on the second law of thermodynamics. The course focuses on traditional power and refrigeration systems. However, nontraditional power generation systems will be considered by way of a special project of each student's choice. It will include an engineering description of the state of the art of the selected topic (e.g., wind or solar power, fuel cell, etc.), and a second law performance analysis of a prototype system will be presented to the class. In addition to the power system topics, the availability analysis will be applied to the combustion and psychrometric processes.

EN.535.630. Kinematics & Dynamics of Robots. 3 Credits.
This course introduces the basic concepts and tools used to analyze the kinematics and dynamics of robot manipulators. Topics include kinematic representations and transformations, positional and differential kinematics, singularity and workspace analysis, inverse and forward dynamics techniques, and trajectory planning and control. Prerequisite(s): The course project and assignments will require some programming experience or familiarity with tools such as MATLAB.

EN.535.631. Intro Finite Element Methods. 3 Credits.
Topics covered by this course include theory and implementation of finite element models for typical linear problems in continuum mechanics including fluid flow, heat transfer, and solid mechanics. Emphasis will be placed on developing a fundamental understanding of the method and its application. Course Note(s): Cannot be counted with 560.730 Finite Element Methods from the full-time Civil Engineering Department.

EN.535.632. Applied Finite Elements. 3 Credits.
This Applied Finite Elements course provides a wide-ranging exploration of the practical applications of finite element analysis (FEA) using both Creo Simulate and Ansys. Creo Simulate's integration with the Creo Parametric, a computer-aided design (CAD) tool, affords a number of advantages, most notably a remarkable efficiency in performing analyses and the possibility for Simulate to seamlessly manipulate the CAD model in performing design optimizations. Within Simulate, students will learn to perform linear structural static 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. Within Ansys, and industry standard FEA program, students will revisit the most common types of analyses, making some comparisons back to the results from Creo Simulate. Next, students will then learn to partition CAD geometry into mesh-able volumes then 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. Opportunities exist throughout the course to individually apply the techniques covered in ways applicable to students' personal interests, career, or career ambitions.

EN.535.633. Intermediate Heat Transfer. 3 Credits.
This course covers the following topics: transient heat conduction, forced and free convection in external and internal flows, and radiation processes and properties. Prerequisite(s): An undergraduate heat transfer course.

EN.535.634. Applied Heat Transfer. 3 Credits.
This course focuses on the inevitable tradeoffs associated with any thermodynamic or heat transfer system, which result in a clear distinction between workable and optimal systems. The point is illustrated by means of a number of concrete problems arising in power and refrigeration systems, electronics cooling, distillations columns, heat exchange, and co-generation systems. Prerequisite(s): An undergraduate heat transfer course.

EN.535.635. Introduction to Mechatronics. 3 Credits.
Mechatronics is the integration of mechanisms, electronics, and control. This interdisciplinary course is primarily lab and project based, but also includes lectures to provide background in key underlying principles. The course's main objective is to provide experience designing and prototyping a mechatronic or robotic system to accomplish a specific task or challenge. Topics include mechanism design, motor and sensor integration and theory, programming of microprocessors, mechanics prototyping, and the design process. Students will work in teams to complete a hardware-based final project. Prerequisite(s): Mathematics through calculus and linear algebra.

EN.535.641. Mathematical Methods For Engineers. 3 Credits.
This course covers a broad spectrum of mathematical techniques needed to solve advanced problems in engineering. Topics include linear algebra, the Laplace transform, ordinary differential equations, special functions, partial differential equations, and complex variables. Application of these topics to the solutions of physics and engineering problems is stressed. Prerequisite(s): Vector analysis and ordinary differential equations.

EN.535.642. Control Systems for Mechanical Engineering Applications. 3 Credits.
This class provides a comprehensive introduction to the theory and application of classical control techniques for the design and analysis of continuous-time control systems for mechanical engineering applications. Topics include development of dynamic models for mechanical, electrical, fluid-flow and process-control systems, introduction to Laplace transforms, stability analysis, time and frequency domain analysis techniques, and classical design methods. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.

EN.535.643. 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.535.645. Digital Control and Systems Applications. 3 Credits.
This class will provide a comprehensive treatment of the analysis and design of discrete-time control systems. The course will build upon the student's knowledge of classical control theory and extend that knowledge to the discretetime domain. This course is highly relevant to aspiring control systems and robotics engineers since most control system designs are implemented in micro-processors(hence the discrete-time domain) vice analog circuitry. Additionally, the course will go into advanced control system designs in the state-space domain and will include discussions of modern control design techniques including linear-quadratic optimal control design, pole-placement design, and state-space observer design. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.
Prerequisite(s): 535.642 Control Systems for Mechanical Engineering Applications.

EN.535.650. Combustion. 3 Credits.
This is a multidisciplinary course involving applications of thermodynamics, fluid mechanics, heat transfer, and chemistry. Course contents include a review of chemical thermodynamics, chemical kinetics, transport theory, and conservation equations; laminar flow in premixed and non-premixed gases; combustion waves; ignition; combustion aerodynamics; multiphase combustion; and turbulent combustion. Selected applications are discussed including gas turbines, spark ignition and diesel engines, jet engines, industrial furnaces, pollutant formation, and control in combustion. Prerequisite(s): Undergraduate-level exposure to thermodynamics, fluid dynamics, differential equations, and basic chemistry.

EN.535.652. Thermal Systems Design and Analysis. 3 Credits.
Thermodynamics, fluid mechanics, and heat transfer principles are applied using a systems perspective to enable students to analyze and understand how interactions between components of piping, power, refrigeration, and thermal management systems affect the performance of the entire system. Following an overview of the fundamental principles involved in thermal and systems analyses, the course will cover mathematical methods needed to analyze the systems and will then explore optimization approaches that can be used to improve designs and operations of the thermal systems to minimize, for example, energy consumption or operating costs. Prerequisite(s): Undergraduate courses in thermodynamics and heat transfer. No computer programming is required.

EN.535.654. Theory/Appl Struct Anlys. 3 Credits.
This is a course in classical plate and shell structures with an emphasis on both analysis and application. Both differential and energy method approaches are presented. Topics include an introduction to thin plate theory, its application to circular and rectangular plates, buckling, and thermal effects. Classical thin shell theory is also presented. Applications to common plate and shell structures are discussed throughout.

EN.535.659. Manufacturing Systems Analysis. 3 Credits.
This course is a review of the fundamentals of modern manufacturing processes, computer-aided design/ manufacturing tools, flexible manufacturing systems, and robots. The course addresses relationships between process machinery, process conditions, and material properties. Examples of how components are manufactured within hightech industries are presented.

EN.535.660. Precision Mechanical Design. 3 Credits.
This course will provide the student with a fundamental understanding of the principles and techniques used to design precision machines, instruments, and mechanisms. Lectures will include discussions on the implementation and design of mechanisms, bearings, actuators, sensors, structures, and precision mounts used in precision design. Upon completion of this course, students will have a clear understanding of positional repeatability and accuracy, deterministic design, exact constraint design, error modeling, and sources of machine and instrumentation errors.

EN.535.661. Biofluid Mechanics. 3 Credits.
Introduction to fundamental fluid mechanics of physiological systems including the blood flow in the cardiovascular system and the air flow in the laryngeal and respiratory systems. Basic physiology of those systems will be introduced. Fundamental principles and mathematical/physical models for the air and blood flows in the physiological systems and their practical applications will be discussed. Simple computer models with MATLAB will be used in the course.

EN.535.662. Energy and Environment. 3 Credits.
The course focuses on advanced topics related to energy and thermodynamics. The objective of this course is to provide a thorough understanding of the environmental impacts related to energy conversion systems. The use of the second law of thermodynamics is introduced to quantify the performance of energy conversion systems. Topics such as global warming, alternative energy sources (solar, wind power, geothermal, tides, etc.), new technologies (fuel cells and hydrogen economy), and resources and sustainable development are addressed. A section of the course is devoted to current trends in nuclear energy generation and associated environmental issues Prerequisite(s): Undergraduate-level exposure to thermodynamics.

EN.535.663. Biosolid Mechanics. 3 Credits.
This class will introduce fundamental concepts of statics and solid mechanics and apply them to study the mechanical behavior of bones, blood vessels, and connective tissues such as tendons and skin. Topics to be covered include concepts of small and large deformation, stress, constitutive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity, and experimental methods. Recommended Background: Linear Algebra, Differential Equations, as well as statics and mechanics.

EN.535.664. Fundamental Principles for Bio-microfluidic Systems. 3 Credits.

EN.535.670. Advanced Aerodynamics. 3 Credits.
This course provides the basic aerodynamic concepts and tools for aerospace vehicle design and analysis, focusing on physical-based approaches with some introduction to numerical-based methods, where experimental wind tunnel or flight test data are considered as the benchmark results. The physical-based part will emphasize inviscid-incompressible flow followed by inviscid-compressible flow and introducing some basic elements of viscous flow plus a brief introduction to computational fluid dynamics (CFD), as the numerical-based methods.

EN.535.672. Advanced Manufacturing Systems. 3 Credits.
This course examines the effect that new technology, engineering, and business strategies have on transforming US industry into a world-class, competitive force. Emphasis is placed on the state of the art of factory automation and computer-integrated manufacturing. Topics include advanced manufacturing processes, rapid prototyping, intelligent manufacturing controls, and information technology in manufacturing. Technical principles related to advanced manufacturing are presented. Examples of actual production systems illustrate how industry is adopting the latest technology to meet customer requirements for quality, low cost, and flexibility.

EN.535.673. Mechanized Assembly: Hardware and Algorithms. 3 Credits.
Generally speaking, manufacturing engineering consists of two large subtopics: fabrication and assembly. This course covers topics in the design and analysis of mechanized assembly systems such as those used in parts feeding and pick-andplace machines. Specific topics will include: Describing Planar and Spatial Rotations, Planar Linkages (4-Bar, Crank-sliders), Classical Theory of Gears, Differential Geometry Methods, Singularities of Mechanisms and Robots, Spatial Linkage Synthesis and Screw Theory, Transmissions and Spatial Gearing, Automated Parts Transfer (Fences and Bowl Feeders), Assembly Planning, Tolerancing, Parts Entropy, Deployable Mechanism Design.

EN.535.675. Thermal Sciences for the Built Environment. 3 Credits.
This course will explore the energy transfer in building applications through study of fundamental heat and mass transfer, principles of vapor compression systems, and simulation of energy flows using publicly available software. Buildings account for 40% of energy consumption in the United States, so application of the principles of mechanical engineering can greatly lessen the environmental impact of the built environment while providing the comfort expected from occupants. This course will study the interplay between energy and issues such as comfort, durability, and indoor air quality.

EN.535.684. Modern Polymeric Materials. 3 Credits.
This course will cover a broad range of topics in the polymeric materials science and engineering field. We will address the structure and property relationships in thermoplastics, thermoset, amorphous, semicrystalline, oriented and biological polymeric materials; synthesis and processing (including rheology) of polymers; flow and fracture of polymeric materials under different conditions. Modern polymer characterization techniques will be introduced. Frontiers in the recent findings in biopolymers, polymer based 3D printing, polymers for tissue engineering will also be discussed.

EN.535.691. Haptic Interface Design. 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.535.711. Symmetries of Crystalline Solids. 3 Credits.
This course covers the mathematical techniques necessary for understanding of symmetry of the solid state topics such as lattices, crystals structure and X-ray diffraction experiment. The class uses examples from crystalline solids and crystallography to introduce mathematical concepts and related problem solving skills. Topics include linear algebra and eigenvalues and eigenvectors, tensor operations, symmetry operations, introduction to Fourier analysis, group theory, and crystallographic groups.

EN.535.712. Applied Fluid Dynamics. 3 Credits.
This course will provide a survey of topics in applied fluid dynamics for the practicing engineer. The first topic will concentrate on pipe and duct flow, looking at friction factors, abrupt changes in area, and pipe systems. This is followed by unsteady flows focusing on pressure transients, such as the water hammer. A section on lubrication theory covering wedge and journal bearings is presented. Open channel flows are discussed with emphasis on optimum cross-sectional shape and specific energy. Turbomachinery such as axial and centrifugal pumps, including specific speed and suction limitations, is described. Fluid dynamic drag and lift from streamlined surfaces are presented, including topics such as vortex shedding, terminal velocity, and cavitation. The approach will emphasize the practical foundation needed to solve real-world problems.
Prerequisite(s): 535.621 Intermediate Fluid Dynamics. Projects will require some programming experience or familiarity with tools such as MATLAB.

EN.535.720. Analysis and Design of Composite Structures. 3 Credits.
Topics in this course include anisotropic elasticity, laminate analysis, strength of laminates, failure theories, bending, buckling, and vibration of composite plates. The second part of the course is devoted to the applications of the structural analysis of composite structures by means of finite-elements computer codes.

EN.535.723. Mechanical Packaging for Electronics Systems. 3 Credits.

EN.535.724. Dynamics of Robots and Spacecraft. 3 Credits.
This course provides 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 by using Lagrange's equations, solutions of equations of motion, Hamilton's principle, and introduction to stability and control theory.

EN.535.726. Robot Control. 3 Credits.
This course focuses on the theory and methods used for the control of robotic manipulators. Topics include review of basic systems theory, robot position control, model-based trajectory tracking, and force control. Stability properties for each control strategy will be analyzed. Practical implementation issues will also be addressed. Students will simulate different control methods using MATLAB.
Prerequisite(s): 535.630 Kinematics and Dynamics of Robots, ordinary differential equations, linear algebra.

EN.535.727. Advanced Machine Design. 3 Credits.
This course provides a broad treatment of stress, strain, and strength with reference to engineering design and analysis. Major emphasis is placed on the analytical and experimental methods of determination of stresses in relationship to the strength properties of machine elements under various loading conditions. Also considered are deflection, post-yield behavior, residual stresses, thermal stresses, creep, and extreme temperature effects as applied to the design of fasteners, shafts, power trains, and rotational machinery.

EN.535.731. Engineering Materials: Properties and Selection. 3 Credits.
Become familiar with different classes of engineering materials and their tradeoffs associated with design criteria such as strength, toughness, corrosion resistance, and fabricability, as well as some common test methods for evaluating material properties. This course will concentrate on metal alloys but will also consider polymers and ceramics. Topics specific to metals will include effects of work hardening and heat treatment, corrosion, and elevated temperature properties. Topics specific to polymers will include viscoelasticity, stress relaxation and creep, and phase transitions. Topics specific to ceramics will include flaw-dominated strength, fracture energy, and statistical determination of strength. The course also includes an introduction to the Ashby method of material selection and optimization.

EN.535.732. Fatigue and Fracture of Materials. 3 Credits.
This course will introduce the theory and application of fracture mechanics (FM) to the design and analysis of fatigue-limited metallic structures. The role of material microstructure on the mechanisms of fatigue and fracture and the associated variability in material properties will be discussed in parallel.Prerequisites: An undergraduate or introductory structural mechanics course. Basic working knowledge of MATLAB.

EN.535.735. Computational Fluid Dynamics. 3 Credits.
This is a three-branch course covering theory, implementation, and application of computational fluid dynamics (CFD). The theory side covers the basics of CFD, finite volume discretization schemes, time integration, solution of systems of equations, boundary conditions, error analysis and turbulence models. On the implementation side students will implement a number of small-scale CFD solvers and pre-processing tools in order to get a working knowledge of the simulation process. The application side covers the use of a fully featured, readily available CFD solver to study an array of gradually complex flow phenomena.

EN.535.736. Computationl Fluid Mech. 3 Credits.
This course explores engineering applications of computational fluid dynamics with background information on the most common numerical methods: two-dimensional inviscid and viscous flows, boundary layer flows, and an introduction to three-dimensional flows. Applications are illustrated utilizing commercially available codes.
Prerequisite(s): 535.621 Intermediate Fluid Dynamics and 535.641 Mathematical Methods for Engineers. Some programming experience is also assumed.

EN.535.737. Multiscale Modeling and Simulation of Mechanical Systems. 3 Credits.
The successful design of complex engineering systems requires understanding physical processes that bridge multiple length and time scales. This course will introduce students to the fascinating field of multiscale modeling and provide a foundation for understanding systems/devices at a molecular, microscopic, and macroscopic levels. Through a combination of lectures, case studies and hands-on applications, students will learn (1) the principles that govern engineering systems at various length/time scales, and (2) how to develop, use, and hybridize multiscale simulation tools.

EN.535.741. Optimal Control and Reinforcement Learning. 3 Credits.
This course will explore advanced topics in nonlinear systems and optimal control theory, culminating with a foundational understanding of the mathematical principals behind Reinforcement learning techniques popularized in the current literature of artificial intelligence, machine learning, and the design of intelligent agents like Alpha Go and Alpha Star. Students will first learn how to simulate and analyze deterministic and stochastic nonlinear systems using well-known simulation techniques like Simulink and standalone C++ Monte-Carlo methods. Students will then be introduced to the foundations of optimization and optimal control theory for both continuous- and discrete- time systems. Closed-form solutions and numerical techniques like co-location methods will be explored so that students have a firm grasp of how to formulate and solve deterministic optimal control problems of varying complexity. Discrete-time systems and dynamic programming methods will be used to introduce the students to the challenges of stochastic optimal control and the curse-of-dimensionality. Supervised learning and maximum likelihood estimation techniques will be used to introduce students to the basic principles of machine learning, neural-networks, and back-propagation training methods. The class will conclude with an introduction of the concept of approximation methods for stochastic optimal control, like neural dynamic programming, and concluding with a rigorous introduction to the field of reinforcement learning and Deep-Q learning techniques used to develop intelligent agents like DeepMind's Alpha Go.
Prerequisite(s): 535.641 Mathematical Methods for Engineers.

EN.535.742. Applied Machine Learning for Mechanical Engineers. 3 Credits.

EN.535.748. Stress Waves, Impacts and Shockwaves. 3 Credits.
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.535.750. Biomechanics of the cell: From nano- and micro-mechanics to cell organization and function. 3 Credits.
Mechanical aspects of the cell are introduced. Discussion of the role of proteins, membranes and cytoskeleton in cellular function and how to describe them using simple mathematical models.

EN.535.782. Haptic Applications. 3 Credits.
An introduction to the required theoretical and practical background in the design and development of haptic applications. Haptic technology enables users to touch and/or manipulate virtual or remote objects in simulated environments or tele-operation systems. This course aims to cover the basics of haptics through lectures, assignments, and readings on current topics in haptics. Prerequisite(s): Recommended course background: graduate and senior undergraduate students who are enthusiastic to learn about haptics and basic familiarity with MATLAB.

EN.535.800. Independent Study. 3 Credits.