EN.580 (BIOMEDICAL ENGINEERING)

EN.580.101. Biomedical Engineering Basecamp. 1 Credit.
This weekly seminar course introduces freshmen to the many opportunities available during their time at Hopkins and throughout their careers. Students will learn about study abroad opportunities, BME focus areas, ethics, and undergraduate research. Freshmen will be introduced to modeling and to the design process. Students will work in teams and continue to meet with their basecamp faculty advisors for discussions.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

EN.580.105. Basic Intellectual Property Law for Scientists and Engineers: Patents, Copyrights and Trademarks. 3 Credits.
The course will outline the basics of intellectual property laws with an emphasis on practical aspects of protection of IP for scientists and engineers. Most of the course will cover the basics of patent law, but introductions will also be given to trademarks and copyrights. Specific problems in the areas of biotechnology, computer science and the Internet will also be highlighted. It is hoped that the attendees will obtain a basic understanding of how intellectual property is protected. No prior legal background is required.
Area: Social and Behavioral Sciences

EN.580.111. Biomedical Engineering and Design. 2 Credits.
Working in teams with upperclassmen this course (1) introduces biomedical engineering freshmen to an orderly method for analyzing and modeling biological systems, (2) introduces engineering principles to solve design problems that are biological, physiological, and/or medical, and (3) considers the ethical and professional responsibility in developing biomedical engineering solutions to health care challenges. Freshmen are expected to use the informational content being taught in calculus, physics and chemistry and to apply this knowledge to the solution of practical problems encountered in biomedical engineering. BME Freshmen only.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class.
Area: Engineering, Natural Sciences

EN.580.112. BME Design Group. 3 Credits.
A two-semester course sequence where freshmen work with groups of BME upperclassmen mentors, and learn to use engineering principles to solve design problems that are biological, physiological, and/or medical. Freshmen are expected to use the informational content being taught in calculus, physics, and chemistry and apply this knowledge to the solution of practical problems encountered in biomedical engineering.
Area: Engineering, Natural Sciences

EN.580.151. Structural Biology of Cells. 3 Credits.
Course provides a rigorous foundation in cell structures and pathways relevant to medicine and bioengineering. Interactive lectures will cover molecular components (biological membranes, proteins, DNA, RNA, glycoproteins); electro-chemical gradients across membranes; structure and functions of the cell nucleus and genome; secretory and endocytic pathways; biomechanics, contractility and cell motility; cell adhesions, tissues and the extracellular matrix; signaling structures and networks; stem cells, cell division and cell specialization; heredity, mutations and phenotypes. This course will feature bioengineering principles including shape, localization, timing and feedback in biological systems. Students also take the 1-credit Structural Biology of Cells Lab.
Area: Engineering, Natural Sciences

EN.580.153. Structural Biology of Cells Laboratory. 1 Credit.
Students will learn how to analyze biological data in computational labs that focus on protein 3D structural data (Structural Protein Engineering), DNA/genomics data (Genomes to Clinical Phenotypes) and live-cell imaging data (Molecular Tracking in Cells) to gain an integrated understanding of cells, tissues and the molecular basis of disease. This lab accompanies the 3-credit Structural Biology of Cells course to provide a rigorous foundation in cell structures, pathways and strategies relevant to medicine and bioengineering.
Area: Engineering, Natural Sciences

EN.580.202. Bme In The Real World. 1 Credit.
Open only to engineering students; A series of weekly lectures to inform students about careers in biomedical engineering and to discuss technological, social, ethical, legal, and economic issues relevant to the profession. Topics include academic careers in biomedical engineering; biomedical engineering in industry (large corporations to sole entrepreneurship); health care delivery; ethical issues; legal issues (patenting, licensing, product liability); standards and government regulations; and economic issues in biomedical engineering industry (start-up companies, global businesses).

EN.580.211. BME Design Group. 3 Credits.
Sophomore-level version of EN.580.311-312 or Perm. Req'd
Area: Engineering, Natural Sciences

EN.580.212. BME Design Group. 3 Credits.
Sophomore-level version of EN.580.111-112. Permission of course directors required.
Area: Engineering, Natural Sciences

EN.580.219. Killer Design: Maximizing Safety in the Design Process. 3 Credits.
A number of courses are offered on product design yet safety is rarely considered as an essential element of design. Learning how to predict and prevent any potential harm should be an early step in product development. In this project-oriented class, multi-disciplinary teams will identify and propose remedies for potential hazards associated with the design of products such as: venetian blinds (strangulation), snow blowers (amputation), and a wide variety of homemade products now being sold through home business consortiums such as Etsy. Students will learn about product design from the perspectives of engineering, injury prevention, law and policy, and behavioral science through a combination of didactic and experiential approaches. This will be a three credit course with a fourth credit available to those students who wish to implement a design of their choice.
Area: Engineering, Social and Behavioral Sciences
Writing Intensive

EN.580.220. he Science of Medicine: Thinking Critically. 3 Credits.
This course investigates some of the most pressing issues in biomedical science with direction from leading clinicians, scientists, policy experts, and industry professionals. The underlying science and ethical implications for topics such as “Rogue Clinics and Designer Babies: How can I decide the genotype of my offspring – and should I,” “Mosquito-borne Diseases: Fighting an enemy that outnumbers us 15,000 to one with genetics,” and “HIV: Pushing for a cure versus settling for a treatment: What makes healthcare sufficient” are explored. The class is taught in a flipped method: students will be expected to listen to e-presentations at home so that class time can be devoted to problem solving activities, experimental design, debates, and discussion. The goal of this course is to teach students how to think critically and to expose students to the great unknowns that remain in science today.
Area: Natural Sciences

EN.580.221. Biochemistry and Molecular Engineering. 4 Credits.
This combined lecture and laboratory course will delve into the workings of the cell and the interactions between cells. The emphasis in this course is on quantitative analysis of reactions between molecules, including receptor-ligand and antigen-antibody specificity, enzyme catalysis, genetic information, protein processing and secretion, cell physiology and cell functions. In the laboratory portion of the course students will gain experimental skills in enzyme kinetics, binding (specificity and affinity), DNA analysis techniques (PCR, forensics), metabolism, membrane potentials and molecular neuroscience. The course will be supplemented with discussion and analysis of classic papers in the field as well as the current literature.Recommended background: Structural Biology of the Cell or a strong background in molecular biology and Chemistry.
Area: Natural Sciences

EN.580.237. Neuro Data Design I. 3 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. This version of Neuro Data Design is designed for students with less coding experience who wish to develop their writing skills.
Area: Engineering
Writing Intensive

EN.580.238. Neuro Data Design II. 3 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. This version of Neuro Data Design is designed for students with less coding experience who wish to develop their writing skills.
Area: Engineering
Writing Intensive

EN.580.241. Statistical Physics. 2 Credits.
Basic principles of statistical physics and thermodynamics of biological systems. Topics included quantitative statistical formulation of entropy and its application in thermodynamic optimizationand conversion principles, the Gibbs/Boltzmann distribution, mixing, and phase transitions.Recommended Background: AS.110.108-109, AS.030.101-102, AS 171.101-102 or equivalent.
Area: Engineering

EN.580.242. Biological Models and Simulations. 2 Credits.
This course introduces students to modeling and analysis of linear biological systems. Topics include viscoelastic materials, pharmacokinetics, reaction-diffusion-convection equation with applications to molecular transport in tissues. The course also introduces students to the Matlab programming language, which allows them to implement the models discussed in the classroom. Recommended course background: AS.110.201 Linear Algebra, AS.110.302 Differential Equations, or EN.553.291 Linear Algebra and Differential Equations.
Area: Engineering

EN.580.243. Linear Signals and Systems. 2 Credits.
An introduction to signals and linear systems. Topics include first and second order systems, linear time variant discrete and continuous systems, convolution, Fourier series, and Fourier transforms.Recommended background: AS.171.102 and AS.110.201, AS.110.302, or 553.291. 110.302 may be taken at the same time.
Area: Engineering

EN.580.244. Nonlinear Dynamics of Biological Systems. 2 Credits.
Analysis and simulation of nonlinear behavior in biological systems: bifurcations (cell-fate decision), limit cycles (cell-cycle, neuronal excitations), chaos, and maps. Matlab will be used to simulate these systems and motivate nonlinear analytic tools and stability analysis. Recommended course background: AS.110.201 Linear Algebra, AS.110.302 Differential Equations, or EN.553.292 Linear Algebra and Differential Equations.
Area: Engineering

EN.580.246. Systems and Controls. 2 Credits.
An introduction to the analysis and synthesis of controllers for linear systems. topics include LaPlace transforms, input output and state space representations of linear systems, stability, observability, controlability, and PID controller design. Recommended course background: AS.110.201 Linear Algebra, AS.110.302 Differential Equations, or EN.553.291 Linear Algebra and Differential Equations.
Prerequisite(s): EN.580.243
Area: Engineering

EN.580.248. Systems Biology of the Cell. 2 Credits.
Cellular systems biology provides a theoretical and quantitative understanding of the interactions between DNA, RNA, and proteins that create the well-regulated system we call life. This course develops first-principles models for the central dogma of molecular biology: information flow through protein signal transduction pathways, gene regulation by protein-DNA physical interactions, transcription of DNA to RNA, translation of RNA to protein, and feedback regulation that closes the cycle. Topics include complex analysis and contour integrals, spectral transforms, linear models for cell signaling, positive and negative feedback, non-linearities introducted by saturation and cooperativity, information content and combinatorial regulation, and instabilities leading to cell fate specification. Recommended Course Background: Linear Algebra, Systems and Controls and programming.
Area: Engineering, Natural Sciences

EN.580.256. Rehabilitation Engineering Seminar. 3 Credits.
The primary objective of this course is to introduce students to the challenges of engineering solutions for persons functioning with disabilities. In order to achieve this goal, other objectives include: gaining a basic appreciation of the modalities used to treat impairments, the opportunities for application of engineering to improve treatment delivery, understanding the science and engineering applied to helping persons with disabilities function in the everyday world and an basic knowledge of the legal, ethical issues and employment opportunities in rehabilitation engineering. Students must attend at least 70% of lectures to receive a satisfactory (S) grade.

EN.580.298. Advanced Design Projects. 3 Credits.
Sophomore-level version of EN.580.498. This independent course will provide project-specific mentorship and guidance for a team to complete a sophisticated prototype and demonstrate technical feasibility towards impacting a clinical problem. Prototyping and testing tools and procedures will be taught and employed on a per-project basis. Documentation of progress through a design history file and course report is required. Teams will be meet biweekly with course faculty through a Desk Review format. Students are expected to work in teams between desk reviews and present progress updates as well as short- and long-term action plans at each desk review. A final presentation is expected at the end of the semester that will involve course faculty as well as a clinical sponsor (called a committee meeting in Design Teams). Additionally, each team must identify a domain expert from the WSE faculty that agrees to attend the final presentation and at least 2 desk reviews. This faculty will focus on guiding and assessing the team's technical achievements within the context of biomedical instrumentation.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

EN.580.302. Careers in Biomedical Engineering. 1 Credit.
This course is designed for upperclassmen that wish to meet with weekly speakers to discuss careers issues.A series of weekly lectures to inform students about careers in biomedical engineering and to discuss technological, social, ethical, legal, and economic issues relevant to the profession. Topics include academic careers in biomedical engineering; biomedical engineering in industry (large corporations to sole entrepreneurship); health care delivery; ethical issues; legal issues (patenting, licensing, product liability); standards and government regulations; and economic issues in biomedical engineering industry (start-up companies, global businesses).Junior/Senior Engineers only.

EN.580.311. BME Design Group. 3 Credits.
A two-semester course sequence where juniors and seniors work with a team leader and a group of BME freshmen and sophomores, to solve open-ended problems in biomedical engineering. Upperclassmen are expected to apply their general knowledge and experience, and their knowledge in their concentration area, to teach lower classmen and to generate the solution to practical problems encountered in biomedical engineering.Perm. Req'd.
Area: Engineering, Natural Sciences

EN.580.312. BME Design Group. 3 Credits.
A two semester course sequence where juniors and seniors work with a team leader and a group of BME freshmen and sophomores, to solve open-ended problems in biomedical engineering. Upperclassmen are expected to apply their general knowledge and experience, and their knowledge in their concentration area, to teach lower classmen and to generate the solution to practical problems encountered in biomedical engineering.
Area: Engineering, Natural Sciences

EN.580.404. Opportunity Definition. 0.5 Credits.
This course will train student BME Design Teams to identify and assess project options for their BME Design Team year-long project the subsequent year. Students will learn clinical observation tools, root cause analysis and need filtering. The outcome of the course is the ranking, justification and selection of the Design Team project.

EN.580.407. Design Team Clinical Immersion. 1 Credit.
In this course design team leaders will undergo training in clinical need identification through clinical immersion in the Johns Hopkins Hospital System. Leaders will learn observation techniques, survey methods, mind-mapping and root-cause analysis.

EN.580.408. Design Team Leader I. 1 Credit.
This course prepares undergraduate students to lead teams for the subsequent Design Teams course. This course will teach leadership skills, expose students to project options and clinical sponsors, and prepare them to plan and execute a biomedical design project. Course will meet in the Clark Hall Design Studio and the Carnegie Building (SoM) Design Studio.

EN.580.410. Effective Teaching and Management of Engineering Teams. 2 Credits.
Senior biomedical engineering students will assist the core course instructors and PhD students in managing the sections and recitations and or lab component of a course.Permission required.

EN.580.411. BME Design Group. 3 Credits.
Perm. Req'd. Senior-level version of EN.580.311-312.
Area: Engineering

EN.580.412. BME Design Group. 3 Credits.
Senior-level version of EN.580.311-312. Permission of course directors required
Area: Engineering

EN.580.413. Design Team, Team Leader Seminar. 1 Credit.
This course is for Design Team leaders actively leading a team for the academic year. This course focuses on development of leadership, communication and team management skills in the context of biodesign.
Area: Engineering

EN.580.414. Design Team Leader III. 1 Credit.
This course is for Design Team leaders actively leading a team for the academic year. This course focuses on development of leadership, communication and team management skills in the context of biodesign.
Area: Engineering

EN.580.418. Principles of Pulmonary Physiology. 3 Credits.
This course will provide students with an introduction to concepts in the structure and function of the respiratory system. Topics to be covered will include basic anatomy, lung mechanics, gas exchange, tests of pulmonary function and cardiopulmonary exercise, and the effects of disease on aspects of the respiratory system. Class sessions will mix both lecture and hands-on measurement, and will include discussion of instrumentation used in pulmonary measurements and a field trip to a clinical physiology laboratory at JHH. Recommended background: Chemistry, Physics, and Calculus II, and EN.580.222 Systems and Controls or equivalent.
Area: Engineering, Natural Sciences

EN.580.420. Build-a-Genome. 4 Credits.
Must understand fundamentals of DNA structure, DNA electrophoresis and analysis, Polymerase Chain Reaction (PCR) and must be either a) Experienced with molecular biology lab work or b) Adept at programming with a biological twist. In this combination lecture/laboratory 'Synthetic Biology' course students will learn how to make DNA building blocks used in an int'l. project to build the world's first synthetic eukaryotic genome, Saccharomyces cerevisiae v. 2.0. Please study the wiki www.syntheticyeast.org for more details about the project. Following a biotechnology boot-camp, students will have 24/7 access to computational and wet-lab resources and will be expected to spend 15-20 hours per week on this course. Advanced students will be expected to contribute to the computational and biotech infrastructure. Successful completion of this course provides 3 credit hours toward the supervised research requirement for Molecular and Cellular Biology majors, or 2 credit hours toward the upper level elective requirement for Biology or Molecular and Cellular Biology majors.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class.
Area: Engineering, Natural Sciences

EN.580.424. Neuroengineering Lab. 3 Credits.
A laboratory course in which various physiological preparations are used as examples of problems of applying technology in biological systems. The emphasis in this course is on the design of experimental measurements and on physical models of biological systems.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

EN.580.425. Radiology for Engineers. 3 Credits.
This course provides engineering students with an introductory understanding of the principles and practice of radiology – including a spectrum of specialties in diagnostic radiology as well as procedures in interventional radiology and digital pathology. The course includes lectures, working with real image data, and visits to clinical areas at Johns Hopkins Hospital. Each segment of the course emphasizes clinical perspective on imaging (including scanner technology and image analysis) in relation to anatomy, physiology, and pathology. Each segment is led by an expert in a particular discipline in collaboration with the course director. Recommended course background: 580.472, 601.455The course is open to senior BME undergraduates. Enrollment is limited by permission from the course director. Audits are not allowed.
Area: Engineering, Natural Sciences

EN.580.429. Systems Bioengineering III. 4 Credits.
Computational and theoretical systems biology at the cellular and molecular level. Topics include organizational patterns of biological networks; analysis of metabolic networks, gene regulatory networks, and signal transduction networks; inference of pathway structure; and behavior of cellular and molecular circuits. Recommended Course Background: EN.580.221 and EN.580.222 or Permission Required.
Area: Engineering, Natural Sciences

EN.580.430. Systems Pharmacology and Personalized Medicine. 4 Credits.
We have moved beyond the 'one-size-fits-all' era of medicine. Individuals are different, their diseases are different, and their responses to drugs are different too. This variability is not just from person to person; heterogeneity is observed even between tumors within the same person, and between sites within the same tumor. These levels of variability among the human population must be accounted for to improve patient outcomes and the efficiency of clinical trials. Some of the ways in which this is being explored include: drugs are being developed hand-in-hand with the tests needed to determine whether or not they will be effective; tumor fragments excised from patients are being cultured in the lab for high-throughput testing of drugs and drug combinations; data-rich assays such as genomics and proteomics identify thousands of potentially significant differences between individuals; and computational models are being used to predict which therapies will work for which patients. This course will focus on the applications of pharmacokinetics and pharmacodynamics to simulating the effects of various drugs across a heterogeneous population of diseased individuals. Such computational approaches are needed to harness and leverage the vast amounts of data and provide insight into the key differences that determine drug responsiveness. These approaches can also explore the temporal dynamics of disease and treatment, and enable the modification of treatment during recovery. Most of the assignments in this course involve some coding and visualization of data (we use Matlab and R), and students undertake a project to simulate a drug or other treatment of their choice. Recommended background: 110.201 Linear Algebra, 110.302 Differential Equations, and 553.311 Probability and Statistics (or equivalent).
Area: Engineering

EN.580.431. Introduction to Computational Medicine: Imaging. 2 Credits.
Computational medicine is an emerging discipline in which computer models of disease are developed, constrained using data measured from individual patients, and then applied to deliver precision health care. This course will cover computational anatomy. Students will learn how to: model anatomies using magnetic resonance imaging data; compare anatomies via mappings onto anatomical atlases; discover anatomical biomarkers of disease; analyze changes in the connectivity of anatomies in disease. Class time will emphasize hands-on learning through data analysis, software development, and simulation. All instructional materials will be made available at the beginning of the course. Recommended Course Background: Matlab or Python. This course can be taken in conjunction with EN.580.433 which covers computational physiological medicine.
Prerequisite(s): (AS.110.107 OR AS.110.109 OR AS.110.113) AND (EN.553.310 OR EN.553.311 OR EN.553.420 OR EN.553.430 OR EN.560.348)

EN.580.433. Introduction to Computational Medicine: The Physiome. 2 Credits.
Computational medicine is an emerging discipline in which computer models of disease are developed, constrained using data measured from individual patients, and then applied to deliver precision health care. Computational physiological medicine: develops computational models of disease at the cellular, tissue, organ, and organism level; develops methods for constraining these models using patient data; applies these models to better treat patients. Students will learn how to: use biophysical laws and data to formulate computational models of physiological systems in health and disease; analyze the behaviors of these models using analytical and simulation approaches; apply models to understand their use in diagnosing and treating disease. Class time will emphasize hands-on learning through data analysis, software development, and simulation. All instructional materials will be made available at the beginning of the course. Recommended Course Background: C++, Matlab or Python.
Prerequisite(s): (AS.110.107 OR AS.110.109 OR AS.110.113) AND (EN.553.310 OR EN.553.311 OR EN.553.420 OR EN.553.430 OR EN.560.348)
Area: Engineering, Natural Sciences

EN.580.435. Applied Bioelectrical Engineering I. 1.5 Credits.
The course is offered in two parts, each a half semester long (1.5 credits each). EN.580.435 explores diverse applications of bioelectrical measurements and manipulation in modern engineering practice. Topics include functional electrical stimulation, deep brain stimulation, cardiac pacing and defibrillation, tissue ablation and cancer treatment. The second part of the course, EN.580.436, is optional and will consist of a lab project involving the physical manipulation of cells, mentored by the instructors and carried out by the entire class.Recommended Course Background: EN.580.421 and EN.580.422.
Area: Engineering

EN.580.436. Applied Bioelectrical Engineering II. 1.5 Credits.
The course is offered in two parts, each a half semester long (1.5 credits each). EN.580.435 explores diverse applications of bioelectrical measurements and manipulation in modern engineering practice. Topics include functional electrical stimulation, deep brain stimulation, cardiac pacing and defibrillation, tissue ablation and cancer treatment. The second part of the course, EN.580.436, is optional and will consist of a lab project involving the physical manipulation of cells, mentored by the instructors and carried out by the entire class.Recommended Course Background: EN.580.421 and EN.580.422.
Area: Engineering

EN.580.437. Neuro Data Design I. 4 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. Recommended Course Background: numerical programming.
Area: Engineering, Natural Sciences

EN.580.438. Neuro Data Design II. 4 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. Recommended background: numerical programming.
Area: Engineering

EN.580.439. Models of the Neuron. 4 Credits.
Single-neuron modeling, emphasizing the use of computational models as links between the properties of neurons at several levels of detail. Topics include thermodynamics of ion flow in aqueous environments, biology and biophysics of ion channels, gating, nonlinear dynamics as a way of studying the collective properties of channels in a membrane, synaptic transmission, integration of electrical activity in multi-compartment dendritic tree models, and properties of neural networks. Students will study the properties of computational models of neurons; graduate students will develop a neuron model using data from the literature. Recommended Course Background: AS.110.302 or equivalent. Meets with EN.580.639.
Area: Engineering, Natural Sciences

EN.580.441. Cellular Engineering. 3 Credits.
This course focuses on principles and applications in cell engineering. Class lectures include an overview of molecular biology fundamentals, protein/ligand binding, receptor/ligand trafficking, cell-cell interactions, cell-matrix interactions, and cell adhesion and migration at both theoretical and experimental levels. Lectures will cover the effects of physical (e.g. shear stress, strain), chemical (e.g. cytokines, growth factors) and electrical stimuli on cell function, emphasizing topics on gene regulation and signal transduction processes. Furthermore, topics in metabolic engineering, enzyme evolution, polymeric biomaterials, and drug and gene delivery will be discussed. This course is intended as Part 1 of a two-semester sequence recommended for students in the Cell and Tissue Engineering focus area. Recommended Course Background: EN.580.221 or AS.020.305 and AS.020.306 or equivalent and AS.030.205Meets with EN.580.641
Area: Engineering

EN.580.442. Tissue Engineering. 3 Credits.
This course focuses on the application of engineering fundamentals to designing biological tissue substitutes. Concepts of tissue development, structure and function will be introduced. Students will learn to recognize the majority of histological tissue structures in the body and understand the basic building blocks of the tissue and clinical need for replacement. The engineering components required to develop tissue-engineered grafts will be explored including biomechanics and transport phenomena along with the use of biomaterials and bioreactors to regulate the cellular microenvironment. Emphasis will be placed on different sources of stem cells and their applications to tissue engineering. Clinical and regulatory perspectives will be discussed. Recommended Course Background: EN.580.221 or AS.020.305 and AS.020.306, AS.030.205Recommended EN.580.441/EN.580.641Co-listed with EN.580.642
Area: Engineering

EN.580.443. Advanced Orthopaedic Tissue Engineering. 3 Credits.
This course is intended to provide a comprehensive overview on the current state of the field of Orthopaedic Tissue Engineering. Students will apply engineering fundamentals learned in the Tissue Engineering course (EN.580.442/642) with special emphasis on how they apply to bone, cartilage, and skeletal muscle tissue engineering. The development, structure, mechanics, and function of each of these tissues will be discussed. Key articles from the last three decades that focus on stem cell- and cell-free, biomaterial-based approaches to regenerate functional tissues will be presented and analyzed. Practical (regulatory/commercial) considerations that restrict the translation of therapies to the clinic will be discussed.
Prerequisite(s): Grade of B or higher in EN.580.442 OR EN.580.642
Area: Engineering

EN.580.444. Biomedical Applications of Glycoengineering. 3 Credits.
This course provides an overview of carbohydrate-based technologies in biotechnology and medicine. The course will begin by briefly covering basics of glycobiology and glycochemistry followed by detailed illustrative examples of biomedical applications of glycoengineering. A sample of these applications include the role of sugars in preventative medicine (e.g., for vaccine development and probiotics), tissue engineering (e.g., exploiting natural and engineered polysaccharides for creating tissue or organs de novo in the laboratory), regenerative medicine (e.g., for the treatment of arthritis or degenerative muscle disease), and therapy (e.g., cancer treatment). A major part of the course grade will be based on class participation with each student expected to provide a “journal club” presentation of a relevant paper as well as participate in a team-based project designed to address a current unmet clinical need that could be fulfilled through a glycoengineering approach. Recommended Course Background: EN.580.221 Molecules and Cells.
Area: Engineering, Natural Sciences

EN.580.446. Physical Epigenetics. 3 Credits.
Epigenetics describes information heritable during cell division other than DNA sequence per se, and regulates gene expression, development, and common human diseases such as cancer. This course will introduce fundamental epigenetic principles, its manifestation through physical changes in chromatin landscape and application to understanding human disease mechanisms. In addition, the students will gain understanding of modern genomic and biophysical tools applied to epigenetics..Recommended background: EN.580.221 Molecules and Cells or equivalent (molecular and cell biology), college level calculus and calculus-based general physics.
Area: Engineering, Natural Sciences

EN.580.447. Computational Stem Cell Biology. 3 Credits.
This course will provide the student with a mechanistic and systems biology-based understanding of the two defining features of stem cells: multipotency and self-renewal. We will explore these concepts across several contexts and perspectives, emphasizing seminal and new studies in development and stem cell biology, and the critical role that computational approaches have played. The course will start with an introduction to stem cells and a tutorial covering computational basics. The biological contexts that we will cover thereafter include 'Cell Identity', 'Pluripotency and multipotency', 'Stem cells and their niche', 'Modeling cell fate decisions', and 'Engineering cell fate'. This class is heavily weighted by individual computational assignments. The motivation for this strategy is that regularly occurring, moderately-sized computational projects are the most efficient way to impart an understanding of our models of this extraordinary class of cells, and to inspire a sense of excitement and empowerment. Preferred background: familiarity with the UNIX shell. Recommended Background: EN.580.221 - Molecules and Cells or Equivalent.
Prerequisite(s): Students may take EN.580.447 or EN.580.647, but not both.
Area: Engineering, Natural Sciences

EN.580.451. Cell and Tissue Engineering Lab. 3 Credits.
Cell and tissue engineering is a field that relies heavily on experimental techniques. This laboratory course will consist of three six experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Students will learn basic cell culture procedures and specialized techniques related to faculty expertise in cell engineering, microfluidics, gene therapy, microfabrication and cell encapsulation. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. Co-listed with EN.530.451. Senior and Graduate students only; others, instructor permission required. Fall semester only. Lab Fee: $100
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering, Natural Sciences

EN.580.452. Cell and Tissue Engineering Lab. 3 Credits.
This laboratory course will consist of three experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering, Natural Sciences

EN.580.454. Methods in Nucleic Acid Sequencing Lab. 3 Credits.
Sequencing technology is a rapidly progressing field that requires experience in both wet (molecular biology) and dry (computational analysis) techniques. This laboratory course will consist of three experimental modules that will provide students with valuable hands-on experience in DNA sequencing and analysis. Students will learn basic sequencing library preparation, perform sequencing experiments and analyze the resulting data. Experiments include human targeted sequencing, metagenomic sequencing and genome assembly.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering, Natural Sciences

EN.580.456. Introduction to Rehabilitation Engineering. 3 Credits.
The primary objective of this course is to introduce biomedical engineering students to the challenges of engineering solutions for persons functioning with disabilities and apply that knowledge to the development of a new, improved device to be used for measurement or treatment of an impairment or disability. In order to achieve this goal, the objectives of the fall semester include: gaining a basic appreciation of the modalities used to treat impairments, the opportunities for application of engineering to improve treatment delivery, understanding the science and engineering applied to helping persons with disabilities function in the everyday world and an basic knowledge of the legal, ethical issues and employment opportunities in rehabilitation engineering. By the conclusion of this class, students should be able to: • Understand the breadth and scope of physical impairment and disability, including its associated pathophysiology • Characterize the material and design properties of current evaluation tools for assessment of impairments and adaptations for disability • Characterize the material and design properties of current modalities of treatment of impairments and adaptations for disability • Apply engineering analysis and design principles to critique current solutions for persons with disabilities in order to suggest improvements In the spring semester (in course EN.580.457), students will learn the biomedical engineering design process and its application to persons with disabilities. Working in groups of four to five, teams will work on a project derived from a needs analysis based on their visits to rehabilitation centers in the fall semester. Project will require instructor approval before the beginning of the spring semester. Each project will consist of a proposal for design of a new device or solution to a problem faced by persons with disabilities, preliminary “virtual” (e.g., CAD), and actual proof of concept working prototype.
Prerequisite(s): EN.580.424
Area: Engineering

EN.580.457. Introduction to Rehabilitation Engineering: Design Lab. 3 Credits.
Students have the opportunity to apply the knowledge they have gained in the fall semest4er of EN.580.456 and their prior coursework to the development of a new, improved device to be used for measurement or treatment of an impairment or disability. In doing so, they will learn the biomedical engineering design process and its application to persons with disabilities. Working in groups of four to five, teams will work on a project derived from a needs analysis based on their visits to rehabilitation centers in the fall semester. Project will require instructor approval before the beginning of the spring semester. Each project will consist of a proposal for design of a new device or solution to a problem faced by persons with disabilities, preliminary “virtual” (e.g., CAD), and actual proof of concept working prototype.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;EN.580.456
Area: Engineering

EN.580.459. Seminar in Epigenetic Engineering. 1 Credit.
This is an interactive discussion course on topics in epigenetic engineering introduced by the instructor and the students, on cutting edge molecular and computational methods and applications to developmental biology and human disease research. It will be focused mostly on analysis of current literature as well as ongoing research in the Center for Epigenetics.Background: laboratory course in organic chemistry, biochemistry, or cell biology; introductory statistics; familiarity with R, Python, or Matlab
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering, Natural Sciences

EN.580.460. Epigenetics at the Crossroads of Genes and the Environment. 1.5 Credits.
This is a seminar-style course focused on cutting edge molecular, cellular, mathematical, and computational biology of mammalian epigenetics and epigenomics in relationship to environmental exposure and human disease. The format is a Socratic-style seminar with three alternating components: (1) “Big Ideas” focused on general principles and especially questions from the students; (2) “Current Literature” focused on how to extract believable information in a reasonable time from current journal articles; and (3) “Methods Development” focused on how methods are invented, including computational genomics and engineering methods, with data analysis by the students.Recommended background: Laboratory course in organic chemistry, biochemistry, or cell biology; introductory statistics; familiarity with R, Python, or Matlab
Area: Engineering, Natural Sciences

EN.580.462. Representations of Choice. 3 Credits.
In this course we will examine key computational topics from the nascent fields of decision neuroscience and neuroeconomics. After taking this course students will have an understanding of how the field emerged and will develop a critical appreciation of the advantages and limitations of different analytical approaches. Students will also be able to discuss the current knowledge on processes of valuation, value-learning and decision-making in relation to their computational representations at the behavioral and neural level.Linear Algebra and programming experience (python, matlab, or C) recommended.
Area: Engineering

EN.580.464. Advanced Data Science for Biomedical Engineering. 4 Credits.
This course covers the basics of data science in biomedical engineering. The main topics include, introductory R, data cleaning, reproducible research, basic statistical inference, machine learning and artificial intillegence. Specific topics include: assessing diagnostic accuracy, basic probability, tidy data principles, prediction and data oriented web-app development using R/shiny. Students taking the course will learn a complete and practical pipeline of going from raw data to a data product. Suggest course background: profeciency in basic programming in at least one language, basic calculus, and linear algebra.

EN.580.471. Principles of Design of BME Instrumentation. 4 Credits.
This core design course will cover lectures and hands-on labs. The material covered will include fundamentals of biomedical sensors and instrumentation, FDA regulations, designing with electronics, biopotentials and ECG amplifier design, recording from heart, muscle, brain, etc., diagnostic and therapeutic devices (including pacemakers and defibrillators), applications in prosthetics and rehabilitation, and safety. The course includes extensive laboratory work involving circuits, electronics, sensor design and interface, and building complete biomedical instrumentation. The students will also carry out design challenge projects, individually or in teams (examples include "smart cane for blind," "computer interface for quadriplegic"). Students satisfying the design requirement must also register for EN.580.571. Lab Fee: $150. Recommended Course Background: EN.520.345
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering, Natural Sciences

EN.580.472. Medical Imaging Systems. 3 Credits.
An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Cross-listed with Neuroscience and Electrical and Computer Engineering (EN.520.432).
Prerequisite(s): EN.580.222 OR EN.520.214
Area: Engineering

EN.580.473. Modern Biomedical Imaging Instrumentation and Techniques. 3 Credits.
An intermediate biomedical imaging course covering modern biomedical imaging instrumentation and techniques as applied to diagnostic radiology and other biomedical applications. It includes recent advances in various biomedical imaging modalities, multi-modality imaging and molecular imaging. The course is team taught by experts in the respective fields and provides a broad based knowledge of modern biomedical imaging to prepare students for graduate studies and research in biomedical imaging. Also, the course will offer tours and practical experience with modern biomedical imaging equipment in clinical and research settings. Co-listed with EN.520.434Recommended course background: EN.520.432 or EN.580.472
Prerequisite(s): Students may take EN.580.773 or EN.580.473 but not both.
Area: Engineering, Natural Sciences

EN.580.475. Biomedical Data Science. 2 Credits.
This course provides an introduction to data science and machine learning for biomedical engineering. The lectures cover topics in biomedical data processing (convolution, denoising, filtering, edge detection, template matching), biomedical data reduction (feature extraction, principal component analysis), and biomedical data regression, classification (including deep learning), and clustering. Background: Signals and Systems
Prerequisite(s): (AS.110.202 OR AS.110.211) AND (AS.110.201 OR AS.110.212 OR EN.553.291) AND (EN.553.310 OR EN.553.311 OR EN.560.348 OR EN.553.420)
Area: Engineering, Natural Sciences

EN.580.477. Biomedical Data Science Laboratory. 1 Credit.
The lab complements methods learned in EN.580.475 by providing a hands-on experience in biomedical applications such as denoising, reconstruction and classification of action potentials, and reconstruction of biomedical images. Lab sessions will include writing Python scripts to analyze both synthetic and real data. Recommended background: familiarity with basic Python programming and Python notebooks is advised.
Area: Engineering, Natural Sciences

EN.580.479. X-ray Imaging and Computed Tomography. 3 Credits.
This course provides students with an intermediate-level understanding of the physics, engineering, algorithms, and applications of medical x-ray imaging and computed tomography (CT). It is intended for senior undergraduates (EN.580.479) and/or graduate students (EN.580.679) in Biomedical Engineering, Computer Science, Electrical and Computer Engineering, or relatedfields in science and engineering. Topics include the physics of x-ray interaction and detection, image quality modeling and assessment, 3D image reconstruction (including analytical and iterative approaches), and applications in diagnostic and image-guided procedures. Recommended Course Background: EN.580.472 and/or EN.580.473 and familiarity with Matlab.
Area: Engineering

EN.580.480. Precision Care Medicine I. 4 Credits.
Precision Care Medicine is a two-semester project-based learning course. Projects will use methods of machine learning and mechanistic and statistical modeling to develop novel data-driven solutions to important health care problems that arise in anesthesiology and critical care medicine. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 3-4, and will work with their project mentors (clinical faculty in the ACCM Department; Drs. Winslow and Sarma) to develop a project work plan. In the remainder of the course, they will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will also be charged with designing, validating and deploying a web-application that delivers the computational method for solving the underlying healthcare problem to the user. HIPAA regulations, use of human subjects data, and requirements for FDA Class II and Medical Device Data Systems approval will be covered.
Area: Engineering
Writing Intensive

EN.580.481. Precision Care Medicine II. 4 Credits.
Precision Care Medicine is a two-semester project-based learning course. Projects will use methods of machine learning and mechanistic and statistical modeling to develop novel data-driven solutions to important health care problems that arise in anesthesiology and critical care medicine. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 3-4, and will work with their project mentors (clinical faculty in the ACCM Department; Drs. Winslow and Sarma) to develop a project work plan. In the remainder of the course, they will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will also be charged with designing, validating and deploying a web-application that delivers the computational method for solving the underlying healthcare problem to the user. HIPAA regulations, use of human subjects data, and requirements for FDA Class II and Medical Device Data Systems approval will be covered.
Area: Engineering
Writing Intensive

EN.580.482. Precision Care Medicine III. 3 Credits.
Precision Care Medicine III follows Precision Care Medicine I - II. Registration is open only to those students who have completed these courses and who wish to continue project course work under the mentorship of the Biomedical and Engineering PIs. Students will have regular meetings with their PIs.

EN.580.485. Computational Medicine: Cardiology. 2 Credits.
A quantitative, model-oriented investigation of the cardiovascular system. The course will for focus on cardiac electrophysiology, mechanics, and hemodynamics using multi-scale physiology-driven models.
Area: Engineering, Natural Sciences

EN.580.487. Computational Medicine: Cardiology Laboratory. 1 Credit.
A laboratory course in which various physiological preparations are used as examples of problems of applying technology in biological systems. The emphasis in this course is on the design of experimental measurements and on physical models of biological systems.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering, Natural Sciences

EN.580.488. Foundations of Computational Biology and Bioinformatics. 4 Credits.
This course is designed to give students a foundation in the basics of statistical and algorithmic approaches developed in computational biology/bioinformatics over the past 30 years, while emphasizing the need to extend these approaches to emerging problems in the field. Topics covered include probabilistic modeling applied to biological sequence analysis, supervised machine learning, interpretation of genetic variants, cancer genomics bioinformatic workflows and computational immuno-oncology. Attending the lab section 'Annotate Your Genome' is required.
Prerequisite(s): EN.601.220
Area: Engineering, Natural Sciences

EN.580.491. Learning, Estimation and Control. 3 Credits.
The course introduces the probabilistic foundations of learning theory. We will discuss topics in regression, estimation, optimal control, system identification, Bayesian learning, and classification. Our aim is to first derive some of the important mathematical results in learning theory, and then apply the framework to problems in biology, particularly animal learning and control of action. Recommended Course Background: AS.110.201 and AS.110.302
Area: Engineering

EN.580.492. Build-a-Genome Mentor. 4 Credits.
In addition to producing and sequencing DNA segments like regular B-a-G students, mentors will help prepare and distribute reagents, and maintain a Moddle site to track student reagent use and productivity. Mentors will also be expected to mentor specific students who are learning new techniques for the first time, contribute to the computational and biotech infrastructure associated with Build-a-Genome, and pursue at least one independent research project. Successful completion of this course provides 3 credit hours toward the supervised research requirement for Molecular and Cellular Biology majors. Co-listed AS.020.451Permission Required.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class.;EN.580.420
Area: Engineering, Natural Sciences

EN.580.493. Imaging Instrumentation. 4 Credits.
This course is intended to introduce students to imaging instrumentation. The class will be lab-oriented, giving hands-on experience with data collection and processing using a configurable optical system. Specific topics will include the programming and control of electromechanical elements, imaging data acquisitions, image formation and processing (e.g. 3D reconstruction), and imaging system analysis and optimization.Recommended Course Background: EN.580.222 Systems and Controls or EN.520.214 Signals and Systems. Programming experience highly desirable.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering

EN.580.494. Build an Imager. 3 Credits.
In this hands-on course, students will build an imaging device and learn to apply signals and systems knowledge in imaging system characterization, optimization, and post-processing. The course includes an introduction to two-dimensional signal processing techniques, basic imaging principles, imaging systems modeling, and optimization methods.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class, or permission of the instructor.
Area: Engineering

EN.580.497. Advanced Design Projects: Instrumentation. 3 Credits.
This course will provide project-specific mentorship and guidance for a team to complete a sophisticated prototype and demonstrate technical feasibility towards impacting a clinical problem. Prototyping and testing tools and procedures will be taught and employed on a per-project basis. Documentation of progress through a design history file and course report is required. Teams will be meet biweekly with course faculty through a Desk Review format. Students are expected to work in teams between desk reviews and present progress updates as well as short- and long-term action plans at each desk review. A final presentation is expected at the end of the semester that will involve course faculty as well as a clinical sponsor (called a committee meeting in Design Teams). Additionally, each team must identify a domain expert from the WSE faculty that agrees to attend the final presentation and at least 2 desk reviews. This faculty will focus on guiding and assessing the team's technical achievements within the context of biomedical instrumentation.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering

EN.580.498. Adv. Design Projects: Instrumentation. 3 Credits.
This course will provide project-specific mentorship and guidance for a team to complete a sophisticated prototype and demonstrate technical feasibility towards impacting a clinical problem. Prototyping and testing tools and procedures will be taught and employed on a per-project basis. Documentation of progress through a design history file and course report is required. Teams will be meet biweekly with course faculty through a Desk Review format. Students are expected to work in teams between desk reviews and present progress updates as well as short- and long-term action plans at each desk review. A final presentation is expected at the end of the semester that will involve course faculty as well as a clinical sponsor (called a committee meeting in Design Teams). Additionally, each team must identify a domain expert from the WSE faculty that agrees to attend the final presentation and at least 2 desk reviews. This faculty will focus on guiding and assessing the team's technical achievements within the context of biomedical instrumentation.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class.
Area: Engineering

EN.580.510. Biomedical Engineering Undergraduate Research. 1 - 3 Credits.
Student participation in ongoing research activities. Research is conducted under the supervision of a faculty member and often in conjunction with other members of the research group.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.580.550. Biomedical Engineering Group Undergraduate Research. 1 - 3 Credits.
Student participation in ongoing research activities. Research is conducted under the supervision of a faculty member and often in conjunction with other members of the research group. This section has a weekly research group meeting that students are expected to attend.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.580.561. Advanced Focus Area Research: Immunoengineering. 3 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. "Advanced Focus Area Research" is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors.Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through "MyLearning" including Bloodborne Pathogens, HIPAA, and any other online training as needed.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Area: Engineering, Quantitative and Mathematical Sciences

EN.580.562. Advanced Focus Area Research: Translational Cell and Tissue Eng. 3 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors.Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through “MyLearning” including Bloodborne Pathogens, HIPAA, and any other online training as needed.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering, Quantitative and Mathematical Sciences

EN.580.563. Advanced Focus Area Research: Computational Medicine. 3 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors.Recommended Course Background:Previous research experience. Students must complete the online Undergraduate Lab safety courses available through “MyLearning” including Bloodborne Pathogens, HIPAA, and any other online training as needed.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Area: Engineering, Quantitative and Mathematical Sciences

EN.580.564. Advanced Focus Area Research: Biomedical Data Science. 3 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors. Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through “MyLearning” including Bloodborne Pathogens, HIPAA, and any other online training as needed.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering, Quantitative and Mathematical Sciences

EN.580.565. Advanced Focus Area Research: Imaging and Medical Devices. 3 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors.Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through “MyLearning” including Bloodborne Pathogens, HIPAA, and any other online training as needed.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Area: Engineering, Quantitative and Mathematical Sciences

EN.580.566. Advanced Focus Area Research: Neuroengineering. 3 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors. Recommended Course Background:Previous research experience. Students must complete the online Undergraduate Lab safety courses available through “MyLearning” including Bloodborne Pathogens, HIPAA, and any other online training as needed.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering, Quantitative and Mathematical Sciences

EN.580.567. Advanced Focus Area Research: Genomics and Systems Biology. 3 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors.Recommended Course Background:Previous research experience. Students must complete the online Undergraduate Lab safety courses available through “MyLearning” including Bloodborne Pathogens, HIPAA, and any other online training as needed.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Area: Engineering, Quantitative and Mathematical Sciences

EN.580.571. Honors Instrumentation. 2 Credits.
Student must have taken 580.471/771. Students will develop a term paper and patent application and carry out a hands-on individual or team project throughout the semester. Previous projects include design of EEG amplifier, voltage clamp and patch clamp, vision aid of blind, pacemaker/defibrillator, sleep detection and alert device, glucose sensor and regulation, temperature controller, eye movement detection and device control, ultrasound ranging and tissue properties, impedance plethysmography, lie detector, blood alcohol detector, pulse oximeter, etc.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.580.580. Senior Design Project. 3 Credits.
Per Independent or team design project to design and evaluate a system. The design should demonstrate creative thinking and experimental skills, and must draw upon advanced topics of biomedical and traditional engineering.Permission Required.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.580.581. Senior Design Project. 3 Credits.
Independent or team design project to design and evaluate a system. The design should demonstrate creative thinking and experimental skills, and must draw upon advanced topics of biomedical and traditional engineering.Permission Required.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.580.583. Research For 3+1 Students. 3 Credits.
Research for 3+1 students only. Lab confirmation and registration approval required. Course is graded P/F only.

EN.580.584. Research For 3+1 Students. 3 Credits.
Research for 3+1 students only. Lab confirmation and registration approval required. Course is graded P/F only.

EN.580.590. Biomedical Internship. 1 Credit.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.580.601. Special Topics in Bioengineering Innovation and Design. 1 Credit.
This year long seminar series features experts from the medical device industry, venture capital firms, FDA, patent attorneys, entrepreneurs, and many more. They will share their real-world insights into the medical device innovation and commercialization process. Some of the topics covered will include bioethics, regulatory and reimbursement planning, medical device recalls, good design practices, and entrepreneurial success stories. The overarching philosophy of this seminar series is to complement the theoretical and practical aspects of the program curriculum, by learning from the experiences and insights of professionals in the field.These seminars are taken in a sequence of summer, fall, and spring. They are required for CBID masters students and are open to those students only.

EN.580.602. Special Topics in Bioengineering Innovation and Design. 1 Credit.
This year long seminar series features experts from the medical device industry, venture capital firms, FDA, patent attorneys, entrepreneurs, and many more. They will share their real-world insights into the medical device innovation and commercialization process. Some of the topics covered will include bioethics, regulatory and reimbursement planning, medical device recalls, good design practices, and entrepreneurial success stories. The overarching philosophy of this seminar series is to complement the theoretical and practical aspects of the program curriculum, by learning from the experiences and insights of professionals in the field.For CBID MSE students only. Registration with instructor's permission only.

EN.580.603. Special Topics in Bioengineering Innovation & Design. 1 Credit.
This year long seminar series features experts from the medical device industry, venture capital firms, FDA, patent attorneys, entrepreneurs, and many more. They will share their real-world insights into the medical device innovation and commercialization process. Some of the topics covered will include bioethics, regulatory and reimbursement planning, medical device recalls, good design practices, and entrepreneurial success stories. The overarching philosophy of this seminar series is to complement the theoretical and practical aspects of the program curriculum, by learning from the experiences and insights of professionals in the field. For CBID MSE students only.

EN.580.607. Regulation of Medical Devices. 1 Credit.
This course introduces graduate students in Bioengineering Innovation and Design to the medical device regulatory framework, as it pertains to bringing a medical device from concept to market. Topics covered include; FDA Design Controls; Regulatory Approval mechanisms, including the 510k and PMA process; Investigational Device exemption (IDE); planning clinical trials needed for bringing a medical device to market; and postmarket surveillance. Students learn from a series of invited lecturers from the FDA as well as professionals from the medical device industry. This summer course is required for CBID masters students and is not open to any other students.

EN.580.608. Identification and Validation of Medical Device Needs. 6 Credits.
This course teaches the art and skill of identifying medical device opportunities by experiencing real world scenarios in an immersive clinical environment. Students rotate through multiple clinical disciplines and become part of the team of senior clinicians, surgeons, residents, fellows, nurses and medical technologists. They learn to identify unmet medical device needs through direct observations in a variety of clinical settings including the hospital ward and operating room, interviews (with patients, doctors, nurses, hospital administration), literature survey, and more. Concurrently, they learn the process of filtering all observations to a few valid medical device opportunities by assessing the market size, intellectual property landscape, regulatory framework, and competitor dynamics in addition to the clinical impact that such a device could have. The ability to identify a relevant medical device need is an important first step in the medical device innovation cycle; this course aims to provide students with practical hands- on training in that process.

EN.580.609. BME Teaching Practicum. 3 Credits.

EN.580.611. Medical Device Design and Innovation. 4 Credits.
This course introduces you to the process of medical device design and innovation. You will learn the art and skill of identifying medical device opportunities through observations, interviews, and research. Through a combination of lectures, hands on activities, and interactions with clinical stakeholders, you will gain the ability to identify unmet, unarticulated, and underserved needs. Subsequently, you will learn the process of developing well thought out conceptual designs that meet those needs. You will learn to apply an iterative approach towards innovation, by involving and engaging multiple stakeholders and their perspectives throughout the process. Throughout the course modules, you will also follow the journey of several innovative startups/products/ services, that started at JHU-CBID and went through the process outlined in this course.

EN.580.612. Medical Device Design and Innovation. 4 Credits.
For CBID MSE students only.

EN.580.618. Needs Identification and Validation for Global Health Innovation. 4 Credits.
Limited to CBID students only

EN.580.619. Bioengineering Innovation and Design - Global Health. 4 Credits.
For CBID MSE students only. Registration with instructor's permission only.

EN.580.620. Principles and Practice of Global Health Innovation and Design. 4 Credits.
For CBID MSE students only. Instructor's Permission Required.

EN.580.621. Insight Informed Innovation I. 3 Credits.
For CBID MSE students only. Registration with instructor's permission only.

EN.580.623. Insight Informed Innovation II. 3 Credits.
This course is intended to equip students with a structured process and the tools required to:1. Identify opportunities for new medical devices through unmet, unarticulated and underserved stakeholder needs2. Link these insights to an exhaustive set of potential solutions3. Synthesize solutions and features into product conceptsRecommended Course Backgroung: Insight Informed Innovation I (summer)

EN.580.625. Structure and Function of the Auditory and Vestibular Systems. 3 Credits.
This course will cover basic functions of the auditory and vestibular pathways responsible for perception of sound and balance. Topics include: hair cell structure and mechanotransduction, hair cell electromotility and cochlear active force production, hair cell synaptic signaling, cochlear development and role of glia in the inner ear, primary auditory and vestibular stimulus encoding, afferents and the first-order brainstem nuclei, as well as clinical consequences of peripheral damage, physiology of hearing loss, vestibular loss, tinnitus, hair cell regeneration and gene therapy. Moving more centrally, synaptic transmission and signal processing in central neurons, and complex sound perception and movement control will be discussed. Aspects such as speech perception, sound localization, vestibular reflexes, vestibular compensation, and self-motion perception are discussed with an integrated perspective covering perceptual, physiological, and mechanistic data. Grades will be based on participation in class, homework, and first-half and second-half exams (both in class, closed book, short answer/essay types). Offered in odd-numbered years. This course will meet in 529 Ross Research Bldg. at the School of Medicine campus.Recommended Background: general introduction to Neuroscience. Undergraduates with knowledge in Neuroscience welcome.

EN.580.626. Structure & Function of the Auditory and Vestibular Brain. 3 Credits.
Brain mechanisms and perception of sound and balance. This course is an accompaniment for EN.580.625, although the courses can be taken in either order. Topics include representation of sound and balance in neural discharge patterns, anatomy of the central auditory and vestibular systems, synaptic transmission and signal processing in central neurons, and complex sound perception and movement control. Aspects such as speech perception, sound localization, vestibular reflexes and vestibular compensation are discussed with an integrated perspective covering perceptual, physiological, and mechanistic data. Recommended Course Background: EN.580.222 and EN.580.422 or equivalent.Taught at the School of Medicine, Traylor Bldg. 529.

EN.580.628. Topics in Systems Neuroscience. 1 Credit.
This course consists of weekly discussions of current literature in systems neuroscience. The selected readings will focus on neural mechanisms for perception, attention, motor behavior, learning, and memory, as studied using physiological, psychophysical, computational, and imaging techniques. Students are expected to give presentations and participate in discussions. Recommended Course Background: AS.110.302, EN.520.214, EN.580.421 or equivalentStudents will have to attend the organizational meeting to be able to enroll. The course is run by the Neuroscience department. Enrollment numbers may be limited by the course directors, and priority will be given to Neuroscience graduate students. Please contact the Neuroscience department for more information and the date of the organizational meeting.

EN.580.630. Theoretical Neuroscience. 3 Credits.
Theoretical methods for analyzing information encoding and functional representations in neural systems. Models of single and multiple neural spike trains based on stochastic processes and information theory; detection and estimation of behaviorally relevant parameters from spike trans; system theoretic methods for analyzing sensory receptive fields; network models of neural systems. Both theoretical methods and the properties of specific well-studied neural systems will be discussed. Recommended Course Background: EN.580.422 or equivalent, EN.553.420 or equivalent, EN.580.222 or equivalent.

EN.580.631. Introduction to Computational Medicine: Imaging. 2 Credits.
Computational medicine is an emerging discipline in which computer models of disease are developed, constrained using data measured from individual patients, and then applied to deliver precision health care. This course will cover computational anatomy. Students will learn how to: model anatomies using magnetic resonance imaging data; compare anatomies via mappings onto anatomical atlases; discover anatomical biomarkers of disease; analyze changes in the connectivity of anatomies in disease. Class time will emphasize hands-on learning through data analysis, software development, and simulation. All instructional materials will be made available at the beginning of the course. Recommended Course Background: Matlab or Python. This course can be taken in conjunction with EN.580.433 which covers computational physiological medicine.

EN.580.635. Applied Bioelectrical Engineering I. 1.5 Credits.
The course is offered in two parts, each a half semester long (1.5 credits each). EN.580.435 explores diverse applications of bioelectrical measurements and manipulation in modern engineering practice. Topics include functional electrical stimulation, deep brain stimulation, cardiac pacing and defibrillation, tissue ablation and cancer treatment. The second part of the course, EN.580.436, is optional and will consist of a lab project involving the physical manipulation of cells, mentored by the instructors and carried out by the entire class. Recommended Course Background: EN.580.421 and EN.580.422.

EN.580.636. Applied Bioelectrical Engineering II. 1.5 Credits.
The course is offered in two parts, each a half semester long (1.5 credits each). EN.580.635 explores diverse applications of bioelectrical measurements and manipulation in modern engineering practice. Topics include functional electrical stimulation, deep brain stimulation, cardiac pacing and defibrillation, tissue ablation and cancer treatment. The second part of the course, EN.580.636, is optional and will consist of a lab project involving the physical manipulation of cells, mentored by the instructors and carried out by the entire class. Recommended Course Background: EN.580.421 and EN.580.422.

EN.580.638. Neuro Data Design II. 4 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. Recommended background: numerical programming.

EN.580.639. Models of the Neuron. 4 Credits.
Single-neuron modeling, emphasizing the use of computational models as links between the properties of neurons at several levels of detail. Topics include thermodynamics of ion flow in aqueous environments, biology and biophysics of ion channels, gating, nonlinear dynamics as a way of studying the collective properties of channels in a membrane, synaptic transmission, integration of electrical activity in multi-compartment dendritic tree models, and properties of neural networks. Students will study the properties of computational models of neurons; graduate students will develop a neuron model using data from the literature. Differs in that an advanced modeling project using data from the literature is required. Graduate version of EN.580.439. Recommended Course Background: AS.110.302 or equivalent.

EN.580.640. Systems Pharmacology and Personalized Medicine. 4 Credits.
We have moved beyond the 'one-size-fits-all' era of medicine. Individuals are different, their diseases are different, and their responses to drugs are different too. This variability is not just from person to person; heterogeneity is observed even between tumors within the same person, and between sites within the same tumor. These levels of variability among the human population must be accounted for to improve patient outcomes and the efficiency of clinical trials. Some of the ways in which this is being explored include: drugs are being developed hand-in-hand with the tests needed to determine whether or not they will be effective; tumor fragments excised from patients are being cultured in the lab for high-throughput testing of drugs and drug combinations; data-rich assays such as genomics and proteomics identify thousands of potentially significant differences between individuals; and computational models are being used to predict which therapies will work for which patients. This course will focus on the applications of pharmacokinetics and pharmacodynamics to simulating the effects of various drugs across a heterogeneous population of diseased individuals. Such computational approaches are needed to harness and leverage the vast amounts of data and provide insight into the key differences that determine drug responsiveness. These approaches can also explore the temporal dynamics of disease and treatment, and enable the modification of treatment during recovery.Recommended background: 110.201 Linear Algebra, 110.302 Differential Equations, and 553.311 Probability and Statistics (or equivalent).

EN.580.641. Cellular Engineering. 4 Credits.
This course focuses on principles and applications in cell engineering. Class lectures include an overview of molecular biology fundamentals, protein/ligand binding, receptor/ligand trafficking, cell-cell interactions, cell-matrix interactions, and cell adhesion and migration at both theoretical and experimental levels. Lectures will cover the effects of physical (e.g. shear stress, strain), chemical (e.g. cytokines, growth factors) and electrical stimuli on cell function, emphasizing topics on gene regulation and signal transduction processes. Furthermore, topics in metabolic engineering, enzyme evolution, polymeric biomaterials, and drug and gene delivery will be discussed. This course meets with EN.580.441 but includes additional requirements designed for the core curriculum of the RIE (Regnerative and Immune Engineering) track of the BME masters program. The course is also appropriate for Cell & Tissue Engineering Ph.D. students and may be taken by advanced undergraduate students upon permission of the instructor. Prerequisites: Graduate standing with background in cell biology and biochemistry or EN.580.221 or AS20.305 and AS.020.306 (or equivalent) and AS.030.205 or permission of the instructor.

EN.580.642. Tissue Engineering. 3 Credits.
This course focuses on the application of engineering fundamentals to designing biological tissue substitutes. Concepts of tissue development, structure and function will be introduced. Students will learn to recognize the majority of histological tissue structures in the body and understand the basic building blocks of the tissue and clinical need for replacement. The engineering components required to develop tissue-engineered grafts will be explored including biomechanics and transport phenomena along with the use of biomaterials and bioreactors to regulate the cellular microenvironment. Emphasis will be placed on different sources of stem cells and their applications to tissue engineering. Clinical and regulatory perspectives will be discussed. Co-listed with EN.580.442.
Recommended Course Background: EN.580.221 or AS.020.305 and AS.020.306, AS.030.205, EN.580.441/EN.580.641
Area: Engineering

EN.580.643. Advanced Orthopaedic Tissue Engineering. 3 Credits.
This course is intended to provide a comprehensive overview on the current state of the field of Orthopaedic Tissue Engineering. Students will apply engineering fundamentals learned in the Tissue Engineering course (580.442/580.642) with special emphasis on how they apply to bone, cartilage, and skeletal muscle tissue engineering. The development, structure, mechanics, and function of each of these tissues will be discussed. Key articles from the lat three decades that focus on stem cell- and cell-free, biomaterial-based approaches to regenerate functional tissues will be presented and analyzed. Practical (regulatory/commercial) considerations that restrict the translation of therapies to the clinic will be discussed. Undergraduate by permission only. Recommend Course Background: EN.580.442 or EN.580.642.

EN.580.644. Biomedical Applications of Glycoengineering. 3 Credits.
This course provides an overview of carbohydrate-based technologies in biotechnology and medicine. The course will begin by briefly covering basics of glycobiology and glycochemistry followed by detailed illustrative examples of biomedical applications of glycoengineering. A sample of these applications include the role of sugars in preventative medicine (e.g., for vaccine development and probiotics), tissue engineering (e.g., exploiting natural and engineered polysaccharides for creating tissue or organs de novo in the laboratory), regenerative medicine (e.g., for the treatment of arthritis or degenerative muscle disease), and therapy (e.g., cancer treatment). A major part of the course grade will be based on class participation with each student expected to provide a "journal club" presentation of a relevant paper as well as participate in a team-based project designed to address a current unmet clinical need that could be fulfilled through a glycoengineering approach. Recommended Course Background: EN.580.221 Molecules and Cells or equivalent (molecular and cell biology), college level calculus and calculus-based general physics.
Area: Engineering, Natural Sciences

EN.580.646. Molecular Immunoengineering. 3 Credits.
An in-depth study of the use of biomolecular engineering tools and techniques to manipulate immune function for clinical translation. The course will begin with a brief overview of the immune system, placing a particular emphasis on the molecular-level interactions that determine phenotypic outcomes. The remainder of the curriculum will address ways in which integrative approaches incorporating biochemistry, structural biophysics, molecular biology, and engineering have been used either to stimulate the immune response for applications in cancer and infectious disease, or to repress immune activation for autoimmune disease therapy. Recommended background: Biochemistry and Cell Biology or the BME Molecules and Cells. Those without recommended background should contact the instructor prior to enrolling.
Area: Engineering, Natural Sciences

EN.580.647. Computational Stem Cell Biology. 3 Credits.
This course will provide the student with a mechanistic and systems biology-based understanding of the two defining features of stem cells: multipotency and self-renewal. We will explore these concepts across several contexts and perspectives, emphasizing seminal and new studies in development and stem cell biology, and the critical role that computational approaches have played. The course will start with an introduction to stem cells and a tutorial covering computational basics. The biological contexts that we will cover thereafter include 'Cell Identity', 'Pluripotency and multipotency', 'Stem cells and their niche', 'Modeling cell fate decisions', and 'Engineering cell fate'. This class is heavily weighted by individual computational assignments. The motivation for this strategy is that regularly occurring, moderately-sized computational projects are the most efficient way to impart an understanding of our models of this extraordinary class of cells, and to inspire a sense of excitement and empowerment. Preferred background: 580.221 Molecules and Cells or equivalent and familiarity with the UNIX shell.
Prerequisite(s): Students may earn credit for EN.580.447 or EN.580.647, but not both.
Area: Engineering, Natural Sciences

EN.580.656. Introduction to Rehabilitation Engineering. 3 Credits.
The primary objective of this course is to introduce biomedical engineering students to the challenges of engineering solutions for persons functioning with disabilities. In order to achieve this goal, other objectives include: gaining a basic appreciation of the modalities used to treat impairments, the opportunities for application of engineering to improve treatment delivery, understanding the science and engineering applied to helping persons with disabilities function in the everyday world and an basic knowledge of the legal, ethical issues and employment opportunities in rehabilitation engineering. By the conclusion of this class, students should be able to: understand the breadth and scope of physical impairment and disability, including its associated pathophysiology; characterize the material and design properties of current evaluation tools for assessment of impairments and adaptations for disability; characterize the material and design properties of current modalities of treatment of impairments and adaptations for disability; apply engineering analysis and design principles to critique current solutions for persons with disabilities in order to suggest improvements.
Area: Engineering

EN.580.664. Advanced Data Science for Biomedical Engineering. 4 Credits.
This course covers the basics of data science in biomedical engineering. The main topics include, introductory R, data cleaning, reproducible research, basic statistical inference, machine learning and artificial intillegence. Specific topics include: assessing diagnostic accuracy, basic probability, tidy data principles, prediction and data oriented web-app development using R/shiny. Students taking the course will learn a complete and practical pipeline of going from raw data to a data product. Suggest course background: profeciency in basic programming in at least one language, basic calculus, and linear algebra.

EN.580.674. Introduction to Neuro-Image Processing. 3 Credits.
Developments in medical image acquisition systems such as magnetic resonance imaging (MRI) and computed tomography (CT) have resulted in large number of clinical images with rich information regarding structure and function of nervous system. A challenging task is to extract clinically relevant information from the raw images that can be used to characterize structural alteration of brain in disease state. This course introduces the underlying physical foundation of different image modalities that are used to study neurological disorders followed by presentation of concepts and techniques that are used to process and extract information from medical images, in particular MRI. Topics that are covered include medical image formats, enhancement, segmentation, registration, and visualization.Suggest Course Background: Mathematical Methods For Engineers or equivalent course, Signals and Systems, and Probability.

EN.580.678. Biomedical Photonics. 4 Credits.
This course will cover the basic optics principles including geometric, beam and wave description of light. The course will also cover the basic generation and detection techniques of light and the principles of optical imaging and spectroscopy. After the basis is established, we will focus on some commonly employed optical techniques and tools for biomedical research including various optical microscopy technologies, fiber optics, Raman spectroscopy, Fluorescence (lifetime), FRAT, FRET and FCS. The recent development in tissue optics, biomedical optical imaging/ spectroscopy techniques (such as OCT, multiphoton fluorescence and harmonics microscopy, Structured Illumination, light scattering, diffuse light imaging and spectroscopy, optical molecular imaging, photo-acoustic imaging) will also be discussed. Representative biomedical applications of translational biomedical photonics technologies will be integrated into the corresponding chapters.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Engineering

EN.580.679. X-ray Imaging and Computed Tomography. 3 Credits.
This course provides students with an intermediate-level understanding of the physics, engineering, algorithms, and applications of medical x-ray imaging and computed tomography (CT). It is intended for senior undergraduates (EN.580.479) and/or graduate students (EN.580.679) in Biomedical Engineering, Computer Science, Electrical and Computer Engineering, or related fields in science and engineering. Topics include the physics of x-ray interaction and detection, image quality modeling and assessment, 3D image reconstruction (including analytical and iterative approaches), and applications in diagnostic and image-guided procedures. Recommended Course Background: EN.580.472 and/or EN.580.473 and familiarity with Matlab.
Area: Engineering

EN.580.680. Precision Care Medicine. 4 Credits.
Precision Care Medicine is a two-semester project-based learning course. Projects will use methods of machine learning and mechanistic and statistical modeling to develop novel data-driven solutions to important health care problems that arise in anesthesiology and critical care medicine. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 3-4, and will work with their project mentors (clinical faculty in the ACCM Department; Drs. Winslow and Sarma) to develop a project work plan. In the remainder of the course, they will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will also be charged with designing, validating and deploying a web-application that delivers the computational method for solving the underlying healthcare problem to the user. HIPAA regulations, use of human subjects data, and requirements for FDA Class II and Medical Device Data Systems approval will be covered.

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EN.580.682. Precision Care Medicine III. 3 Credits.
Precision Care Medicine III follows Precision Care Medicine I - II. Registration is open only to those students who have completed these courses and who wish to continue project course work under the mentorship of the Biomedical and Engineering PIs. Students will have regular meetings with their PIs.

EN.580.688. Foundations of Computational Biology and Bioinformatics. 4 Credits.
This course will introduce probabilistic modeling and information theory applied to biological sequence analysis, focusing on statistical models of protein families, alignment algorithms, and models of evolution. Topics will include probability theory, score matrices, hidden Markov models, maximum likelihood, expectation maximization and dynamic programming algorithms. Homework assignments will require programming in Python. Recommended Course Background: Math through linear algebra and differential equations, EN.580.221 or equivalent, EN.601.226 or equivalent.

EN.580.691. Learning, Estimation and Control. 3 Credits.
This course introduces the probabilistic foundations of learning theory. We will discuss topics in regression, estimation, Kalman filters, Bayesian learning, classification, reinforcement learning, and active learning. Our focus is on iterative rather than batch methods for parameter estimation. Our aim is to use the mathematical results to model learning processes in the biological system. Recommended Course Background: Probability and Linear Algebra.

EN.580.693. Imaging Instrumentation. 4 Credits.
This course is intended to introduce students to imaging instrumentation. The class will be lab-oriented, giving hands-on experience with data collection and processing using a configurable optical system. Specific topics will include the programming and control of electromechanical elements, imaging data acquisitions, image formation and processing (e.g. 3D reconstruction), and imaging system analysis and optimization.Recommended Course Background: EN.580.222 Systems and Controls or EN.520.214 Signals and Systems. Programming experience highly desirable.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

EN.580.697. Neuro Data Design I. 4 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. Recommended Course Background: numerical programming.

EN.580.701. CBID Masters Advanced Project. 3 - 10 Credits.
For second year CBID students.

EN.580.702. CBID Masters Advanced Project. 3 - 10 Credits.

EN.580.704. Mathematical Foundations of BME I. 4 Credits.
The course introduces modern techniques in mathematical analysis of biomedical data. Techniques include maximum likelihood, estimation theory via Kalman equation, state-space models, Bayesian estimation, classification of labeled data, support vector machine, dimensionality reduction via principal component analysis, clustering, expectation maximization, and dynamic programming via the Bellman equation.

EN.580.706. Introduction to Biomedical Rodent Surgery Laboratory and Grantsmanship. 3 Credits.
This course has been specifically designed for students interested in understanding the translational aspects of biomedical research and pursuing research as a career. The course aims to introduce diverse yet interlinked research concepts that will equip students with the necessary knowledge and expertise to independently carry out research endeavors in the future. A part of the course includes supervised hands-on in vivo workshops, in which students will learn basic rodent anatomy, physiology and some general experimental procedures. A second component will introduce research methodology, which will enable students to develop their scientific thought process and enhance their critical thinking skills by formulating hypothesis, developing aims, searching PubMed for related literature, understanding ethical guidelines and other regulatory issues. In today’s scenario, scientists also need to have a strong communication ability to ensure that their research is accessible at a global platform. This requires skill and knowledge of scientifically drafting manuscripts, writing grants and articulating business plans as well as effectively presenting their research results (presentation, poster, etc.). We will allocate necessary time to develop this science-art as well. Students’ attendance and active participation will enrich this exciting and interactive course, which is entirely based on in-class learning.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

EN.580.709. Sparse Representations in Computer Vision and Machine Learning. 2 Credits.
Sparse and redundant representations constitutes a fascinating area of research in signal and image processing. This is a relatively young field that has been taking form for the last 15 years or so, with contributions from harmonic analysis, numerical algorithms and machine learning, and has been vastly applied to myriad of problems in computer vision and other domains. This course will focus on sparsity as a model for general data, generalizing many different other constructions or priors. This idea - that signals can be represented with just 'a few' coefficients - leads to a long series of beautiful (and surprisingly, solvable) theoretical and numerical problems, and many applications that can benefit directly from the new developed theory. In this course we will survey this field, starting with the theoretical foundations, and systematically covering the knowledge that has been gathered in the past years. This course will touch on theory, numerical algorithms, and applications in image processing and machine learning. Recommended course background: Linear Algebra, Signals and Systems, Numerical Analysis.

EN.580.721. Systems Bioengineering I. 4 Credits.
A quantitative, model-oriented investigation of the cardiovascular system. Topics are organized in three segments. (1) Molecular/cellular physiology, including electrical signaling and muscle contraction. (2) Systems cardiovascular physiology, emphasizing circuit-diagram analysis of hemodynamics. (3) Cardio-vascular horizons and challenges for biomedical engineers, including heart failure and its investigation/treatment by computer simulation, by gene-array analysis, by stem-cell technology, and by mechanical devices (left-ventricular assist and total-heart replacement). Recommended Course Background: EN.580.221 and EN.580.222

EN.580.722. Systems Bioengineering II. 4 Credits.
A quantitative, model-oriented approach to the study of the nervous system. Topics include functional anatomy of the central and autonomic nervous systems, neurons and networks, learning and memory, structure and function of the auditory and visual systems, motor systems, and neuro-engineering.Recommended Course Background: EN.580.221, EN.580.222, EN.580.223, AS.110.302, EN.580.421; Corequisite: EN.580.424

EN.580.723. Introduction to MRI in Medicine. 3 Credits.
Advances in magnetic resonance Imaging (MRI) have resulted in developing techniques such as diffusion imaging, delayed contrast enhanced imaging, tagged, flow map and many other imaging contrasts. These techniques offer insights into the structure and function of brain and other anatomical regions in the body. With increased availability of these techniques in clinical MRI machines, they are now entering clinical practice for the evaluation of disease. This course presents the underlying physical foundation of MRI, with a focus on more advanced techniques and their application in clinical research and practice. Topics that are covered include foundations of MRI (signal detection and construction, image contrast), diffusion weighted imaging, and cardiac imaging. Attention is also drawn to possible artifacts and pitfalls.Suggested course background: Signals and systems/multi-dimensional digital signal processing, differential equations, linear algebra.

EN.580.725. Radiology for Engineers. 3 Credits.
This course provides engineering students with an introductory understanding of the principles and practice of radiology – including a spectrum of specialties in diagnostic radiology as well as procedures in interventional radiology and digital pathology. The course includes lectures, working with real image data, and visits to clinical areas at Johns Hopkins Hospital. Each segment of the course emphasizes clinical perspective on imaging (including scanner technology and image analysis) in relation to anatomy, physiology, and pathology. Each segment is led by an expert in a particular discipline in collaboration with the course director. Recommended course background: 580.472, 601.455Restricted to BME MSE and BME PhD students only. Others by instructor permission. Audits are not allowed.
Area: Engineering, Natural Sciences

EN.580.727. Cell Engineering and Regenerative Medicine Seminar Series. 1 Credit.
Top researchers from around the world will present the latest research on stem cell science and clinical application followed by discussion.School of Medicine campus: PCTB, Mountcastle Auditorium

EN.580.735. Advanced Seminars in Computational Medicine. 1 Credit.
In this course, students will review current literature on the most salient and interesting topics in the emerging field of Computational Medicine, which is focused on the development of quantitative approaches for understanding the mechanisms, diagnosis and treatment of human disease through applications of mathematics, engineering, and computational science. Whenever possible, the publications considered will be directly relevant to the lectures delivered by visiting scholars in the Institute for Computational Medicine's seminar series. Students will be required to search for the most relevant papers in the current literature; read and critically interpret these papers; conduct interactive teaching sessions with the course instructor, other students, and trainees/faculty from the Institute. Potential topics will include: computational anatomy; computational molecular medicine; computational physiological medicine; and computational healthcare. Evaluation will be by the course instructor (pass/fail). Graduate level. Seniors by permission. All registrants must be approved by the course instructor.

EN.580.736. Distinguished Seminar Series in Computational Medicine. 1 Credit.
We live in a new era in the understanding, diagnosis and treatment of human disease. Over the past ten years, extraordinary advances in modeling and computing technologies have opened the door to an array of possibilities that were previously beyond the reach of biomedical researchers. Today's powerful computational platforms are allowing us to begin to identify, analyze, and compare the fundamental biological components and processes that regulate human diseases and their impact on the body. The next step, then, is to harness the potential of these theoretical and computational tools and theory in a meaningful way -that is, to apply this 'new medicine' to the exploration and treatment of many of our current diseases. This lecture series will feature world experts in computational medicine as well as laboratories at JHU's institute for Computational Medicine (ICM). Fall semester only. S/U grading only.

EN.580.737. Distinguished Seminar Series in Computational Medicine. 1 Credit.
We live in a new era in the understanding, diagnosis and treatment of human disease. Over the past ten years, extraordinary advances in modeling and computing technologies have opened the door to an array of possibilities that were previously beyond the reach of biomedical researchers. Today's powerful computational platforms are allowing us to begin to identify, analyze, and compare the fundamental biological components and processes that regulate human diseases and their impact on the body.The next step, then, is to harness the potential of these theoretical and computational tools and theory in a meaningful way -that is, to apply this 'new medicine' to the exploration and treatment of many of our current diseases. This lecture series will feature world experts in computational medicine as well as laboratories at JHU's institute for Computational Medicine (ICM). Spring semester only.

EN.580.738. Advanced Seminars in Cardiac Electrophysiology and Mechanics. 1 Credit.
This course uses the current literature to teach advanced topics in cardiac electrophysiology and mechanics. Students will be required to read current articles and then conduct interactive teaching sessions with faculty and other students. Potential topics will include: ion channels, cardiac excitation-contraction coupling, myofilament regulation, cardiac arrhythmias, heart failure, therapies for arrhythmias and pump dysfunction. Evaluation will be both by faculty and fellow students.Graduate Level. Seniors by permission. Fall semester only.

EN.580.739. Advanced Seminars in Cardiac Electrophysiology and Mechanics. 1 Credit.
This course uses the current literature to teach advanced topics in cardiac electrophysiology and mechanics. Students will be required to read current articles and then conduct interactive teaching sessions with faculty and other students. Potential topics will include: ion channels, cardiac excitation-contraction coupling, myofilament regulation, cardiac arrhythmias, heart failure, therapies for arrhythmias and pump dysfunction. Evaluation will be both by faculty and fellow students.Graduate Level. Seniors by permission only (signed add/drop form). Spring semester only.

EN.580.740. Surgery for Engineers. 3 Credits.
This course provides an introduction to basic principles and emerging techniques in surgery, interventional radiology, and radiation therapy for engineering students. Basic principles include introduction to fundamental surgical approaches and tools as well as sub-specialties, including neurosurgery, orthopaedic surgery, ENT surgery, thoracic surgery, and laparoscopic surgery as well as minimally invasive (body and neurovascular) interventional radiology as well as radiotherapy (external beam and brachytherapy). Introduction to cutting edge and emerging technologies include intraoperative imaging (all modalities), surgical navigation, and robotics. Requisite background for engineering students includes analytic geometry, linear algebra, computing (Matlab, Python, or C++), and basic familiarity with the physics of medical imaging. Safety Training: certificate in Bloodborne Pathogens and HIPAA & Research. Recommended course background: 580.472, 601.455

EN.580.741. Models of Cardiac Electrophysiology and Arrhythmia. 1 Credit.
This course will cover the fundamentals of different experimental and computational models of cardiac electrophysiology and when particular models are appropriate for use. Students will be required to read review articles and engage in interactive discussion with faculty and other students. with some projects and presentations to reinforce important concepts. Topics will include measurement of cardiac electrical signals, stimulation of cardiac tissue, single cell and tissue level electrical properties, excitation-contraction coupling, and mechanisms of arrhythmia.Seniors by permission.

EN.580.742. Neural Implants and Interfaces. 3 Credits.
This course will focus on invasive neural implants that electrically interface with the peripheral or central nervous system. We will investigate the different types of recording and stimulating neural interface technologies currently in use in patients as well as coverage of the biophysics, neural coding, and hardware. We will also cover computational modeling of neurophysiology in the context of implantable devices and their neural interfaces. A final group project will be required for simulating a neural interface system. Recommended course background includes cell biology, physics with electromagnetics (or electrical circuits), chemistry, differential equations, and computer programming.

EN.580.745. Mathematics of Deep Learning. 1.5 Credits.
The past few years have seen a dramatic increase in the performance of recognition systems thanks to the introduction of deep networks for representation learning. However, the mathematical reasons for this success remain elusive. For example, a key issue is that the training problem is nonconvex, hence optimization algorithms are not guaranteed to return a global minima. Another key issue is that while the size of deep networks is very large relative to the number of training examples, deep networks appear to generalize very well to unseen examples and new tasks. This course will overview recent work on the theory of deep learning that aims to understand the interplay between architecture design, regularization, generalization, and optimality properties of deep networks. Recommended background: machine learning (EN.601.475), deep learning (EN.520.438 or EN.601.482), graduate-level matrix analysis and linear algebra (EN.553.792) and graduate-level optimization (EN.553.762).

EN.580.746. Imaging Science Seminar. 1 Credit.
Fall semester only.

EN.580.747. Imaging Science Seminar. 1 Credit.
In this seminar course, students will review current literature on the most salient and interesting topics in the fields of Imaging and Data Science through a series of invited talks by leading experts, from foundational ideas to exciting applications. This course is held concurrently to the seminar series of the Center for Imaging Science (CIS) and the Mathematical Institute for Data Science (MINDS). More information will be periodically updated and posted at the CIS and MINDS websites. Graduate level. Seniors by permission.

EN.580.749. Advanced Seminars in Magnetic Resonance Imaging. 3 Credits.
This course uses the current literature to teach advanced topics in magnetic resonance imaging. Students will be required to read current papers, selected textbook chapters and online content to prepare for interactive teaching sessions with faculty and other students. Potential topics will include: image artifacts, effect of motion, resolution and SNR, realtime imaging, clinical applications. Evaluation will be both by faculty and fellow students. Spring semester only.

EN.580.750. Surgineering: Systems Engineering and Data Science in Interventional Medicine. 3 Credits.
This course provides engineering students with deep clinical immersion in interventional medicine complemented by instruction in systems engineering and data science pertaining to medical technology, information, and workflow. The course involves one-to-one matching of students with Clinical Mentors, who oversee the students' clinical immersion and involvement on clinical teams. Weekly class meetings with visitation by one or more of the Clinical Mentors focus on principles of systems engineering and data science as well as journal articles on emerging topics in technology and information science in interventional medicine. Each student completes a course project that addresses a particular question or challenge in technology integration, data-flow, workflow, patient safety, and quality assurance in one of the clinical areas covered in the course. Prerequisites and CertificatesPrerequisite for the course is 580.740 (Surgery for Engineers), which introduces principles and practice of interventional medicine – including open and minimally invasive surgical approaches as well as interventional radiology and radiation oncology. Students must provide a copy of the following certifications, each available as Hopkins myLearning modules at myJHU:• Bloodborne Pathogens• Fluoroscopy Refresher• Patient Privacy for Workforce Members

EN.580.751. Cell & Tssue Engineering Lab. 4 Credits.
Cell and tissue engineering is a field that relies heavily on experimental techniques. This laboratory course will consist of three six experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Students will learn specialized techniques related to faculty expertise in cell engineering, microfluidics, gene therapy, microfabrication and cell encapsulation. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. This course includes an 'advanced topics' component designed to fulfill toe core curriculum requirements of the RIE (Regenerative and Immune Engineering) track of the BME masters program. Offered the first half of fall semester only.

EN.580.752. Advanced Topics in Regenerative and Immune Engineering. 4 Credits.
This course is designed as part of the core curriculum for the RIE track fo the BME masters program. Topics will be selected based on current methods, basic research, and clinical translation of regenerative medicine and immune engineering technologies. Background Knowledge: EN.580.641, EN.580.642, and EN.580.751 or graduate standing and permission of the instructor.

EN.580.753. Cell and Tissue Engineering Lab Advanced Project. 1 Credit.
This one credit laboratory course provides students with the opportunity to obtain experience in advanced project design and implementation in conjunction with the graduate-level Cell & Tissue Laboratory course (EN.580.751/4). It is appropriate for students who have previously taken the undergraduate version of this course to fulfill the core curriculum requirement of the RIE (Regenerative and Immune Engineering) track of the BME master's program. Graduate students may also take this course will permission of the instructor to pursue additional 'advanced topics' laboratory modules. The work will be completed over the course of the semester in conjunction with the "advanced topics" component of the regular graduate level version of the lab course.
Prerequisite(s): EN.580.451 AND EN.580.452

EN.580.754. Cell & Tissue Engineering Lab. 4 Credits.
Cell and tissue engineering is a field that relies heavily on experimental techniques. This laboratory course will consist of experiments and a project that will provide students with valuable hands-on experience in cell and tissue engineering. Students will learn specialized techniques related to faculty expertise in cell engineering, microfluidics, gene therapy, microfabrication and cell encapsulation. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. This course includes an 'advanced topics' component designed to fulfill the core curriculum requirements of the RIE (Regenerative and Immune Engineering) track of the BME masters program.

EN.580.771. Principles of the Design of Biomedical Instrumentation. 4 Credits.
This course is designed for graduate students interested in learning basic biomedical instrumentation design concepets and translating these into advanced projects based on their research on current state-of-the-art. They will first gain the basic knowledge of instrumentation design, explore various applications, and critically gain hands-on experience through laboratory and projects. At the end of the course, students would get an excellent awareness of biological or clinical measurement techniques, design of sensors and electronics (or electromechanical/chemical, microprocessor system and their use). They will systematically learn to design instrumentation with a focuson the use of sensors, electronics to design a core instrumentation system such as an ECG amplifier. Armed with that knowledge and lab skills, students will be encouraged to discuss various advanced instrumentation applications, such as brain monitor, pacemaker/defibrillator, or prosthetics. Further, they will be "challenged" to come up with some novel design ideas and implement them in a semester-long design project. Students will take part in reading the literature, learning about the state-of-the-art through journal papers and patents, and discussing, critiquing, and improving on these ideas. Finally, they will be implementing a selected idea into a semester-long advanced group project.Meets with 580.471 Graduate students only
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

EN.580.773. Modern Biomedical Imaging Instrumentation and Techniques. 3 Credits.
An intermediate biomedical imaging course covering modern biomedical imaging instrumentation and techniques as applied to diagnostic radiology and other biomedical applications. It includes recent advances in various biomedical imaging modalities, multi-modality imaging and molecular imaging. The course is team taught by experts in the respective fields and provides a broad based knowledge of modern biomedical imaging to prepare students for graduate studies and research in biomedical imaging. Also, the course will offer tours and practical experience with modern biomedical imaging equipment in clinical and research settings. Recommended course background: EN.520.432 or EN.580.472
Prerequisite(s): Students may take EN.580.473 or EN.580.773 but not both.
Area: Engineering

EN.580.775. Build Your Own Prosthesis. 4 Credits.
This is a graduate level hands-on course to learn how to make prosthetic limbs. The course will begin with doing background literature and technology review. The students will then do up to 8 laboratory exercises and then follow up with 4 weeks of hands on project building on one of the laboratories to take the idea to cutting edge research in the field. The laboratory exercises will include 1) Electrodes for muscle (EMG) and brain (EEG) signal recording. 2) Circuits for signal amplification and acquisition. 3) Signal processing of EMG and ECG using conventional spectral and discriminant analysis. 4) Design of Control of prosthetic fingers and hands. 5) Soft robotics – design of a prosthetic finger. 6) Tactile sensor design. 7) Tactile sensing and feedback for prosthesis. 8) Simulation using graphical animation and augmented reality. The projects done by students will be on advanced topics such as: A) Pattern recognition and machine intelligence of EMG decoding for dexterous hand control. B) Design of soft robotic multi-finger hand. C) Sensory perceptions: perceiving light touch to pain. D) Augmented reality learning, training and performance. In addition, the students will visit prosthetics/robotics laboratories, startup company and Applied Physics Lab where upper limb prosthesis development takes place. They will be expected to devote equivalent of 8 hours of hands on laboratory time, and as much time reviewing the literature, writing laboratory reports, and the final project report as a paper and a patent, and do a demonstration and make a full presentation. The course will be self-paced and open to graduate students who will take part in the laboratory and project development, learn by doing, and demonstrate ability to take basic ideas to advanced, novel solutions. Selection will be based on an interview about skills, readiness, and motivation.

EN.580.779. Systems Bioengineering III. 4 Credits.
Computational and theoretical systems biology at the cellular and molecular level. Topics include organizational patterns of biological networks; analysis of metabolic networks, gene regulatory networks, and signal transduction networks; inference of pathway structure; and behavior of cellular and molecular circuits. Recommended Course Background: EN.580.221 and EN.580.222 or Permission Required.

EN.580.781. Biomedical Engineering Seminar. 1 Credit.

EN.580.782. Biomedical Engineering Seminar. 1 Credit.

EN.580.788. Biomedical Photonics II. 4 Credits.
This course serves as the continuation of 580.678 (520.678), Biomedical Photonics I. It will cover the advanced topics on biomedical photonics, including, but not limited to, light scattering (Rayleigh and Mie scattering), photon diffusion, polarization (birefringence), fluorescence, lifetime measurements, confocal microscopy, optical coherence tomography, nonlinear microscopy, and super-resolution microscopy. Representative biomedical applications of some of these technologies will be integrated into the relevant chapters. A hand-on lab section (optional) for students to design and build an imaging instrument, space permitting.

EN.580.791. Biomedical Engineering Project Design and Proposal Development I. 2 Credits.
The goal of this class is to provide students with experience in designing and implementing a biomedical engineering research project. Students will select a laboratory to host their research rotation within the first two weeks (ideally, before the start of the term) and will participate in lab-related activities for a minimum of 6 hours a week that involve “in person” interaction between the PI or other members of the sponsoring lab and the student. Activities will include attendance at lab meetings, preparation of a research proposal, and “hands on” experimental, computational, or modeling tasks: in addition, attendance at department research seminars and class meetings is required. Periodic reports on your research proposal/project and progress, as well providing feedback on your ‘colleagues’ projects and proposals are also expected. This is a companion course to Biomedical Engineering Project Design and Proposal Development II; the two courses can be taken sequentially in subsequent academic terms (recommended) or concurrently during a single semester.

EN.580.801. Research in Biomedical Engineering. 3 - 10 Credits.
Graduate Students only

EN.580.802. Research in Biomedical Engineering. 3 - 10 Credits.
Directed research for MSE and PhD students

EN.580.803. Research in Biomedical Engineering. 3 - 10 Credits.
Course is for students conducting research for credit.P/F grading only

EN.580.821. Applied Research and Grant Methodology I. 3 Credits.
Students will select a laboratory to host their research rotation within the first two weeks (ideally, before the start of the term) and will participate in lab-related activities for a minimum of 12 hours a week; at least 6 hours a week is expected to involve “in person” interaction between the PI or other members of the sponsoring lab and the student. Activities will include attendance at lab meetings, preparation of a research proposal, and “hands on” experimental, computational, or modeling tasks: in addition, attendance at department research seminars and class meetings is required. Periodic reports on your research proposal/project and progress, as well providing feedback on your ‘colleagues’ projects and proposals will also be expected. A final research proposal (to be presented in the format of a NIH R21-type grant application) will provide evidence that a student is capable of carrying out advanced research by identifying a significant biomedical problem, developing innovative approaches to solve it, and then designing a relevant and implementable research plan.

EN.580.822. Applied Research and Grant Methodology II. 3 Credits.
Students will participate in lab related activities for at least 12 hours a week. These activities will include attendance at lab meetings, preparation of a research proposal, and “hands on” experimental, computational, or modeling tasks. In addition, attendance at research seminars and class meetings is expected. Finally, periodic reports on your research project and progress, as well providing feedback on your ‘colleagues’ projects and proposals, will be required. Finally a research proposal essay (to be presented in the format of a NIH F31 (or NSF equivalent) grant application will be required (it is expected that the application will be submitted to the funding agency for students interested in continuing their research career); it is anticipated that this proposal will include data generated by the student over the Fall, Intersession, or Spring term(s).
Prerequisite(s): EN.580.821 OR EN.580.706

EN.580.850. BME MSE Research Practicum. 6 Credits.
BME MSE Research Practicum For Thesis-Track Students

ME.210.801. Special Studies in Biomedical Engineering (Summer 2).
Studies conducted in any area of biomedical engineering on a tutorial basis by prior arrangement with a member of the faculty. May be taken more than once.