MECHANICAL ENGINEERING (COURSE 2)

Freshman Year Introductory Subjects

Same subject as 16.00A[J]
Prereq: Physics I (GIR), Calculus I (GIR)
U (Spring)
Not offered regularly; consult department
3-3-3 units
Student teams formulate and complete space/earth/ocean exploration-based design projects with weekly milestones. Introduces core engineering themes, principles, and modes of thinking. Specialized learning modules enable teams to focus on the knowledge required to complete their projects, such as machine elements, electronics, design process, visualization and communication. Includes exercises in written and oral communication and team building. Examples of projects include surveying a lake for millfoil, from a remote controlled aircraft, and then sending out robotic harvesters to clear the invasive growth; and exploration to search for the evidence of life on a moon of Jupiter, with scientists participating through teleoperation and supervisory control of robots. Enrollment limited; preference to freshmen.
A. H. Techet, D. Newman

2.00B Toy Product Design
Prereq: None
U (Spring)
3-5-1 units
Provides students with an overview of design for entertainment and play, as well as opportunities in creative product design and community service. Students develop ideas for new toys that serve clients in the community, and work in teams with local sponsors and with experienced mentors on a themed toy design project. Students enhance creativity and experience fundamental aspects of the product development process, including determining customer needs, brainstorming, estimation, sketching, sketch modeling, concept development, design aesthetics, detailed design, and prototyping. Includes written, visual, and oral communication. Enrollment limited; preference to freshmen.
D. R. Wallace

Core Undergraduate Subjects

2.00 Introduction to Design
Prereq: None
U (Fall; second half of term)
2-2-2 units
Project-based introduction to product development and engineering design. Emphasizes key elements of the design process, including defining design problems, generating ideas, and building solutions. Presents a range of design techniques to help students think about, evaluate, and communicate designs, from sketching to physical prototyping, as well as other types of modeling. Students work both individually and in teams. Enrollment limited; preference to Course 2-A sophomores.
M. Yang

2.001 Mechanics and Materials I
Prereq: Physics I (GIR); Coreq: 18.03 or 2.087
U (Fall, Spring)
3-2-7 units. REST
Introduction to statics and the mechanics of deformable solids. Emphasis on the three basic principles of equilibrium, geometric compatibility, and material behavior. Stress and its relation to force and moment; strain and its relation to displacement; linear elasticity with thermal expansion. Failure modes. Application to simple engineering structures such as rods, shafts, beams, and trusses. Application to biomechanics of natural materials and structures.
G. Barbastathis, A. E. Hosoi, K. Kamrin

2.002 Mechanics and Materials II
Prereq: 2.001; Chemistry (GIR)
U (Spring)
3-3-6 units
Introduces mechanical behavior of engineering materials, and the use of materials in mechanical design. Emphasizes the fundamentals of mechanical behavior of materials, as well as design with materials. Major topics: elasticity, plasticity, limit analysis, fatigue, fracture, and creep. Materials selection. Laboratory experiments involving projects related to materials in mechanical design. Enrollment may be limited due to laboratory capacity; preference to Course 2 majors and minors.
L. Anand, K. Kamrin, P. Reis
2.003[J] Dynamics and Control I
Same subject as 1.053[J]
Prereq: Physics II; Coreq: 18.03 or 2.087
U (Fall, Spring)
4-1-7 units. REST


J. K. Vandiver, N. C. Makris, N. M. Patrikalakis, T. Peacock, D. Gossard, K. Turitsyn

2.004 Dynamics and Control II
Prereq: 2.003[J] or 2.03; Physics II (GIR)
U (Fall, Spring)
4-2-6 units

Modeling, analysis, and control of dynamic systems. System modeling: lumped parameter models of mechanical, electrical, and electromechanical systems; interconnection laws; actuators and sensors. Linear systems theory: linear algebra; Laplace transform; transfer functions, time response and frequency response, poles and zeros; block diagrams; solutions via analytical and numerical techniques; stability. Introduction to feedback control: closed-loop response; PID compensation; steady-state characteristics, root-locus design concepts, frequency-domain design concepts. Laboratory experiments and control design projects. Enrollment may be limited due to laboratory capacity; preference to Course 2 majors and minors.

G. Barbastathis, D. Del Vecchio, D. C. Gossard, D. E. Hardt, S. Lloyd

2.005 Thermal-Fluids Engineering I
Prereq: Physics II (GIR), Calculus II (GIR); 2.086, 6.0002, or 18.06; or permission of instructor
U (Fall, Spring)
5-0-7 units


J. G. Brisson, J. Buongiorno, P. F. J. Lermusiaux, K. Varanasi

2.006 Thermal-Fluids Engineering II
Prereq: 2.005; or 2.051, 2.06
U (Fall, Spring)
5-0-7 units


J. G. Brisson, A. E. Hosoi, R. Karnik, G. H. McKinley

2.007 Design and Manufacturing I
Prereq: 2.001; 2.670; Coreq: 2.086
U (Spring)
3-4-5 units

Develops students’ competence and self-confidence as design engineers. Emphasis on the creative design process bolstered by application of physical laws. Instruction on how to complete projects on schedule and within budget. Robustness and manufacturability are emphasized. Subject relies on active learning via a major design-and-build project. Lecture topics include idea generation, estimation, concept selection, visual thinking, computer-aided design (CAD), mechanism design, machine elements, basic electronics, technical communication, and ethics. Lab fee. Limited enrollment. Pre-registration required for lab assignment; special sections by lottery only.

D. Frey, S. Kim, A. Winter
2.008 Design and Manufacturing II
Prereq: 2.007 or Coreq: 2.017(J); 2.005 or 2.051
U (Fall, Spring)
3-3-6 units. 1/2 Institute LAB
Integration of design, engineering, and management disciplines and practices for analysis and design of manufacturing enterprises. Emphasis is on the physics and stochastic nature of manufacturing processes and systems, and their effects on quality, rate, cost, and flexibility. Topics include process physics and control, design for manufacturing, and manufacturing systems. Group project requires design and fabrication of parts using mass-production and assembly methods to produce a product in quantity. Six units may be applied to the General Institute Lab Requirement. Enrollment may be limited due to laboratory capacity; preference to Course 2 majors and minors.

2.009 The Product Engineering Process
Prereq: 2.001; 2.003(J) or 2.03; 2.005 or 2.051; 2.670, 2.678 or 2.00B
U (Fall)
3-3-6 units
Students develop an understanding of product development phases and experience working in teams to design and construct high-quality product prototypes. Design process learned is placed into a broader development context. Primary goals are to improve ability to reason about design alternatives and apply modeling techniques appropriate for different development phases; understand how to gather and process customer information and transform it into engineering specifications; and use teamwork to resolve the challenges in designing and building a substantive product prototype. Instruction and practice in oral communication provided. Enrollment may be limited due to laboratory capacity; preference to Course 2 seniors.
D. R. Wallace

2.013 Engineering Systems Design
Prereq: 2.001; 2.003(J) or 2.03; 2.005 or 2.051; 2.670, 2.678 or 2.00B
U (Fall)
0-6-6 units
Focuses on the design of engineering systems to satisfy stated performance, stability, and/or control requirements. Emphasizes individual initiative, application of fundamental principles, and the compromises inherent in the engineering design process. Culminates in the design of an engineering system, typically a vehicle or other complex system. Includes instruction and practice in written and oral communication through team presentations, design reviews, and written reports. Enrollment may be limited due to laboratory capacity; preference to Course 2 majors and minors.
D. Hart

2.014 Engineering Systems Development
Prereq: 2.001; 2.003(J) or 2.03; 2.005 or 2.051; 2.670, 2.678 or 2.00B
U (Spring)
0-6-6 units
Can be repeated for credit.
Focuses on implementation and operation of engineering systems. Emphasizes system integration and performance verification using methods of experimental inquiry. Students refine their subsystem designs and the fabrication of working prototypes. Includes experimental analysis of subsystem performance and comparison with physical models of performance and with design goals. Component integration into the full system, with detailed analysis and operation of the complete vehicle in the laboratory and in the field. Includes written and oral reports. Students carry out formal reviews of the overall system design. Instruction and practice in oral and written communication provided. Enrollment may be limited due to laboratory capacity; preference to Course 2 majors and minors.
D. Hart

2.016 Hydrodynamics
Prereq: 2.001
U (Fall)
4-2-6 units
Principles of conservation of mass, momentum and energy in fluid mechanics. Basic geophysical fluid mechanics, including the effects of salinity, temperature, and density; heat balance in the ocean; large scale flows. Hydrostatics. Linear free surface waves, wave forces on floating and submerged structures. Added mass, lift and drag forces. Introduction to ocean acoustics; sound propagation and refraction. Sonar equation. Laboratory sessions in wave propagation, lift and drag forces on submerged bodies, and sound propagation. Meets with 2.06 first half of term.
A. H. Techet, P. D. Sclavounos
2.017[J] Design of Electromechanical Robotic Systems
Same subject as 1.015[J]
Prereq: 2.003[J] or 2.03; Coreq: 2.005, 2.05 and 2.051, or 2.016; 2.671
U (Spring)
3-3-6 units. 1/2 Institute LAB

Design, construction, and testing of field robotic systems, through team projects with each student responsible for a specific subsystem. Projects focus on electronics, instrumentation, and machine elements. Design for operation in uncertain conditions is a focus point, with ocean waves and marine structures as a central theme. Basic statistics, linear systems, Fourier transforms, random processes, spectra and extreme events with applications in design. Lectures on ethics in engineering practice included. Enrollment may be limited due to laboratory capacity.

F. S. Hover, J. J. Leonard

2.019 Design of Ocean Systems
Prereq: 2.001; 2.003[J]; 2.005 or 2.016
U (Spring)
3-3-6 units

Complete cycle of designing an ocean system using computational design tools for the conceptual and preliminary design stages. Team projects assigned, with each student responsible for a specific subsystem. Lectures cover hydrodynamics; structures; power and thermal aspects of ocean vehicles, environment, materials, and construction for ocean use; generation and evaluation of design alternatives. Focus on innovative design concepts chosen from high-speed ships, submersibles, autonomous vehicles, and floating and submerged deep-water offshore platforms. Lectures on ethics in engineering practice included. Instruction and practice in oral and written communication provided. Enrollment may be limited due to laboratory capacity; preference to Course 2 seniors.

C. Chryssostomidis, M. S. Triantafyllou

2.02A Engineering Materials: Properties and Applications
Prereq: 2.001
U (Fall; first half of term)
2-0-4 units

Introduction to the physical mechanisms that give rise to mechanical properties of engineering materials: stiffness, creep, stress-relaxation, strength, fracture-toughness, and fatigue. Also covers materials selection for mechanical design. Includes case studies on materials-limited problems in engineering design.

A. Kolpak

2.03 Dynamics I
Prereq: Physics II; Coreq: 18.03 or 2.087
U (Fall, Spring; first half of term)
2-0-4 units


D. Gossard, K. Turitsyn, T. Peacock

2.031 Dynamics II
Prereq: 2.03
U (Fall, Spring; second half of term)
2-0-4 units

Continuation of topics introduced in 2.03, including work-energy concepts, Lagrange’s equations for systems of particles and rigid bodies in planar motion, and matrix eigenvalue problems. Meets with 2.003[J] second half of term.

D. Gossard, K. Turitsyn, T. Peacock

2.04A Systems and Controls
Prereq: None. Coreq: 2.03
U (Spring; second half of term)
2-1-3 units

Introduction to linear systems, transfer functions, and Laplace transforms. Covers stability and feedback, and provides basic design tools for specifications of transient response. Briefly covers frequency-domain techniques. Enrollment may be limited due to laboratory capacity.

G. Barbastathis
2.04B Introduction to Mechanical Vibration
Prereq: 2.03, 2.086
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: U (Fall; second half of term)
2-1-3 units

Analyzes the time domain response of single- and multiple-degree-of-freedom (DOF) systems to initial conditions and force inputs. Uses matrix formulation of multiple-DOF problems, including finding natural frequencies and mode shapes. Provides an introduction to the method of normal mode superposition. Includes transfer function analysis of the response of linear systems to steady state harmonic inputs, with application to vibration isolation and dynamic absorbers. Also includes application to the analysis of machines with rotating imbalances. Enrollment may be limited due to lab capacity; preference to Course 2 majors and minors.
J. K. Vandiver

2.05 Thermodynamics
Prereq: 2.001
U (Fall; first half of term)
3-0-3 units

Provides an introduction to thermodynamics, including first law (coupled and uncoupled systems, incompressible liquid, ideal gas) and second law (equilibrium, reversibility and irreversibility). Explores systems in communication with heat reservoirs; quasi-static processes; and heat engines and refrigeration. Properties of open systems, including mass, energy and entropy transfer.
C. Buie

2.051 Introduction to Heat Transfer
Prereq: 2.05
U (Fall; second half of term)
2-0-4 units

J. H. Lienhard, E. N. Wang, A. Hosoi

2.06 Fluid Dynamics
Prereq: 2.001
U (Fall, Spring; first half of term)
2-0-4 units

G. H. McKinley, K. Varanasi, A. Techet

2.086 Numerical Computation for Mechanical Engineers
Prereq: Physics I (GIR), Calculus II (GIR); Coreq: 18.03 or 2.087
U (Fall, Spring)
1-3-8 units. REST

Covers elementary programming concepts, including variable types, data structures, and flow control. Provides an introduction to linear algebra and probability. Numerical methods relevant to MechE, including approximation (interpolation, least squares, and statistical regression), integration, solution of linear and nonlinear equations, and ordinary differential equations. Presents deterministic and probabilistic approaches. Uses examples from MechE, particularly from robotics, dynamics, and structural analysis. Assignments require MATLAB programming. Enrollment may be limited due to laboratory capacity; preference to Course 2 majors and minors.
N. Hadjiconstantinou, A. Patera, D. Frey, A. Hosoi

2.087 Engineering Mathematics: Linear Algebra and ODEs
Prereq: Calculus II (GIR), Physics I (GIR)
U (Fall, Spring; first half of term)
2-0-4 units

Introduction to linear algebra and ordinary differential equations (ODEs), including general numerical approaches to solving systems of equations. Linear systems of equations, existence and uniqueness of solutions, Gaussian elimination. Initial value problems, 1st and 2nd order systems, forward and backward Euler, RK4. Eigenproblems, eigenvalues and eigenvectors, including complex numbers, functions, vectors and matrices.
A. Hosoi, T. Peacock


Dynamics and Acoustics

2.032 Dynamics
Prereq: 2.003[J]
G (Fall)
4-0-8 units


T. R. Akylas, T. Peacock, N. Hadjiconstantinou

2.033[J] Nonlinear Dynamics and Turbulence (New)
Same subject as 1.686[J], 18.358[J]
Subject meets with 1.068
Prereq: Permission of instructor
Acad Year 2016-2017: G (Spring)
Acad Year 2017-2018: Not offered
3-0-9 units

See description under subject 1.686[J].
L. Bourouiba

2.034[J] Nonlinear Dynamics and Waves
Same subject as 1.685[J], 18.377[J]
Prereq: Permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring)
3-0-9 units

A unified treatment of nonlinear oscillations and wave phenomena with applications to mechanical, optical, geophysical, fluid, electrical and flow-structure interaction problems. Nonlinear free and forced vibrations; nonlinear resonances; self-excited oscillations; lock-in phenomena. Nonlinear dispersive and nondispersive waves; resonant wave interactions; propagation of wave pulses and nonlinear Schrodinger equation. Nonlinear long waves and breaking; theory of characteristics; the Korteweg-de Vries equation; solitons and solitary wave interactions. Stability of shear flows. Some topics and applications may vary from year to year.

T. R. Akylas

2.036[J] Nonlinear Dynamics and Chaos
Same subject as 18.385[J]
Prereq: 18.03 or 18.034
Acad Year 2016-2017: G (Fall)
Acad Year 2017-2018: Not offered
3-0-9 units

See description under subject 18.385[J].
R. R. Rosales

2.050[J] Nonlinear Dynamics: Chaos
Same subject as 12.006[J], 18.353[J]
Prereq: 18.03 or 18.034; Physics II (GIR)
U (Fall)
3-0-9 units

See description under subject 12.006[J].
P-T. Brun

2.060[J] Structural Dynamics and Vibrations
Same subject as 1.581[J], 16.221[J]
Subject meets with 1.058
Prereq: Permission of instructor
G (Fall)
3-1-8 units

See description under subject 1.581[J].
E. Kausel, J. K. Vandiver

2.062[J] Wave Propagation
Same subject as 1.138[J], 18.376[J]
Prereq: 2.003[J], 18.075
Acad Year 2016-2017: G (Spring)
Acad Year 2017-2018: Not offered
3-0-9 units


T. R. Akylas, R. R. Rosales
2.065 Acoustics and Sensing
Subject meets with 2.066
Prereq: 2.003[J], 2.04B, 6.003, 8.03, or 16.003
U (Spring)
3-0-9 units

2.066 Acoustics and Sensing
Subject meets with 2.065
Prereq: 2.003[J], 2.04B, 6.003, 8.03, 16.003, or permission of instructor
G (Spring)
3-0-9 units

Introduces the fundamental concepts of acoustics and sensing with waves. Provides a unified theoretical approach to the physics of image formation through scattering and wave propagation in sensing. The linear and nonlinear acoustic wave equation, sources of sound, including musical instruments. Reflection, refraction, transmission and absorption. Bearing and range estimation by sensor array processing, beamforming, matched filtering, and focusing. Diffraction, bandwidth, ambient noise and reverberation limitations. Scattering from objects, surfaces and volumes by Green's Theorem. Forward scatter, shadows, Babinet's principle, extinction and attenuation. Ray tracing and waveguides in remote sensing. Applications to acoustic, radar, seismic, thermal and optical sensing and exploration. Students taking the graduate version of the subject complete additional assignments.
N. C. Makris

Solid Mechanics and Materials

2.071 Mechanics of Solid Materials
Prereq: 2.002 or 2.02A
G (Spring)
4-0-8 units

Fundamentals of solid mechanics applied to the mechanical behavior of engineering materials. Kinematics of deformation, stress, and balance principles. Isotropic linear elasticity and isotropic linear thermal elasticity. Variational and energy methods. Linear viscoelasticity. Small-strain elastic-plastic deformation. Mechanics of large deformation; nonlinear hyperelastic material behavior. Foundations and methods of deformable-solid mechanics, including relevant applications. Provides base for further study and specialization within solid mechanics, including continuum mechanics, computational mechanics (e.g., finite-element methods), plasticity, fracture mechanics, structural mechanics, and nonlinear behavior of materials.
L. Anand, D. M. Parks

2.072 Mechanics of Continuous Media
Prereq: 2.071
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Fall)
3-0-9 units

Principles and applications of continuum mechanics. Kinematics of deformation. Thermomechanical conservation laws. Stress and strain measures. Constitutive equations including some examples of their microscopic basis. Solution of some basic problems for various materials as relevant in materials science, fluid dynamics, and structural analysis. Inherently nonlinear phenomena in continuum mechanics. Variational principles.
L. Anand

2.073 Solid Mechanics: Plasticity and Inelastic Deformation
Prereq: 2.071
Acad Year 2016-2017: G (Fall)
Acad Year 2017-2018: Not offered
3-0-9 units

Physical basis of plastic/inelastic deformation of solids; metals, polymers, granular/rock-like materials. Continuum constitutive models for small and large deformation of elastic-(visco)plastic solids. Analytical and numerical solution of selected boundary value problems. Applications to deformation processing of metals.
L. Anand, D. M. Parks

2.074 Solid Mechanics: Elasticity
Prereq: 2.002, 18.03
G (Fall)
3-0-9 units

R. Abeyaratne

2.076[J] Mechanics of Heterogeneous Materials
Same subject as 16.223[J]
Prereq: 2.002, 3.032, 16.20, or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Fall)
3-0-9 units

See description under subject 16.223[J].
B. L. Wardle, S-G. Kim
2.080[J] Structural Mechanics
Same subject as 1.573[J]
Prereq: 2.002
G (Fall)
4-0-8 units

Presents fundamental concepts of structural mechanics with applications to marine, civil, and mechanical structures. Covers residual stresses; thermal effects; analysis of beams, columns, tensioned beams, trusses, frames, arches, cables, and shafts of general shape and material, including composites; elastic buckling of columns; exact and approximate methods, energy methods, principle of virtual work, and introduction to computational structural mechanics.
T. Wierzbicki, H. Schmidt

2.081[J] Plates and Shells: Static and Dynamic Analysis
Same subject as 16.230[J]
Prereq: 2.071, 2.080[J], or permission of instructor
G (Spring)
3-1-8 units

T. Sapsis

2.082 Ship Structural Analysis and Design
Prereq: 2.081[J], 2.701
G (Spring; second half of term)
3-0-3 units

Design application of analysis developed in 2.081[J]. Ship longitudinal strength and hull primary stresses. Ship structural design concepts. Design limit states including plate bending, column and panel buckling, panel ultimate strength, and plastic analysis. Matrix stiffness, and introduction to finite element analysis. Computer projects on the structural design of a midship module.
R. S. McCord, T. Wierzbicki

2.084[J] Structural Mechanics in Nuclear Power Technology
Same subject as 1.56[J], 22.314[J]
Prereq: 2.001 or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Fall)
3-0-9 units

See description under subject 22.314[J].
Staff

Computational Engineering

2.089[J] Computational Geometry
Same subject as 1.128[J]
Prereq: Permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-9 units

N. M. Patrikalakis, D. C. Gossard

2.091[J] Software and Computation for Simulation
Same subject as 1.124[J]
Prereq: 1.00 or permission of instructor
G (Fall)
Not offered regularly; consult department
3-0-9 units

See description under subject 1.124[J].
J. R. Williams

2.092 Finite Element Analysis of Solids and Fluids I
Subject meets with 2.093
Prereq: 2.001; 2.003[J] or 2.03
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: U (Fall)
3-0-9 units
2.093 Finite Element Analysis of Solids and Fluids I
Subject meets with 2.092
Prereq: 2.001; 2.003[J] or 2.03
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Fall)
3-0-9 units
Finite element methods for analysis of steady-state and transient problems in solid, structural, fluid mechanics, and heat transfer. Presents finite element methods and solution procedures for linear and nonlinear analyses using largely physical arguments. Demonstrates finite element analyses. Homework involves use of an existing general purpose finite element analysis program. Includes modeling of problems and interpretation of numerical results. Students taking graduate version complete additional assignments.
K. J. Bathe

2.096[J] Introduction to Numerical Simulation
Same subject as 6.336[J], 16.910[J]
Prereq: 18.03 or 18.06
G (Fall)
3-3-6 units
See description under subject 6.336[J].
L. Daniel, J. K. White

2.097[J] Numerical Methods for Partial Differential Equations
Same subject as 6.339[J], 16.920[J]
Prereq: 18.03 or 18.06
G (Fall)
3-0-9 units
See description under subject 16.920[J].
Q. Wang, J. K. White

2.099[J] Computational Mechanics of Materials
Same subject as 16.225[J]
Prereq: Permission of instructor
G (Fall)
Not offered regularly; consult department
3-0-9 units
See description under subject 16.225[J].
R. Radovitzky

System Dynamics and Control

2.110[J] Information, Entropy, and Computation
Same subject as 6.050[J]
Prereq: Physics I (GIR)
U (Spring)
3-0-6 units
See description under subject 6.050[J].
P. Penfield, Jr., S. Lloyd

2.111[J] Quantum Computation
Same subject as 8.370[J], 18.435[J]
Prereq: Permission of instructor
G (Fall)
3-0-9 units
See description under subject 18.435[J].
I. Chuang, E. Farhi, S. Lloyd, P. Shor

2.12 Introduction to Robotics
Subject meets with 2.120
Prereq: 2.004, or 2.031 and 2.04A
U (Fall)
3-2-7 units
Enrollment may be limited due to laboratory capacity; preference to Course 2 majors and minors.

2.120 Introduction to Robotics
Subject meets with 2.12
Prereq: 2.004, or 2.031 and 2.04A, or permission of instructor
G (Fall)
3-2-7 units
Presents the fundamentals of robot mechanisms, dynamics, and controls. Planar and spatial kinematics, differential motion, energy method for robot mechanics; mechanism design for manipulation and locomotion; multi-rigid-body dynamics; force and compliance control, balancing control, visual feedback, human-machine interface; actuators, sensors, wireless networking, and embedded software. Weekly laboratories include real-time control, vehicle navigation, arm and end-effector design, and balancing robot control. Group term project requires design and fabrication of robotic systems. Students taking graduate version complete additional assignments. Enrollment may be limited due to laboratory capacity.
H. Asada, J. J. Leonard
2.122 Stochastic Systems (New)
Prereq: 2.004, 2.087
G (Spring)
4-0-8 units
G. Barbastathis, P. F. Lermusiaux, N. C. Makris, N. M. Patrikalakis, T. P. Sapsis, M. S. Triantafyllou

2.131 Advanced Instrumentation and Measurement
Prereq: Permission of Instructor
G (Spring)
3-6-3 units
Provides training in advanced instrumentation and measurement techniques. Topics include system level design, fabrication and evaluation with emphasis on systems involving concepts and technology from mechanics, optics, electronics, chemistry and biology. Simulation, modeling and design software. Use of a wide range of instruments/techniques (e.g., scanning electron microscope, dynamic signal/system analyzer, impedance analyzer, laser interferometer) and fabrication/machining methods (e.g., laser micro-machining, stereo lithography, computer controlled turning and machining centers). Theory and practice of both linear and nonlinear system identification techniques. Lab sessions include instruction and group project work. No final exam.
I. W. Hunter

2.14 Analysis and Design of Feedback Control Systems
Subject meets with 2.140
Prereq: 2.004, 2.04A, or 2.04B
U (Spring)
3-3-6 units
Enrollment may be limited due to laboratory capacity; preference to Course 2 majors and minors.

2.140 Analysis and Design of Feedback Control Systems
Subject meets with 2.14
Prereq: 2.004, 2.04A, 2.04B, or permission of instructor
G (Spring)
3-3-6 units
Develops the fundamentals of feedback control using linear transfer function system models. Analysis in time and frequency domains. Design in the s-plane (root locus) and in the frequency domain (loop shaping). Describing functions for stability of certain non-linear systems. Extension to state variable systems and multivariable control with observers. Discrete and digital hybrid systems and use of z-plane design. Extended design case studies and capstone group projects. Student taking graduate version complete additional assignments. Enrollment may be limited due to laboratory capacity.
D. Rowell, D. L. Trumper, K. Youcef-Toumi

2.141 Modeling and Simulation of Dynamic Systems
Prereq: 2.151
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Fall)
3-0-9 units
Modeling multidomain engineering systems at a level of detail suitable for design and control system implementation. Network representation, state-space models; multiprot energy storage and dissipation, Legendre transforms; nonlinear mechanics, transformation theory, Lagrangian and Hamiltonian forms; Control-relevant properties. Application examples may include electromechanical transducers, mechanisms, electronics, fluid and thermal systems, compressible flow, chemical processes, diffusion, and wave transmission.
N. Hogan

2.151 Advanced System Dynamics and Control
Prereq: 2.004, 18.06; or 2.087, 2.04A
G (Fall)
4-0-8 units
Analytical descriptions of state-determined dynamic physical systems; time and frequency domain representations; system characteristics - controllability, observability, stability; linear and nonlinear system responses. Modification of system characteristics using feedback. State observers, Kalman filters. Modeling/ performance trade-offs in control system design. Basic optimization tools. Positive systems. Emphasizes applications to physical systems.
J.-J. E. Slotine, K. Youcef-Toumi, N. Hogan
2.152[J] Nonlinear Control
Same subject as 9.110[J]
Prereq: 2.151, 6.241[J], 16.31, or permission of instructor
G (Spring)
3-0-9 units


J.-J. E. Slotine

2.153 Adaptive Control
Prereq: 2.151
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring)
3-0-9 units

Introduces the foundation of adaptive control in continuous-time and discrete-time systems. Adaptive control is the ability to self-correct a controller in the presence of parametric uncertainties using online information is its main and most compelling feature. Examples drawn from aerospace, propulsion, automotive, and energy systems will be used to elucidate the underlying concepts.

A. Annaswamy

2.154 Maneuvering and Control of Surface and Underwater Vehicles
Prereq: 2.22
G (Fall)
3-0-9 units


M. S. Triantafyllou

2.160 Identification, Estimation, and Learning
Prereq: 2.151
Acad Year 2016-2017: G (Spring)
Acad Year 2017-2018: Not offered
3-0-9 units

Provides a broad theoretical basis for system identification, estimation, and learning. Least squares estimation and its convergence properties, Kalman filter and extended Kalman filter, noise dynamics and system representation, function approximation theory, neural nets, radial basis functions, wavelets, Volterra expansions, informative data sets, persistent excitation, asymptotic variance, central limit theorems, model structure selection, system order estimate, maximum likelihood, unbiased estimates, Cramer-Rao lower bound, Kullback-Leibler information distance, Akaike’s information criterion, experiment design, and model validation.

H. Asada, J.-J. E. Slotine

2.165[J] Robotics
Same subject as 9.175[J]
Prereq: 2.151 or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring)
3-0-9 units


J.-J. E. Slotine, H. Asada

2.166 Autonomous Vehicles
Prereq: 6.041B or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring)
3-1-8 units

Theory and application of probabilistic techniques for autonomous mobile robotics. Topics include probabilistic state estimation and decision making for mobile robots; stochastic representations of the environment; dynamic models and sensor models for mobile robots; algorithms for mapping and localization; planning and control in the presence of uncertainty; cooperative operation of multiple mobile robots; mobile sensor networks; application to autonomous marine (underwater and floating), ground, and air vehicles.

J. J. Leonard
2.167 Hands-On Marine Robotics
Prereq: None
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: U (Fall)
Units arranged [P/D/F]
Can be repeated for credit.

Direct experience in developing marine robotic systems, from conceptualization and design through manufacture and testing. The class consists of a weekly seminar with readings and discussions, and significant outside work on student projects, culminating in a written report each term. Seminar topics include tools for unmanned marine work and their history, analysis of mission requirements, conceptual design and modeling of systems, experiments and proofs of concept, and project pacing and time management. A total of up to 12 hours credit may be taken over one or two terms; seminar topics repeat yearly.

F. S. Hover

2.171 Analysis and Design of Digital Control Systems
Prereq: 2.14, 2.151, or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Fall)
3-3-0-9 units

A comprehensive introduction to digital control system design, reinforced with hands-on laboratory experiences. Major topics include discrete-time system theory and analytical tools; design of digital control systems via approximation from continuous time; direct discrete-time design; loop-shaping design for performance and robustness; state-space design; observers and state-feedback; quantization and other nonlinear effects; implementation issues. Laboratory experiences and design projects connect theory with practice.

D. L. Trumper

2.180[J] Biomolecular Feedback Systems
Same subject as 6.027[J]
Subject meets with 2.180[J], 6.557[J]
Prereq: 18.03, Biology (GIR), or permission of instructor
U (Spring)
3-0-9 units

Comprehensive introduction to dynamics and control of biomolecular systems with emphasis on design/analysis techniques from control theory. Provides a review of biology concepts, regulation mechanisms, and models. Covers basic enabling technologies, engineering principles for designing biological functions, modular design techniques, and design limitations. Students taking graduate version complete additional assignments.

D. Del Vecchio

2.183[J] Biomechanics and Neural Control of Movement
Same subject as 9.34[J]
Subject meets with 2.183[J], 9.34[J]
Prereq: 2.004, 2.04A, or permission of instructor
G (Spring)
3-0-9 units

2.184 Biomechanics and Neural Control of Movement
Subject meets with 2.183[J], 9.34[J]
Prereq: 2.004, 2.04A, or permission of instructor
U (Spring)
3-0-9 units

Quantitative knowledge of human movement behavior is important in a growing number of engineering applications (medical and rehabilitation technology, athletic and military equipment, human-computer interaction, vehicle performance, etc.). Presents a quantitative, model-based description of how biomechanical and neural factors interact in human sensory-motor behavior, focusing mainly on the upper limbs. Students survey recent literature on how motor behavior is controlled, comparing biological and robotic approaches to similar tasks. Topics may include a review of relevant neural, muscular and skeletal physiology, neural feedback and "equilibrium-point" theories, co-contraction strategies, impedance control, kinematic redundancy, optimization, intermittency, contact tasks and tool use. Students taking the graduate version will complete additional assignments.

N. Hogan
Fluid Mechanics and Combustion

2.20 Marine Hydrodynamics
Prereq: 1.060B, 2.006, 2.06, or 2.016
G (Fall)
4-1-7 units


D. K. P. Yue

2.22 Design Principles for Ocean Vehicles
Prereq: 2.20
G (Spring)
3-3-6 units

Design tools for analysis of linear systems and random processes related to ocean vehicles; description of ocean environment including random waves, ocean wave spectra and their selection; short and long term wave statistics; and ocean currents. Advanced hydrodynamics for design of ocean vehicles and offshore structures including wave forces on towed and moored structures; inertia vs. drag dominated flows; vortex induced vibrations of offshore structures; ship seakeeping and sensitivity of seakeeping performance. Design exercises in application of principles. Several laboratory exercises emphasizing modern measurement techniques, model testing, and flow diagnostic tools.

M. S. Triantafyllou

2.23 Hydrofoils and Propellers
Prereq: 2.20, 18.085
Acad Year 2016-2017: G (Fall; first half of term)
Acad Year 2017-2018: Not offered
2-0-4 units

Reviews the theory and design of hydrofoil sections; lifting and thickness problems for sub-cavitating sections and unsteady flow problems. Covers lifting line and lifting surface theory with applications to hydrofoil craft, rudder, control surface, propeller and wind turbine rotor design. Topics include propeller lifting line and lifting surface theory; wake adapted propellers, steady and unsteady propeller thrust and torque; waterjets; performance analysis and design of wind turbine rotors. Presents numerical principles of vortex lattice and lifting surface panel methods. Projects illustrate the development of theoretical and computational methods for lifting, propulsion and wind turbine applications.

P. D. Sclavounos

2.24[J] Ocean Wave Interaction with Ships and Offshore Energy Systems
Same subject as 1.692[J]
Prereq: 2.20, 18.085
Acad Year 2016-2017: G (Spring)
Acad Year 2017-2018: Not offered
4-0-8 units

Surface wave theory, conservation laws and boundary conditions, properties of regular surface waves and random ocean waves. Linearized theory of floating body dynamics, kinematic and dynamic free surface conditions, body boundary conditions. Simple harmonic motions. Diffraction and radiation problems, added mass and damping matrices. General reciprocity identities on diffraction and radiation. Ship wave resistance theory, Kelvin wake physics, ship seakeeping in regular and random waves. Discusses point wave energy absorbers, beam sea and head-sea devises, oscillating water column device and Well’s turbine. Discusses offshore floating energy systems and their interaction with ambient waves, current and wind, including oil and gas platforms, liquefied natural gas (LNG) vessels and floating wind turbines. Homework drawn from real-world applications.

P. D. Sclavounos
2.25 Fluid Mechanics
Prereq: 2.006 or 2.06; Coreq: 18.075 or 18.085
G (Fall)
4-0-8 units
A. F. Ghoniem, A. E. Hosoi, G. H. McKinley, A. T. Patera

2.250[J] Fluid Dynamics and Disease (New)
Same subject as 1.631[J], HST.537[J]
Prereq: None
G (Spring)
3-0-9 units
See description under subject 1.631[J].
L. Bourouiba

2.26[J] Advanced Fluid Dynamics
Same subject as 1.63[J]
Prereq: 18.085; 2.25 or permission of instructor.
G (Spring)
4-0-8 units
Fundamentals of fluid dynamics intrinsic to natural physical phenomena and/or engineering processes. Discusses a range of topics and advanced problem-solving techniques. Sample topics include brief review of basic laws of fluid motion, scaling and approximations, creeping flows, boundary layers in high-speed flows, steady and transient, similarity method of solution, buoyancy-driven convection in porous media, dispersion in steady or oscillatory flows, physics and mathematics of linearized instability, effects of shear and stratification. In alternate years, two of the following modules will be offered: I: Geophysical Fluid Dynamics of Coastal Waters, II: Capillary Phenomena, III: Non-Newtonian Fluids, IV: Flagellar Swimming.
T. R. Akylas, G. H. McKinley, R. Stocker

2.28 Fundamentals and Applications of Combustion
Prereq: 2.006, or 2.051 and 2.06
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Fall)
3-0-9 units
A. F. Ghoniem

2.29 Numerical Fluid Mechanics
Prereq: 2.006, 2.06, 2.016, 2.20, or 2.25; 18.075
G (Spring)
4-0-8 units
P. F. J. Lermusiaux
2.341[J] Macromolecular Hydrodynamics
Same subject as 10.531[J]
Prereq: 2.25, 10.301, or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring)
3-0-6 units


R. C. Armstrong, G. H. McKinley

MEMS and Nanotechnology

2.37 Fundamentals of Nanoengineering
Subject meets with 2.370
Prereq: Permission of instructor
G (Spring)
3-0-9 units

2.370 Fundamentals of Nanoengineering
Subject meets with 2.37
Prereq: 2.001; Chemistry (GIR)
U (Spring)
3-0-9 units

Presents the fundamentals of molecular modeling in engineering in the context of nanoscale mechanical engineering applications. Statistical mechanics and its connection to engineering thermodynamics. Molecular origin and limitations of macroscopic descriptions and constitutive relations for equilibrium and non-equilibrium behavior. Introduction to molecular simulation, solid-state physics and electrokinetic phenomena. Discusses molecular approaches to modern nanoscale engineering problems. Graduate students are required to complete additional assignments with stronger analytical content.

N. G. Hadjiconstantinou

2.372[J] Design and Fabrication of Microelectromechanical Systems
Same subject as 6.777[J]
Subject meets with 2.372[J], 6.717[J]
Prereq: 6.003 or 2.003[J], Physics II (GIR); or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring)
3-0-9 units

2.374[J] Design and Fabrication of Microelectromechanical Systems
Same subject as 6.717[J]
Subject meets with 2.372[J], 6.777[J]
Prereq: 6.003 or 2.003[J], Physics II (GIR); or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: U (Spring)
3-0-9 units

See description under subject 6.717[J].

Staff

2.391[J] Nanostructure Fabrication
Same subject as 6.781[J]
Prereq: 6.152[J], 6.161, or 2.710; or permission of instructor
G (Spring)
4-0-8 units

See description under subject 6.781[J].

K. K. Berggren

Thermodynamics

2.42 General Thermodynamics
Prereq: Permission of instructor
G (Fall)
3-0-9 units

General foundations of thermodynamics from an entropy point of view, entropy generation and transfer in complex systems. Definitions of work, energy, stable equilibrium, available energy, entropy, thermodynamic potential, and interactions other than work (nonwork, heat, mass transfer). Applications to properties of materials, bulk flow, energy conversion, chemical equilibrium, combustion, and industrial manufacturing.

J. Brisson
Heat and Mass Transfer

2.500 Desalination and Water Purification
Prereq: 1.020, 2.006, 10.302, or 2.051 and 2.06, or permission of instructor
G (Spring)
Not offered regularly; consult department
3.0-9 units

Introduces the fundamental science and technology of desalinating water to overcome water scarcity and ensure sustainable water supplies. Covers basic water chemistry, flash evaporation, reverse osmosis and membrane engineering, electrodialysis, nanofiltration, solar desalination, energy efficiency of desalination systems, fouling and scaling, environmental impacts, and economics of desalination systems. Open to upper-class undergraduates.
J. H. Lienhard, M. Balaban

2.51 Intermediate Heat and Mass Transfer
Prereq: 2.006, or 2.051 and 2.06, or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: U (Fall)
3.0-9 units

Analysis, modeling, and design of heat and mass transfer processes with application to common technologies. Unsteady heat conduction in one or more dimensions, steady conduction in multidimensional configurations, numerical simulation; forced convection in laminar and turbulent flows; natural convection in internal and external configurations; phase change heat transfer; thermal radiation, black bodies, grey radiation networks, spectral and solar radiation; mass transfer at low rates, evaporation.
J. H. Lienhard, E. N. Wang

2.52[J] Modeling and Approximation of Thermal Processes
Same subject as 4.424[J]
Prereq: 2.51
G (Fall)
3.0-9 units

Provides instruction on how to model thermal transport processes in typical engineering systems such as those found in manufacturing, machinery, and energy technologies. Successive modules cover basic modeling tactics for particular modes of transport, including steady and unsteady heat conduction, convection, multiphase flow processes, and thermal radiation. Includes a creative design project executed by the students.
L. R. Glicksman

2.55 Advanced Heat and Mass Transfer
Prereq: 2.51
G (Spring)
4.0-8 units

Advanced treatment of fundamental aspects of heat and mass transport. Covers topics such as diffusion kinetics, conservation laws, laminar and turbulent convection, mass transfer including phase change or heterogeneous reactions, and basic thermal radiation. Problems and examples include theory and applications drawn from a spectrum of engineering design and manufacturing problems.
J. H. Lienhard

2.57 Nano-to-Macro Transport Processes
Subject meets with 2.570
Prereq: 2.005, 2.051, or permission of instructor
G (Spring)
Not offered regularly; consult department
3.0-9 units

Parallel treatments of photons, electrons, phonons, and molecules as energy carriers; aiming at a fundamental understanding of descriptive tools for energy and heat transport processes, from nanoscale to macroscale. Topics include energy levels; statistical behavior and internal energy; energy transport in the forms of waves and particles; scattering and heat generation processes; Boltzmann equation and derivation of classical laws; and deviation from classical laws at nanoscale and their appropriate descriptions. Applications in nanotechnology and microtechnology. Students taking the graduate version complete additional assignments.
G. Chen

2.59[J] Thermal Hydraulics in Power Technology
Same subject as 10.536[J], 22.313[J]
Prereq: 2.006, 10.302, 22.312, or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring)
3.2-7 units

See description under subject 22.313[J].
E. Baglietto
Energy and Power Systems

2.60J [J] Fundamentals of Advanced Energy Conversion
Same subject as 10.390[J]
Subject meets with 2.62[J], 10.392[J], 22.40[J]
Prereq: 2.006, or 2.051 and 2.06, or permission of instructor
U (Spring)
4-0-8 units

Fundamentals of thermodynamics, chemistry, and transport applied to energy systems. Analysis of energy conversion and storage in thermal, mechanical, chemical, and electrochemical processes in power and transportation systems, with emphasis on efficiency, performance, and environmental impact. Applications to fuel reforming and alternative fuels, hydrogen, fuel cells and batteries, combustion, catalysis, combined and hybrid power cycles using fossil, nuclear and renewable resources. CO₂ separation and capture. Biomass energy. Students taking graduate version complete additional assignments.
A. F. Ghoniem, W. Green

2.61 Internal Combustion Engines
Prereq: 2.006
G (Spring)
3-1-8 units

Fundamentals of how the design and operation of internal combustion engines affect their performance, efficiency, fuel requirements, and environmental impact. Study of fluid flow, thermodynamics, combustion, heat transfer and friction phenomena, and fuel properties, relevant to engine power, efficiency, and emissions. Examination of design features and operating characteristics of different types of internal combustion engines: spark-ignition, diesel, stratified-charge, and mixed-cycle engines. Engine Laboratory project. For graduate and senior undergraduate students.
W. K. Cheng

2.611 Marine Power and Propulsion
Subject meets with 2.612
Prereq: 2.005
U (Fall)
4-0-8 units

Selection and evaluation of commercial and naval ship power and propulsion systems. Analysis of propulsors, prime mover thermodynamic cycles, propeller-engine matching. Propeller selection, waterjet analysis, review of alternative propulsors; thermodynamic analyses of Rankine, Brayton, Diesel, and Combined cycles, reduction gears and integrated electric drive. Battery operated vehicles, fuel cells. Term project requires analysis of alternatives in propulsion plant design for given physical, performance, and economic constraints. Graduate students complete different assignments and exams.
J. Harbour, M. S. Triantafyllou, R. S. McCord

2.612 Marine Power and Propulsion
Subject meets with 2.611
Prereq: 2.005
U (Fall)
4-0-8 units

Selection and evaluation of commercial and naval ship power and propulsion systems. Analysis of propulsors, prime mover thermodynamic cycles, propeller-engine matching. Propeller selection, waterjet analysis, review of alternative propulsors; thermodynamic analyses of Rankine, Brayton, Diesel, and Combined cycles, reduction gears and integrated electric drive. Battery operated vehicles, fuel cells. Term project requires analysis of alternatives in propulsion plant design for given physical, performance, and economic constraints. Graduate students complete different assignments and exams.
J. Harbour, M. S. Triantafyllou, R. S. McCord

Same subject as 10.392[J], 22.40[J]
Subject meets with 2.60[J], 10.390[J]
Prereq: 2.006, or 2.051 and 2.06, or permission of instructor
G (Spring)
4-0-8 units

Fundamentals of thermodynamics, chemistry, and transport applied to energy systems. Analysis of energy conversion and storage in thermal, mechanical, chemical, and electrochemical processes in power and transportation systems, with emphasis on efficiency, performance and environmental impact. Applications to fuel reforming and alternative fuels, hydrogen, fuel cells and batteries, combustion, catalysis, combined and hybrid power cycles using fossil, nuclear and renewable resources. CO₂ separation and capture. Biomass energy. Meets with 2.60[J] when offered concurrently; students taking the graduate version complete additional assignments.
A. F. Ghoniem, W. Green
2.625[J] Electrochemical Energy Conversion and Storage: Fundamentals, Materials and Applications  
Same subject as 10.625[J]  
Prereq: 2.005, 3.046, 3.53, 10.40, or 2.051 and 2.06, or permission of instructor  
G (Fall)  
4-0-8 units  
Fundamental concepts, tools, and applications in electrochemical science and engineering. Introduces thermodynamics, kinetics and transport of electrochemical reactions. Describes how materials structure and properties affect electrochemical behavior of particular applications, for instance in lithium rechargeable batteries, electrochemical capacitors, fuel cells, photo electrochemical cells, and electrolytic cells. Discusses state-of-the-art electrochemical energy technologies for portable electronic devices, hybrid and plug-in vehicles, electrical vehicles. Theoretical and experimental exploration of electrochemical measurement techniques in cell testing, and in bulk and interfacial transport measurements (electronic and ionic resistivity and charge transfer across the electrode-electrolyte interface).  
Y. Shao-Horn  

2.626 Fundamentals of Photovoltaics  
Subject meets with 2.627  
Prereq: Permission of instructor  
Acad Year 2016-2017: Not offered  
Acad Year 2017-2018: G (Fall)  
4-0-8 units  

2.627 Fundamentals of Photovoltaics  
Subject meets with 2.626  
Prereq: Permission of instructor  
Acad Year 2016-2017: Not offered  
Acad Year 2017-2018: U (Fall)  
4-0-8 units  
T. Buonassisi  

2.64 Superconducting Magnets  
Prereq: 2.51, permission of instructor  
G (Spring)  
3-0-9 units  
Covers design, manufacture, and operation issues of superconducting magnets for major engineering applications in biomedical science (MRI & NMR magnets), high-energy physics (dipole/quadrupole/detector magnets), and electric power (motor/generator/transmission cable) as well as laboratory use. Topics include electromagnetic field analyses, mechanical stress analyses, thermal stability analyses, protection circuit design, cryogenics, and experimental techniques.  
Y. Iwasa, S. Hahn  

2.65[J] Sustainable Energy  
Same subject as 1.818[J], 10.391[J], 11.371[J], 22.811[J]  
Subject meets with 2.650[J], 10.291[J], 22.081[J]  
Prereq: Permission of instructor  
G (Fall)  
3-1-8 units  
See description under subject 22.811[J].  
M. W. Golay  

2.650[J] Introduction to Sustainable Energy  
Same subject as 10.291[J], 22.081[J]  
Subject meets with 1.818[J], 2.65[J], 10.391[J], 11.371[J], 22.811[J]  
Prereq: Permission of instructor  
U (Fall)  
3-1-8 units  
See description under subject 22.081[J]. Limited to juniors and seniors.  
M. W. Golay  

2.651[J] D-Lab: Energy  
Same subject as EC.711[J]  
Subject meets with EC.791  
Prereq: None  
U (Spring)  
3-3-6 units  
See description under subject EC.711[J]. Enrollment limited by lottery; must attend first class session.  
S. L. Hsu
Same subject as 1.044[J], 4.42[J]
Prereq: Physics I (GIR), Calculus II (GIR)
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: U (Fall)
3-2-7 units. REST
See description under subject 4.42[J].
L. R. Glicksman

Experimental Engineering

2.670 Mechanical Engineering Tools
Prereq: None
U (IAP)
0-1-2 units
Introduces the fundamentals of machine tools use and fabrication techniques. Students work with a variety of machine tools including the bandsaw, milling machine, and lathe. Mechanical Engineering students are advised to take this subject in the first IAP after declaring their major. Enrollment may be limited due to laboratory capacity. Preference to Course 2 majors and minors.
M. Culpepper

2.671 Measurement and Instrumentation
Prereq: 2.001; 2.003[J] or 2.03; 2.086; Physics II (GIR)
U (Fall, Spring)
3-3-6 units. Institute LAB
Experimental techniques for observation and measurement of physical variables such as force, strain, temperature, flow rate, and acceleration. Emphasizes principles of transduction, measurement circuitry, MEMS sensors, Fourier transforms, linear and nonlinear function fitting, uncertainty analysis, probability density functions and statistics, system identification, electrical impedance analysis and transfer functions, computer-aided experimentation, and technical reporting. Typical laboratory experiments involve oscilloscopes, electronic circuits including operational amplifiers, thermocouples, strain gauges, digital recorders, lasers, etc. Basic material and lab objectives are developed in lectures. Instruction and practice in oral and written communication provided. Enrollment limited.
I. W. Hunter, J. J. Leonard

2.673[J] Instrumentation and Measurement for Biological Systems
Same subject as 20.309[J]
Subject meets with 20.409
Prereq: Biology (GIR), Physics II (GIR), 6.0002, 18.03; or permission of instructor
U (Fall, Spring)
3-6-3 units
See description under subject 20.309[J]. Enrollment limited; preference to Course 20 undergraduates.
Fall: P. Blainey, S. Manalis, E. Frank, S. Wasserman, J. Bagnall
Spring: E. Boyden, P. So, S. Wasserman, J. Bagnall, E. Frank

2.674 Micro/Nano Engineering Laboratory
Prereq: 2.001; 2.003[J] or 2.03; 2.671; Coreq: 2.005, or 2.051 and 2.06; or permission of instructor
U (Fall, Spring)
1-3-2 units
Concepts, ideas, and enabling tools of nanoengineering taught through lab modules and imaging tools, which include microfluidics, microthermal systems, MEMS, nanomaterials, SEM, TEM, and AFM. Provides practical knowledge and experience via building, observing and manipulating micro- and nanoscale structures. Teaches students how to apply engineering knowledge to practical fluid, thermal, and dynamic systems at small scales. Meets with 2.675 in the fall term. Enrollment limited; preference to Course 2 majors and minors.
S. G. Kim, G. Chen, E. Wang, R. Karnik

2.675 Micro/Nano Engineering Laboratory
Prereq: 2.25; 2.372[J] or permission of instructor
G (Fall)
2-3-7 units
Concepts, ideas, and enabling tools of nanoengineering taught through lab modules and imaging tools, which include microfluidics, microthermal systems, MEMS, nanomaterials, SEM, TEM, and AFM. Provides practical knowledge and experience via building, observing and manipulating micro- and nanoscale structures. Teaches students how to apply engineering knowledge to practical fluid, thermal, and dynamic systems at small scales. Meets with 2.674 in the fall term. Enrollment limited.
S. G. Kim, G. Chen, E. Wang, R. Karnik
2.678 Electronics for Mechanical Systems  
Prereq: Physics II (GIR)  
U (Fall, Spring)  
2-2-2 units  

Practical introduction to the fundamentals of electronics in the context of electro-mechanical systems, with emphasis on experimentation and project work in basic electronics. Laboratory exercises include the design and construction of simple electronic devices, such as power supplies, amplifiers, op-amp circuits, switched mode dc-dc converters, and dc motor drivers. Surveys embedded microcontrollers as system elements. Laboratory sessions stress the understanding of electronic circuits at the component level, but also point out the modern approach of system integration using commercial modules and specialized integrated circuits. Enrollment may be limited due to laboratory capacity; preference to Course 2 majors and minors.  
D. Rowell

Oceanographic Engineering and Acoustics

2.680 Unmanned Marine Vehicle Autonomy, Sensing, and Communication  
Prereq: Permission of instructor  
G (Spring)  
2-6-4 units  

Focuses on software and algorithms for autonomous decision making (autonomy) by underwater vehicles operating in ocean environments. Discusses how autonomous marine vehicles (UMVs) adapt to the environment for improved sensing performance. Covers sensors for acoustic, biological and chemical sensing and their integration with the autonomy system for environmentally adaptive undersea mapping and observation. Introduces students to the underwater acoustic communication environment and various options for undersea navigation, highlighting their relevance to the operation of collaborative undersea networks for environmental sensing. Labs involve the use of the MOOP-IvP autonomy software for the development of integrated sensing, modeling and control solutions. Solutions modeled in simulation environments and include field tests with small autonomous surface and underwater vehicles operated on the Charles River. Limited enrollment.  
H. Schmidt, J.J. Leonard, M. Benjamin

2.681 Environmental Ocean Acoustics  
Prereq: 2.066, 18.075 or permission of instructor  
Acad Year 2016-2017: G (Spring)  
Acad Year 2017-2018: Not offered  
3-0-9 units  

Fundamentals of underwater sound, and its application to mapping and surveillance in an ocean environment. Wave equations for fluid and elastic media. Reflection and transmission of sound at plane interfaces. Wave theory representation of acoustic source radiation and propagation in shallow and deep ocean waveguides. Interaction of underwater sound with elastic waves in the seabed and an Arctic ice cover, including effects of porosity and anisotropy. Numerical modeling of the propagation of underwater sound, including spectral methods, normal mode theory, and the parabolic equation method, for laterally homogeneous and inhomogeneous environments. Doppler effects. Effects of oceanographic variability and fluctuation - spatial and temporal coherence. Generation and propagation of ocean ambient noise. Modeling and simulation of signals and noise in traditional sonar systems, as well as modern, distributed, autonomous acoustic surveillance systems.  
H. Schmidt

2.682 Acoustical Oceanography  
Prereq: 2.681  
Acad Year 2016-2017: Not offered  
Acad Year 2017-2018: G (Spring)  
3-0-9 units  
Can be repeated for credit.  

Provides brief overview of what important current research topics are in oceanography (physical, geological, and biological) and how acoustics can be used as a tool to address them. Three typical examples are climate, bottom geology, and marine mammal behavior. Addresses the acoustic inverse problem, reviewing inverse methods (linear and nonlinear) and the combination of acoustical methods with other measurements as an integrated system. Concentrates on specific case studies, taken from current research journals.  
J. F. Lynch, Woods Hole Staff
2.683 Marine Bioacoustics and Geoacoustics
Prereq: 2.681
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring)
3-0-9 units
Can be repeated for credit.

Both active and passive acoustic methods of measuring marine organisms, the seafloor, and their interactions are reviewed. Acoustic methods of detecting, observing, and quantifying marine biological organisms are described, as are acoustic methods of measuring geological properties of the seafloor, including depth, and surficial and volumetric composition. Interactions are also described, including effects of biological scatterers on geological measurements, and effects of seafloor scattering on measurements of biological scatterers on, in, or immediately above the seafloor. Methods of determining small-scale material properties of organisms and the seafloor are outlined. Operational methods are emphasized, and corresponding measurement theory is described. Case studies are used in illustration. Principles of acoustic-system calibration are elaborated.

K. G. Foote, Woods Hole Staff

2.684 Wave Scattering by Rough Surfaces and Inhomogeneous Media
Prereq: 2.066 or permission of instructor
Acad Year 2016-2017: G (Spring)
Acad Year 2017-2018: Not offered
3-0-9 units
Can be repeated for credit.

An advanced-level subject designed to give students a working knowledge of current techniques in this area. Material is presented principally in the context of ocean acoustics, but can be used in other acoustic and electromagnetic applications. Includes fundamentals of wave propagation through, and/or scattering by: random media, extended coherent structures, rough surfaces, and discrete scatterers.

T. K. Stanton, A. C. Lavery, Woods Hole Staff

2.687 Time Series Analysis and System Identification
Prereq: 6.011, 18.06
G (Fall)
Not offered regularly; consult department
3-0-9 units
Can be repeated for credit.

Covers matched filtering, power spectral (PSD) estimation, and adaptive signal processing / system identification algorithms. Algorithm development is framed as an optimization problem, and optimal and approximate solutions are described. Reviews time-varying systems, first and second moment representations of stochastic processes, and state-space models. Also covers algorithm derivation, performance analysis, and robustness to modeling errors. Algorithms for PSD estimation, the LMS and RLS algorithms, and the Kalman Filter are treated in detail.

J. C. Preisig, Woods Hole Staff

2.688 Principles of Oceanographic Instrument Systems -- Sensors and Measurements
Prereq: 18.075, 2.671
G (Fall)
3-3-6 units

Introduces theoretical and practical principles of design of oceanographic sensor systems. Transducer characteristics for acoustic, current, temperature, pressure, electric, magnetic, gravity, salinity, velocity, heat flow, and optical devices. Limitations on these devices imposed by ocean environment. Signal conditioning and recording; noise, sensitivity, and sampling limitations; standards. Principles of state-of-the-art systems being used in physical oceanography, geophysics, submersibles, acoustics discussed in lectures by experts in these areas. Day cruises in local waters during which the students will prepare, deploy and analyze observations from standard oceanographic instruments constitute the lab work for this subject.

H. Singh, R. Geyer, A. Michel

2.689[J] Projects in Oceanographic Engineering
Same subject as 1.699[J]
Prereq: Permission of instructor
G (Fall, Spring, Summer)
Units arranged [P/D/F]
Can be repeated for credit.

Projects in oceanographic engineering, carried out under supervision of Woods Hole Oceanographic Institution staff. Given at Woods Hole Oceanographic Institution.

J. Preisig, Woods Hole Staff
2.690 Corrosion in Marine Engineering
Prereq: 3.012, permission of instructor
G (Summer)
3-0-3 units
Introduction to forms of corrosion encountered in marine systems material selection, coatings and protection systems. Case studies and causal analysis developed through student presentations.
J. Page, T. Eagar

Naval Architecture

2.700 Principles of Naval Architecture
Subject meets with 2.701
Prereq: 2.002
U (Fall)
4-2-6 units
See description under subject *UNKNOWN*.
F. S. Hover, A. H. Techet, J. Harbour, P. D. Sclavounos, J. Page

2.701 Principles of Naval Architecture
Subject meets with 2.700
Prereq: 2.002
G (Fall)
4-2-6 units
Presents principles of naval architecture, ship geometry, hydrostatics, calculation and drawing of curves of form, intact and damage stability, hull structure strength calculations and ship resistance. Introduces computer-aided naval ship design and analysis tools. Projects include analysis of ship lines drawings, calculation of ship hydrostatic characteristics, analysis of intact and damaged stability, ship model testing, and hull structure strength calculations. Students taking graduate version complete additional assignments.
J. Harbour, S. Brizzolara, J. Page

2.702 Systems Engineering and Naval Ship Design
Prereq: 2.701
G (Spring)
3-3-3 units
Introduces principles of systems engineering and ship design with an overview of naval ship design and acquisition processes, requirements setting, formulation of a systematic plan, design philosophy and constraints, formal decision making methods, selection criteria, optimization, variant analysis, trade-offs, analysis of ship design trends, risk, and cost analysis. Emphasizes the application of principles through completion of a design exercise and project.
J. Harbour, J. Page

2.703 Principles of Naval Ship Design
Prereq: 2.082, 2.20, 2.611, 2.702
G (Fall)
4-2-6 units
Covers the design of surface ship platforms for naval applications. Includes topics such as hull form selection and concept design synthesis, topside and general arrangements, weight estimation, and technical feasibility analyses (including strength, stability, seakeeping, and survivability.). Practical exercises involve application of design principles and utilization of advanced computer-aided ship design tools.
J. Harbour, J. Page

2.704 Projects in Naval Ship Conversion Design
Prereq: 2.703
G (IAP, Spring)
1-6-5 units
Focuses on conversion design of a naval ship. A new mission requirement is defined, requiring significant modification to an existing ship. Involves requirements setting, design plan formulation and design philosophy, and employs formal decision-making methods. Technical aspects demonstrate feasibility and desirability. Includes formal written and verbal reports and team projects.
J. Harbour, J. Page

2.705 Projects in New Concept Naval Ship Design
Prereq: 2.704
G (Fall, Spring)
Units arranged
Can be repeated for credit.
Focus on preliminary design of a new naval ship, fulfilling a given set of mission requirements. Design plan formulation, system level trade-off studies, emphasizes achieving a balanced design and total system integration. Formal written and oral reports. Team projects extend over three terms.
J. Harbour, J. Page
2.707 Submarine Structural Acoustics
Prereq: 2.066
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring; first half of term)
2-0-4 units
Introduction to the acoustic interaction of submerged structures with the surrounding fluid. Fluid and elastic wave equations. Elastic waves in plates. Radiation and scattering from planar structures as well as curved structures such as spheres and cylinders. Acoustic imaging of structural vibrations. Students can take 2.085 in the second half of term.
H. Schmidt

2.708 Traditional Naval Architecture Design
Prereq: None
G (IAP)
2-0-1 units
Week-long intensive introduction to traditional design methods in which students hand draw a lines plan of a N. G. Herreshoff (MIT Class of 1870) design based on hull shape offsets taken from his original design model. After completing the plan, students then carve a wooden half-hull model of the boat design. Covers methods used to develop hull shape analysis data from lines plans. Provides students with instruction in safe hand tool use and how to transfer their lines to 3D in the form of their model. Limited to 15.
K. Hasselbalch, J. Harbour

Optics

2.71 Optics
Subject meets with 2.710
Prereq: Physics II (GIR); 18.03; 2.004, 2.04A, 2.04B, or permission of instructor
U (Fall)
3-0-9 units
Introduction to optical science with elementary engineering applications. Geometrical optics: ray-tracing, aberrations, lens design, apertures and stops, radiometry and photometry. Wave optics: basic electrodynamics, polarization, interference, wave-guiding, Fresnel and Fraunhofer diffraction, image formation, resolution, space-bandwidth product. Emphasis on analytical and numerical tools used in optical design. Graduate students are required to complete additional assignments with stronger analytical content, and an advanced design project.
G. Barbastathis, P. T. So

2.710 Optics
Subject meets with 2.71
Prereq: Physics II (GIR); 18.03; 2.004, 2.04A, 2.04B, or permission of instructor
G (Fall)
3-0-9 units
Introduction to optical science with elementary engineering applications. Geometrical optics: ray-tracing, aberrations, lens design, apertures and stops, radiometry and photometry. Wave optics: basic electrodynamics, polarization, interference, wave-guiding, Fresnel and Fraunhofer diffraction, image formation, resolution, space-bandwidth product. Emphasis on analytical and numerical tools used in optical design. Graduate students are required to complete additional assignments with stronger analytical content, and an advanced design project.
G. Barbastathis, P. T. So

2.715[J] Optical Microscopy and Spectroscopy for Biology and Medicine
Same subject as 20.487[J]
Prereq: Permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-9 units
Introduces the theory and the design of optical microscopy and its applications in biology and medicine. The course starts from an overview of basic optical principles allowing an understanding of microscopic image formation and common contrast modalities such as dark field, phase, and DIC. Advanced microscopy imaging techniques such as total internal reflection, confocal, and multiphoton will also be discussed. Quantitative analysis of biochemical microenvironment using spectroscopic techniques based on fluorescence, second harmonic, Raman signals will be covered. We will also provide an overview of key image processing techniques for microscopic data.
P. T. So, C. Sheppard
2.717 Optical Engineering
Prereq: 2.710 or permission of instructor
Acad Year 2016-2017: G (Fall)
Acad Year 2017-2018: Not offered
3-0-9 units

Theory and practice of optical methods in engineering and system design. Emphasis on diffraction, statistical optics, holography, and imaging. Provides engineering methodology skills necessary to incorporate optical components in systems serving diverse areas such as precision engineering and metrology, bio-imaging, and computing (sensors, data storage, communication in multiprocessor systems). Experimental demonstrations and a design project are included.

P. T. So, G. Barbastathis

2.718 Photonic Materials
Subject meets with 2.719
Prereq: 2.003[J], 8.03, 6.161, or permission of instructor
U (Fall)
3-0-9 units

2.719 Photonic Materials
Subject meets with 2.718
Prereq: 2.003[J], 8.03, 6.161, or permission of instructor
G (Fall)
3-0-9 units


G. Barbastathis, N. Fang

Design

2.70 FUNdaMENTALS of Precision Product Design
Subject meets with 2.77
Prereq: 2.008
U (Spring)
3-3-6 units

Enrollment limited.

2.77 FUNdaMENTALS of Precision Product Design
Subject meets with 2.70
Prereq: 2.008
G (Spring)
3-3-6 units

Examines design, selection, and combination of machine elements to produce a robust precision system. Introduces process, philosophy and physics-based principles of design to improve/enable renewable power generation, energy efficiency, and manufacturing productivity. Topics include linkages, power transmission, screws and gears, actuators, structures, joints, bearings, error apportionment, and error budgeting. Considers each topic with respect to its physics of operation, mechanics (strength, deformation, thermal effects) and accuracy, repeatability, and resolution. Includes guest lectures from practicing industry and academic leaders. Students design, build, and test a small benchtop precision machine, such as a heliostat for positioning solar PV panels or a two or three axis machine. Prior to each lecture, students review the pre-recorded detailed topic materials and then converge on what parts of the topic they want covered in extra depth in lecture. Students are assessed on their preparation for and participation in class sessions. Students taking graduate version complete additional assignments. Enrollment limited.

A. Slocum

2.72 Elements of Mechanical Design
Subject meets with 2.720
Prereq: 2.005 or 2.051; 2.008; Coreq: 2.671
U (Spring)
3-3-6 units

Advanced study of modeling, design, integration, and best practices for use of machine elements, such as bearings, bolts, belts, flexures, and gears. Modeling and analysis is based upon rigorous application of physics, mathematics, and core mechanical engineering principles, which are reinforced via laboratory experiences and a design project in which students model, design, fabricate, and characterize a mechanical system that is relevant to a real-world application. Activities and quizzes are directly related to, and coordinated with, the project deliverables. Develops the ability to synthesize, model and fabricate a design subject to engineering constraints (e.g., cost, time, schedule). Students taking graduate version complete additional assignments. Enrollment limited.

M. L. Culpepper
2.720 Elements of Mechanical Design
Subject meets with 2.72
Prereq: permission of instructor
G (Spring)
3-3-6 units
Advanced study of modeling, design, integration, and best practices for use of machine elements, such as bearings, bolts, belts, flexures, and gears. Modeling and analysis is based upon rigorous application of physics, mathematics, and core mechanical engineering principles, which are reinforced via laboratory experiences and a design project in which students model, design, fabricate, and characterize a mechanical system that is relevant to a real-world application. Activities and quizzes are directly related to, and coordinated with, the project deliverables. Develops the ability to synthesize, model and fabricate a design subject to engineering constraints (e.g., cost, time, schedule). Students taking graduate version complete additional assignments.
M. L. Culpepper

2.722[J] D-Lab: Design
Same subject as EC.720[J]
Prereq: 2.670 or permission of the instructor
U (Spring)
3-0-9 units
See description under subject EC.720[J]. Enrollment limited by lottery; must attend first class session.
A. B. Smith, M. McCambridge

2.723 Engineering Innovation and Design
Engineering School-Wide Elective Subject.
Offered under: 2.723, 6.902, 16.662
Prereq: None
U (Fall, Spring)
3-0-3 units
See description under subject 6.902.
B. Kotelly

2.729[J] D-Lab: Design for Scale
Same subject as EC.729[J]
Prereq: Permission of instructor
U (Fall)
3-2-7 units
See description under subject EC.729[J].
M. McCambridge, M. Yang, H. Quintus-Bosz

2.737 Mechatronics
Prereq: 6.071 or 6.002; 2.14, 6.302, or 16.30
G (Fall)
3-5-4 units
Introduction to designing mechatronic systems, which require integration of the mechanical and electrical engineering disciplines within a unified framework. Significant laboratory-based design experiences form subject's core. Final project. Topics include: low-level interfacing of software with hardware; use of high-level graphical programming tools to implement real-time computation tasks; digital logic; analog interfacing and power amplifiers; measurement and sensing; electromagnetic and optical transducers; control of mechatronic systems. Limited to 20.
D. L. Trumper, K. Youcef-Toumi

2.739[J] Product Design and Development
Same subject as 15.783[J]
Prereq: 2.009, 15.761, 15.778, 15.810, or permission of instructor
G (Spring)
3-3-6 units
See description under subject 15.783[J]. Engineering students accepted via lottery based on WebSIS pre-registration.
S. Eppinger, M. C. Yang

2.74 Bio-inspired Robotics
Subject meets with 2.740
Prereq: 2.004 or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: U (Fall)
3-3-6 units
Interdisciplinary approach to bio-inspired design, with emphasis on principle extraction applicable to various robotics research fields, such as robotics, prosthetics, and human assistive technologies. Focuses on three main components: biomechanics, numerical techniques that allow multi-body dynamics simulation with environmental interaction and optimization, and basic robotics techniques and implementation skills. Students integrate the components into a final robotic system project of their choosing through which they must demonstrate their understanding of dynamics and control and test hypothesized design principles. Students taking graduate version complete additional assignments. Enrollment may be limited due to laboratory capacity.
S. Kim
2.740 Bio-inspired Robotics
Subject meets with 2.74
Prereq: 2.004 or permission of instructor
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Fall)
3-3-6 units

Interdisciplinary approach to bio-inspired design, with emphasis on principle extraction applicable to various robotics research fields, such as robotics, prosthetics, and human assistive technologies. Focuses on three main components: biomechanics, numerical techniques that allow multi-body dynamics simulation with environmental interaction and optimization, and basic robotics techniques and implementation skills. Students integrate the components into a final robotic system project of their choosing through which they must demonstrate their understanding of dynamics and control and test hypothesized design principles. Students taking graduate version complete additional assignments. Enrollment may be limited due to lab capacity.
S. Kim

2.744 Product Design
Prereq: 2.009
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Spring)
3-0-9 units

Project-centered subject addressing transformation of ideas into successful products which are properly matched to the user and the market. Students are asked to take a more complete view of a new product and to gain experience with designs judged on their aesthetics, ease of use, and sensitivities to the realities of the marketplace. Lectures on modern design process, industrial design, visual communication, form-giving, mass production, marketing, and environmentally conscious design.
D. R. Wallace

2.750[J] Medical Device Design
Same subject as 6.025[J]
Subject meets with 2.75[J], 6.525[J], HST.552[J]
Prereq: 2.70, 2.72, 2.678, 6.115, 22.071, or permission of instructor
U (Fall)
3-0-9 units

Application of mechanical and electrical engineering fundamentals to the design of medical devices that address clinical needs. Throughout the term, students work in small teams on a major project to translate a clinical challenge into a proof-of-concept prototype device. Students conduct user analysis, develop design specifications, and follow a structured process to cultivate creative designs and apply analytical techniques to optimize them. They deepen their understanding of art and intellectual property by researching prior representations. Develops practical skills in prototyping and testing as well as project management. Includes lectures, problem sets and exams that focus on design fundamentals. Instruction and practice in written and oral communication provided. Students taking graduate version complete additional assignments. Enrollment limited.
A. H. Slocum, G. Hom

2.752 Development of Mechanical Products
Subject meets with 2.753
Prereq: 2.750[J], 2.009, or permission of instructor
U (Spring)
3-0-9 units

Enrollment limited; preference to Course 2 majors and minors.

2.753 Development of Mechanical Products
Subject meets with 2.752
Prereq: 2.750[J], 2.009, or permission of instructor
G (Spring)
3-0-9 units

Focuses on evolving a product from proof-of-concept to beta prototype: Includes team building, project planning, budgeting, resource planning; models for scaling, tolerancing and reliability, patents, business planning. Students/teams start with a proof-of-concept product they bring to class or select from projects provided by instructor. In lieu of taking 12 units of 2.THU, Course 2 majors taking 2.752 may write a bachelor's thesis that documents their contributions to the product developed in the team project. Students taking the graduate version complete additional assignments. Enrollment limited.
A. Slocum
2.76 Global Engineering
Subject meets with 2.760
Prereq: 2.008 or permission of instructor
G (Fall)
3-0-9 units
Combines rigorous engineering theory and user-centered product design to create technologies for developing and emerging markets. Covers machine design theory to parametrically analyze technologies; bottom-up/top-down design processes; engagement of stakeholders in the design process; socioeconomic factors that affect adoption of products; and developing/emerging market dynamics and their effect on business and technology. Includes guest lectures from subject matter experts in relevant fields and case studies on successful and failed technologies. Student teams apply course material to term-long projects to create new technologies, developed in collaboration with industrial partners and other stakeholders in developing/emerging markets. Students taking graduate version complete additional assignments.
A. Winter

2.760 Global Engineering
Subject meets with 2.76
Prereq: 2.008 or permission of instructor
U (Fall)
3-0-9 units
Combines rigorous engineering theory and user-centered product design to create technologies for developing and emerging markets. Covers machine design theory to parametrically analyze technologies; bottom-up/top-down design processes; engagement of stakeholders in the design process; socioeconomic factors that affect adoption of products; and developing/emerging market dynamics and their effect on business and technology. Includes guest lectures from subject matter experts in relevant fields and case studies on successful and failed technologies. Student teams apply course material to term-long projects to create new technologies, developed in collaboration with industrial partners and other stakeholders in developing/emerging markets. Students taking graduate version complete additional assignments.
A. Winter

Bioengineering

2.772[J] Thermodynamics of Biomolecular Systems
Same subject as 20.110[J]
Prereq: Calculus II (GIR), Chemistry (GIR), Physics I (GIR)
U (Fall, Spring)
5-0-7 units. REST
See description under subject 20.110[J].
Fall: M. Birnbaum C. Voigt
Spring: E. Alt, C. Voigt

2.78[J] Principles and Practice of Assistive Technology (New)
Same subject as 6.811[J], HST.420[J]
Prereq: Permission of instructor
U (Fall)
2-4-6 units
See description under subject 6.811[J].
R. C. Miller, J. E. Greenberg, J. J. Leonard

2.782[J] Design of Medical Devices and Implants
Same subject as 3.961[J], HST.524[J]
Prereq: Chemistry (GIR), Biology (GIR), Physics I (GIR); or permission of instructor
G (Spring)
3-0-9 units
I. V. Yannas, M. Spector

2.785[J] Cell-Matrix Mechanics
Same subject as 3.97[J], HST.523[J]
Prereq: 2.001, or 2.01 and 2.02A; Chemistry (GIR), Biology (GIR); or permission of instructor
G (Fall)
3-0-9 units
Mechanical forces play a decisive role during development of tissues and organs, during remodeling following injury as well as in normal function. A stress field influences cell function primarily through deformation of the extracellular matrix to which cells are attached. Deformed cells express different biosynthetic activity relative to undeformed cells. The unit cell process paradigm combined with topics in connective tissue mechanics form the basis for discussions of several topics from cell biology, physiology, and medicine.
I. V. Yannas, M. Spector
2.791[J] Cellular Neurophysiology
Same subject as 6.021[J], 20.370[J]
Subject meets with 2.794[J], 6.521[J], 20.470[J], HST.541[J]
Prereq: Physics II (GIR); 2.005, 6.002, 6.003, 6.071, 10.301, 20.110[J], or permission of instructor
U (Fall)
5-2-5 units
See description under subject 6.021[J]. Preference to juniors and seniors.
J. Han, T. Heldt, J. Voldman

2.792[J] Quantitative Systems Physiology
Same subject as 6.022[J], HST.542[J]
Subject meets with 2.796[J], 6.522[J]
Prereq: Physics II (GIR), 18.03, or permission of instructor
U (Spring)
4-2-6 units
See description under subject 6.022[J].
T. Heldt, R. G. Mark, C. M. Stultz

2.793[J] Fields, Forces and Flows in Biological Systems
Same subject as 6.023[J], 20.330[J]
Prereq: Physics II (GIR); 2.005, 6.021[J], or permission of instructor, Coreq: 20.309[J]
U (Spring)
4-0-8 units
See description under subject 20.330[J].
J. Han, S. Manalis

2.794[J] Cellular Neurophysiology
Same subject as 6.521[J], 20.470[J], HST.541[J]
Subject meets with 2.791[J], 6.021[J], 20.370[J]
Prereq: Physics II (GIR); 18.03; 2.005, 6.002, 6.003, 6.071, 10.301, 20.110[J], or permission of instructor
G (Fall)
5-2-5 units
See description under subject 6.521[J].
J. Han, T. Heldt

2.795[J] Fields, Forces, and Flows in Biological Systems
Same subject as 6.561[J], 10.539[J], 20.430[J]
Prereq: 6.013, 2.005, 10.302, or permission of instructor
G (Fall)
3-0-9 units
See description under subject 20.430[J].
M. Bathe, A. J. Grodzinsky

2.796[J] Quantitative Physiology: Organ Transport Systems
Same subject as 6.522[J]
Subject meets with 2.792[J], 6.022[J], HST.542[J]
Prereq: 2.006 or 6.013; 6.021[J]
G (Spring)
4-2-6 units
See description under subject 6.522[J].
T. Heldt, R. G. Mark, C. M. Stultz
2.797[J] Molecular, Cellular, and Tissue Biomechanics
Same subject as 3.053[J], 6.024[J], 20.310[J]
Prereq: 2.370 or 2.772[J]; 18.03 or 3.016; Biology (GIR)
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: U (Spring)
4-0-8 units
Develops and applies scaling laws and the methods of continuum mechanics to biomechanical phenomena over a range of length scales. Topics include structure of tissues and the molecular basis for macroscopic properties; chemical and electrical effects on mechanical behavior; cell mechanics, motility and adhesion; biomembranes; biomolecular mechanics and molecular motors. Experimental methods for probing structures at the tissue, cellular, and molecular levels.
R. D. Kamm, A. J. Grodzinsky, K. Van Vliet

2.798[J] Molecular, Cellular, and Tissue Biomechanics
Same subject as 3.971[J], 6.524[J], 10.537[J], 20.410[J]
Prereq: Biology (GIR); 2.002, 2.006, 6.013, 10.301, or 10.302
G (Fall)
3-0-9 units
Develops and applies scaling laws and the methods of continuum mechanics to biomechanical phenomena over a range of length scales. Topics include structure of tissues and the molecular basis for macroscopic properties; chemical and electrical effects on mechanical behavior; cell mechanics, motility and adhesion; biomembranes; biomolecular mechanics and molecular motors. Experimental methods for probing structures at the tissue, cellular, and molecular levels.
R. D. Kamm, K. J. Van Vliet

2.799 The Cell as a Machine
Prereq: 5.07[J], 18.03, or 7.05
Acad Year 2016-2017: Not offered
Acad Year 2017-2018: G (Fall)
3-3-6 units
Examines a variety of essential cellular functions from the perspective of the cell as a machine. Includes phenomena such as nuclear organization, protein synthesis, cell and membrane mechanics, cell migration, cell cycle control, cell transformation. Lectures are provided by video twice per week; live 3-hour recitation one evening per week. Course is taken simultaneously by students at multiple universities; homework and take-home exams common to all students. Preference to students in Courses 2 and 20.
R. Kamm, M. Sheetz, H. Yu

Manufacturing

2.810 Manufacturing Processes and Systems
Prereq: 2.001, 2.006, 2.008
G (Fall)
3-3-6 units
Introduction to manufacturing processes and manufacturing systems including assembly, machining, injection molding, casting, thermoforming, and more. Emphasis on the physics and randomness and how they influence quality, rate, cost, and flexibility. Attention to the relationship between the process and the system, and the process and part design. Project (in small groups) requires fabrication (and some design) of a product using several different processes (as listed above). Enrollment may be limited due to laboratory constraints.
T. G. Gutowski

2.813 Energy, Materials, and Manufacturing
Subject meets with 2.83
Prereq: 2.008 or permission of instructor
U (Spring)
3-0-9 units
Introduction to the major dilemma that faces manufacturing and society for the 21st century: how to support economic development while protecting the environment. Subject addresses industrial ecology, materials flows, life-cycle analysis, thermodynamic analysis and exergy accounting, manufacturing process performance, product design analysis, design for the environment, recycling and ecological economics. Combines lectures and group discussions of journal articles and selected literature, often with opposing views. Graduate students complete term-long project with report required for graduate credit.
T. G. Gutowski

2.821[J] Selection and Processing of Structural Materials
Same subject as 3.371[J]
Prereq: Permission of instructor
G (Fall, Spring, Summer; partial term)
3-0-9 units
Can be repeated for credit.
See description under subject 3.371[J].
T. Eagar
2.83 Energy, Materials and Manufacturing
Subject meets with 2.813
Prereq: 2.008 or permission of instructor
G (Spring)
3-0-9 units
Introduction to the major dilemma that faces manufacturing and society for the 21st century: how to support economic development while protecting the environment. Subject addresses industrial ecology, materials flows, life-cycle analysis, thermodynamic analysis and exergy accounting, manufacturing process performance, product design analysis, design for the environment, recycling and ecological economics. Combines lectures and group discussions of journal articles and selected literature, often with opposing views. Graduate students complete term-long project with report required for graduate credit.  
T. G. Gutowski

2.830[J] Control of Manufacturing Processes
Same subject as 6.780[J]
Prereq: 2.008, 6.041B, 6.152[J], or 15.064[J]
G (Spring)
3-0-9 units
Statistical modeling and control in manufacturing processes. Use of experimental design and response surface modeling to understand manufacturing process physics. Defect and parametric yield modeling and optimization. Forms of process control, including statistical process control, run by run and adaptive control, and real-time feedback control. Application contexts include semiconductor manufacturing, conventional metal and polymer processing, and emerging micro-nano manufacturing processes.  
D. E. Hardt, D. S. Boning

2.831[J] System Optimization and Analysis for Operations
Same subject as 15.066[J]
Prereq: Calculus II (GIR)
G (Summer)
4-0-8 units
See description under subject 15.066[J]. Restricted to Leaders for Global Operations students.  
V. Farias

2.852 Manufacturing Systems Analysis
Prereq: 6.041B or permission of instructor
Acad Year 2016-2017: G (Spring)
Acad Year 2017-2018: Not offered
3-0-9 units
Models of manufacturing systems, including transfer lines and flexible manufacturing systems. Calculation of performance measures, including throughput, in-process inventory, and meeting production commitments. Real-time control of scheduling. Effects of machine failure, set-ups, and other disruptions on system performance.  
S. B. Gershwin

2.853 Introduction to Manufacturing Systems
Subject meets with 2.854
Prereq: 2.008
U (Fall)
3-0-9 units

2.854 Introduction to Manufacturing Systems
Subject meets with 2.853
Prereq: Undergraduate mathematics
G (Fall)
3-0-9 units
Provides ways to analyze manufacturing systems in terms of material flow and storage, information flow, capacities, and times and durations of events. Fundamental topics include probability, inventory and queuing models, forecasting, optimization, process analysis, and linear and dynamic systems. Factory planning and scheduling topics include flow planning, bottleneck characterization, buffer and batch-size tactics, seasonal planning, and dynamic behavior of production systems. Graduate students are required to complete additional assignments.  
S. B. Gershwin

2.888 Professional Seminar in Global Manufacturing Innovation and Entrepreneurship
Prereq: None
G (Spring)
2-0-1 units
Covers a broad range of topics in modern manufacturing, from models and structures for 21st-century operations, to case studies in leadership from the shop floor to the executive office. Also includes global perspectives from Asia, Europe and North America, with guest speakers from all three regions. Explores opportunities for new ventures in manufacturing. Intended primarily for Master of Engineering in Manufacturing students.  
D. E. Hardt, S. B. Gershwin
2.890[J] Global Operations Leadership Seminar
Same subject as 10.792[J], 15.792[J], 16.985[J]
Prereq: None
G (Fall, Spring)
Units arranged [P/D/F]
Can be repeated for credit.

See description under subject 15.792[J]. Preference to LGO students.
T. Roemer

2.900 Ethics for Engineers
Engineering School-Wide Elective Subject.
Offered under: 1.082, 2.900, 6.904, 10.01, 22.014
Prereq: None
U (Fall, Spring)
2-0-4 units

See description under subject 10.01.
D. Doneson, B. L. Trout

2.912[J] Venture Engineering (New)
Same subject as 3.085[J], 15.373[J]
Prereq: None
U (Spring)
3-0-9 units

Provides a framework for the development, implementation, and growth of innovative ventures in dynamic environments. Deepens understanding of the core technical, customer, and strategic choices and challenges facing start-up innovators. Emphasizes the interdependent choices entrepreneurs must make under conditions of high uncertainty. Intended for students who seek to leverage their engineering and science background through innovation-driven entrepreneurship.
S. Stern, E. Fitzgerald

2.916[J] Funding Strategies for Startups
Same subject as 10.407[J]
Prereq: None
G (Spring; second half of term)
2-0-4 units

See description under subject 10.407[J].
S. Loessberg, D. P. Hart

2.96 Management in Engineering
Engineering School-Wide Elective Subject.
Offered under: 2.96, 6.930, 10.806, 16.653
Prereq: None
U (Fall)
3-1-8 units

Restricted to juniors and seniors.

2.961 Management in Engineering
Prereq: None
G (Fall)
3-1-8 units

Introduction and overview of engineering management. Financial principles, management of innovation, technical strategy and best management practices. Case study method of instruction emphasizes participation in class discussion. Focus is on the development of individual skills and management tools.
J.-H. Chun, H. S. Marcus

2.965[J] Global Supply Chain Management
Same subject as 1.265[J], 15.765[J], SCM.265[J]
Prereq: 1.260[J], 1.261[J], 15.761, 15.778, or permission of instructor
G (Spring)
2-0-4 units

See description under subject SCM.265[J].
B. Arntzen

Advanced Topics and Special Subjects

2.98 Sports Technology: Engineering & Innovation (New)
Prereq: None
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Examines the future of sports technology across technical disciplines including mechanical design, biomechanics, quantified self, sports analytics, and business strategies. Leaders in the field will be brought in to discuss various industries, career pathways and opportunities for innovation in the field. Class projects will explore and potentially kickoff larger research and/or entrepreneurial initiatives. Open to undergraduate and graduate students.
A. Hosoi, C. Chase
2.981 New England Coastal Ecology
Prereq: None
U (IAP)
2-0-1 units
Provides exposure to marine communities found along the coast of New England and how they fit into global patterns. Focuses on the ecology of salt marshes and rocky shores, and the biology of plants and animals that live in these complex habitats. Prepares students to recognize common inhabitants of these two communities and develops understanding of the major environmental factors affecting them, the types of ecological services they provide, and likely impacts of current and future climate change. Includes visits to field and research centers. Limited to 20.
Consult C. Bastidas

2.990 Practical Work Experience
Prereq: None
U (Fall, IAP, Spring)
0-1-0 units
Can be repeated for credit.
For Mechanical Engineering undergraduates participating in curriculum-related off-campus work experiences in mechanical engineering. Before enrolling, students must have an employment offer from a company or organization and must find a Mech E supervisor. Upon completion of the work the student must submit a detailed design notebook, approved by the MIT supervisor. Subject to departmental approval. Consult Department Undergraduate Office for details on procedures and restrictions.
A. Slocum

2.993, 2.994 Independent Study
Prereq: None
U (Fall, IAP, Spring, Summer)
Units arranged [P/D/F]
Can be repeated for credit.
Designed for undergraduates wanting to continue substantial projects of own choice, under faculty supervision, in mechanical engineering. Work may be of experimental, theoretical, or design nature. Projects may be arranged individually in most fields of department interest, i.e., in mechanics, design and manufacturing, controls and robotics, thermal science and energy engineering, bioengineering, ocean engineering and nanotechnology. 2.993 is letter-graded; 2.994 is P/D/F.
Consult A. E. Hosoi

2.995 Advanced Topics in Mechanical Engineering
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
Units arranged
Can be repeated for credit.
Assigned reading and problems or research in distinct areas, either theoretical or experimental, or design. Arranged on individual basis with instructor in the following areas: mechanics and materials, thermal and fluid sciences, systems and design, biomedical engineering, and ocean engineering. Can be repeated for credit only for completely different subject matter.
Consult R. Abeyaratne

2.996-2.998 Advanced Topics in Mechanical Engineering
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
Units arranged
Can be repeated for credit.
Assigned reading and problems or research in distinct areas, either theoretical or experimental, or design. Arranged on individual basis with instructor in the following areas: mechanics and materials, thermal and fluid sciences, systems and design, biomedical engineering, and ocean engineering. Can be repeated for credit only for completely different subject matter.
Consult R. Abeyaratne

2.5790-2.5792 Graduate Special Subject in Bioengineering
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.
Advanced lecture, seminar or laboratory course consisting of material in the broadly-defined field of bioengineering not offered in regularly scheduled subjects. Can be repeated for credit only for completely different subject matter.
Consult R. Kamm

2.597 Undergraduate Special Subject in Mechanical Engineering
Prereq: None
U (IAP)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.
2.S971 Undergraduate Special Subject in Mechanical Engineering
Prereq: None
U (IAP)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

2.S972 Undergraduate Special Subject in Mechanical Engineering
Prereq: None
U (Fall)
Units arranged [P/D/F]
Can be repeated for credit.

2.S973 Undergraduate Special Subject in Mechanical Engineering
Prereq: None
U (Fall)
Units arranged [P/D/F]
Can be repeated for credit.

2.S974 Undergraduate Special Subject in Mechanical Engineering
Prereq: None
U (IAP)
Not offered regularly; consult department
Units arranged [P/D/F]
Can be repeated for credit.

Lecture, seminar or laboratory course consisting of material not offered in regularly scheduled subjects. Can be repeated for credit only for completely different subject matter. 2.S972-2.S974 are graded P/D/F.
Consult A. E. Hosoi

2.S980 Graduate Special Subject in Mechanical Engineering
Prereq: Permission of instructor
G (IAP)
Not offered regularly; consult department
Units arranged [P/D/F]
Can be repeated for credit.

2.S981 Graduate Special Subject in Mechanical Engineering
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

2.S982 Graduate Special Subject in Mechanical Engineering
Prereq: Permission of instructor
G (Fall, IAP, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

2.S992 Undergraduate Special Subject in Mechanical Engineering
Prereq: None
U (Fall)
Not offered regularly; consult department
Units arranged [P/D/F]
Can be repeated for credit.

2.S993 Undergraduate Special Subject in Mechanical Engineering
Prereq: None
U (Fall)
Units arranged
Can be repeated for credit.

2.S994 Undergraduate Special Subject in Mechanical Engineering
Prereq: None
U (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

2.S995 Undergraduate Special Subject in Mechanical Engineering
Prereq: None
U (Fall)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

2.S996 Graduate Special Subject in Mechanical Engineering
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
Units arranged [P/D/F]
Can be repeated for credit.

2.S997 Graduate Special Subject in Mechanical Engineering
Prereq: Permission of instructor
G (Fall, IAP, Spring)
Units arranged
Can be repeated for credit.
2.5998 Graduate Special Subject in Mechanical Engineering
Prereq: Permission of instructor
G (Fall)
Units arranged
Can be repeated for credit.

2.5999 Graduate Special Subject in Mechanical Engineering
Prereq: Permission of instructor
G (Fall)
Units arranged
Can be repeated for credit.

Advanced lecture, seminar, or laboratory consisting of material not offered in regularly scheduled subjects. Can be repeated for credit only for completely different subject matter. 2.5980 and 2.5996 are graded P/D/F.
Consult R. Abeyaratne

Thesis, Research and Practice

2.978 Instruction in Teaching Engineering
Subject meets with 1.95[J], 5.95[J], 7.59[J], 8.395[J], 18.094[J]
Prereq: Permission of instructor
G (Fall)
Units arranged [P/D/F]
Participatory seminar focuses on the knowledge and skills necessary for teaching engineering in higher education. Topics include research on learning; course development; promoting active learning, problem solving, and critical thinking in students; communicating with a diverse student body; using educational technology to further learning; lecturing; creating effective tests and assignments; and assessment and evaluation. Field-work teaching various subjects in the Mechanical Engineering department will complement classroom discussions.
J. Rankin

2.979 Undergraduate Teaching
Prereq: None
U (Fall, IAP, Spring)
Units arranged [P/D/F]
Can be repeated for credit.
For students participating in departmentally approved undergraduate teaching programs. Students assist faculty in the design and execution of the curriculum and actively participate in the instruction and monitoring of the class participants. Students prepare subject materials, lead discussion groups, and review progress. Credit is arranged on a subject-by-subject basis and is reviewed by the department.
A. E. Hosoi

2.999 Engineer's Degree Thesis Proposal Preparation
Prereq: Permission of instructor
G (Fall, Spring, Summer)
Units arranged
Can be repeated for credit.
For students who must do additional work to convert an SM thesis to an ME thesis, or for students who write an ME thesis after having received an SM degree.
R. Abeyaratne, M. S. Triantafyllou

2.EPE UPOP Engineering Practice Experience
Engineering School-Wide Elective Subject.
Offered under: 1.EPE, 2.EPE, 3.EPE, 6.EPE, 10.EPE, 16.EPE, 22.EPE
Prereq: 2.EPW or permission of instructor
U (Fall, Spring)
0-0-1 units
Provides sophomores with guided practice in finding opportunities and excelling in the world of practice. Building on the skills and relationships acquired in the Engineering Practice Workshop, students receive coaching to articulate goals, invoke the UPOP network of mentors and employers, identify and pursue opportunities and negotiate terms of their summer assignment. Students complete a 10-12 week internship, which includes filing three progress reports, conducting one informational interview, and possibly hosting a site visit by MIT staff. Returning to campus as juniors, UPOP students take part in reflective exercises that aid assimilation of learning objectives and reinforce the cognitive link between all aspects of the UPOP experience and disciplinary fields of study. Sequence begins in the spring of sophomore year and ends in the fall of junior year.
Staff
2.EPW UPOP Engineering Practice Workshop  
Engineering School-Wide Elective Subject.  
Offered under: 1.EPW, 2.EPW, 3.EPW, 6.EPW, 10.EPW, 16.EPW, 20.EPW, 22.EPW  
Prereq: None  
U (Fall, IAP)  
1-0-0 units  
Develops foundational skills for the world of practice in science, technology, and engineering. Sophomores receive classroom instruction, and one-on-one and small-group coaching in basics of professional identity building. They attend field trips to local employers and receive job interview practice, coached by industry volunteers. Over IAP, students attend a weeklong Team Training Camp of experiential learning modules - led by MIT faculty with the help of MIT alums and other senior professionals in business, engineering, and science where students participate in creative simulations, team problem-solving challenges, and oral presentations, and practice networking with employers. Enrollment limited.  
Staff

2.THG Graduate Thesis  
Prereq: Permission of advisor  
G (Fall, IAP, Spring, Summer)  
Units arranged  
Can be repeated for credit.  
Program of research leading to the writing of an SM, PhD, or ScD thesis; to be arranged by the student and an appropriate MIT faculty member.  
Consult R. Abeyaratne

2.THU Undergraduate Thesis  
Prereq: None  
U (Fall, IAP, Spring, Summer)  
Units arranged  
Can be repeated for credit.  
Individual self-motivated study, research, or design project under faculty supervision. Departmental program requirement: minimum of 6 units. Instruction and practice in written communication provided.  
Consult A. E. Hosoi

2.URG Undergraduate Research in Mechanical Engineering  
Prereq: None  
U (Fall, IAP, Spring, Summer)  
Units arranged  
Can be repeated for credit.  
Individual study, research, or laboratory investigations under faculty supervision, including individual participation in an ongoing research project. See projects listing in Undergraduate Office, 1-110, for guidance.  
Consult N. Fang, K. Kamrin