

# EN.580 (BIOMEDICAL ENGINEERING)

## Courses

### EN.580.110. Immersive Summer Program for Education, Enrichment, and Distinction in Biomedical Engineering. 3 Credits.

This cross-disciplinary, project-based course will introduce students to the field of biomedical engineering with particular emphasis on applying engineering principles to solve problems related to human health. Throughout the course, students will learn and implement modern techniques and methodology to address biomedical questions using biological, computational, and design approaches. Students will (1) apply molecular biology, cell culture, and other wet-lab techniques to answer hypothesis-driven experimental questions; (2) apply programming, coding, and machine learning techniques to analyze data and model disease; and (3) work in small groups to identify, design, and prototype solutions to unmet clinical needs. Guest lectures and workshops will round out the course, introducing students to careers in biomedical engineering, enhancing professional development skills, and providing other tools necessary for future success in the field.

### EN.580.111. Biomedical Engineering: Health and Human Physiology. 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. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN Foundational Abilities: Ethical Reflection (FA5)

### EN.580.112. Design Team Health-Tech Project II. 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.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

### EN.580.151. Cellular and Molecular Foundations. 2 Credits.

This course provides a rigorous foundation in cell structures and pathways relevant to medicine and bioengineering. We will review the recurring principles, including biomechanics and bioenergetics, guiding the dynamics, localization and regulation of key subcellular structures. Biological membranes provide multiple gateway functions for the nucleus, secretory pathway, as well as for the whole cell. Cell division requires mechanical forces and careful sorting to avoid cancer and preserve stem cells. Muscle contraction requires coordination of multiple cell types. Roles for different bioengineering focus areas will be included. Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

### EN.580.204. Social Justice: Fndts & Personal Commitments. 3 Credits.

The course will teach historical concepts from the post civil war years to #blacklivesmatter and will cover key periods in the American experience including Reconstruction, Jim Crow, the struggle for civil rights, and #blacklivesmatter. The course emphasizes an understanding of both policy and practice, and engages students in series of case studies, practical frameworks, selected readings, and guest lectures. Students will contemplate and study the ways in which racial justice plays out across a variety of contexts, including public spaces, the workplace, school, family and relationships, and public policy. The series of guest lectures will be delivered by practitioners and leaders in the movement for racial justice. Ultimately, the course aims to empower students to advance racial justice through self, individual and systems advocacy. At the end of the course, students can expect to walk away with a) a broad understanding of the drivers of structural racism, b) models of advocacy in advancing policy change, c) individual and institutional core competencies for anti-racist practices. Recommended background: an authentic interest in racial justice and models for social change, a willingness to engage in candid, constructive, and challenging conversations and a desire to learn tools with practical applications in the workforce, community organizing, and social activism.

Distribution Area: Social and Behavioral Sciences

EN Foundational Abilities: Engagement with Society (FA4)

### EN.580.211. Design Team Health-Tech Project I. 3 Credits.

Sophomore-level version of EN.580.311-312 or Perm. Req'd

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

### EN.580.212. Design Team Health-Tech Project II. 4 Credits.

Sophomore-level version of EN.580.111-112. Permission of course directors required.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

### 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.

Distribution Area: Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.580.240. Introduction to Biomedical Data Science. 2 Credits.**

This course provides a foundational introduction to the principles, methods, and applications of data science in biomedical research. Key topics include data preprocessing, statistical analysis, machine learning, data visualization, and ethical considerations in biomedical data science. The course emphasizes hands-on experience with real-world biomedical datasets using programming tools such as Python. By the end of the course, students will be equipped with the skills to analyze, interpret, and present data-driven insights in biomedical and healthcare domains.

**Prerequisite(s):** EN.500.112 OR EN.500.113

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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 optimization and 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.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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 EN.553.291 and AS.110.302 may be taken at the same time.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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, controllability, 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

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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 introduced 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.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.580.298. Advanced Design Team. 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 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 Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

**EN.580.311. Design Team Health-Tech Project I. 4 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.

**Prerequisite(s):** EN.580.221 OR EN.580.241 OR EN.580.242 OR EN.580.244

Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**EN.580.312. Design Team Health-Tech Project II. 4 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.

**Prerequisite(s):** EN.580.246 OR EN.580.248

Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**EN.580.336. Distinguished Seminar Series in Computational Medicine. 1 Credit.**

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. 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 course will require students to attend seminars hosted by JHU's Institute for Computational Medicine (ICM) once a month in addition to weekly discussions of recent scholarly advances in computational medicine and conversations with invited seminar speakers. Seminars are hosted on the first Tuesday of each month at 4:00 pm.

**EN.580.351. Immunoengineering Laboratory. 3 Credits.**

This half-semester flipped-content laboratory course will consist of modules that provide students with valuable hands-on experience in cell-based immunoengineering. Modules contain experiments including immune cell culture techniques, immunofluorescence labeling and imaging, inflammatory pathway stimulation, and immune-induced cytotoxicity. Students will collect and analyze their own experimental data, write-up results in publication structured reports, and engage in active discussion of current scientific literature. Requirement(s): Bloodborne Pathogens training to remain enrolled in this class. To access the tutorial, login to myLearning and enter the title in the Search box to locate the appropriate module.

**Prerequisite(s):** Students who have taken EN.580.453 prior to Fall 24 may not enroll.; Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); EN.580.221

Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**EN.580.352. Cell and Tissue Engineering Lab. 3 Credits.**

This half-semester flipped-content laboratory course will consist of modules that provide students with valuable hands-on experience in cell and tissue engineering. Modules contain experiments including the basics of cell culture techniques, gene delivery, small molecule delivery, and tissue modeling. Students will collect and analyze their own experimental data, write-up results in publication structured reports, and engage in active discussion of current scientific literature. Students actively pursuing a Master's degree should prioritize the full semester 580.754 Cell & Tissue Engineering Lab. Pre-requisites: Students must have completed the online "Introductory Laboratory Safety" and "Bloodborne Pathogens" prior to registering for this class. To access these courses, log in to MyLearning and identify these tutorials.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); EN.580.221

Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**EN.580.402. Commitments of Conscience Leadership. 1 Credit.**

Each week we will review one of the chapters from the book, 15 commitments of conscious leadership <https://a.co/d/99uD6BS>. It is an Amazon best-seller, the co-authors coach many tech CEOs, including the leadership team of Asana, which has the best culture in tech according to Fast Company (<https://www.fastcompany.com/3069240/how-asana-built-the-best-company-culture-in-tech>). Weekly assignments will include reading a chapter, watching some videos, doing some personal worksheets, and a partner practice. We will go deep. In the 1 hr weekly class, we discuss the commitment of the week for the hour.

**EN.580.404. Design Team Project 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.580.405. Radical Innovation in BME. 3 Credits.**

What will be the biggest disrupters in biomedical engineering in the next 10-20 years? What areas of healthcare will see transformational change? In this course students will work through a set of tools, techniques and templates to build a portfolio of radical innovation targets in health engineering. Students will assess these targets for impact and feasibility, finally forming a team within the class to propose a solution concept space for their top target.

**EN.580.408. Design Team Leader Project Management. 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. Design Team Health-Tech Project I. 4 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. Senior-level version of EN.580.311-312.

**Prerequisite(s):** EN.580.221 OR EN.580.241 OR EN.580.242 OR EN.580.244

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.412. Design Team Health-Tech Project II. 4 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. Senior-level version of EN.580.311-312. Permission of course directors required.

**Prerequisite(s):** EN.580.246 OR EN.580.248

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.413. Design Team Leader I. 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.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.417. Algorithms for Analysis of Genomic Sequence Data. 3 Credits.**

This course is aimed at introducing students to the concepts of computational bioinformatics and genomics. Emphasis will be placed on algorithms and data structures for genomic data. The course will cover how genomic and transcriptomic data are produced, data file formats, and basic tools for processing the data. It will also include algorithms used in the alignment and assembly of genomic sequence data, with hands-on computational examples, followed by topics in genome sequence analysis and annotation.

**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.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.580.419. Philosophy of Life: A Data Science Perspective. 3 Credits.**

We all want to flourish. Whatever it means, however we each uniquely define it, our desire to flourish is the primary driving force in each of our lives. But what does that mean? And how do we do it? Lots of people—poets, mystics, theologians, philosophers—have attempted to describe what constitutes flourishing. But we don't really understand what they are talking about. We believe if we did understand their guidance, we could flourish more. Previous teachings, however, typically lacked access to recent developments in neural and cognitive sciences (natural intelligence) and also machine learning and computer science (artificial intelligence). We therefore describe what we think flourishing means, and how to achieve it, using modern insights from intelligence sciences. Our goal is to describe the path to increased flourishing using concepts that anyone can understand. Our belief is that a deeper understanding of these concepts will facilitate greater collective flourishing. Recommended background courses: Basic Probability and Statistics.

Distribution Area: Humanities

**EN.580.420. Immunomodulatory Biomaterials: Design, Synthesis, and Applications. 3 Credits.**

The objective of this course is to teach students the chemistry, immunology, and materials engineering fundamentals necessary to develop novel materials that modulate immune responses for the treatment and prevention of diseases. This course will present many of the small molecule and polymer chemistry strategies used to synthesize state-of-the-art biomaterials. The concepts of spatio-temporal delivery of therapeutics, biomaterials degradation, biocompatibility, and various structure-function relationships between biomaterials and the immune system will be introduced. The role played by adaptive and innate immunity in the development and persistence of cancer, infectious diseases, and autoimmunity will be explored. Emphasis will be placed on the design elements that have been, and could be, engineered into immunomodulatory materials to improve human health outcomes. Recommended background: Organic Chemistry I

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Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.580.423. 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.

Distribution Area: Natural Sciences



**EN.580.424. Neuroengineering and 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 ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.580.426. Neuroengineering: The Neural Control of Movement. 3 Credits.**

This half-semester course will delve into how the brain encodes and controls movement. The emphasis in this course is on the theoretical, computational, and experimental approaches that provide the basis of our understanding of how we interact with the world. Lectures will focus on the neural circuits underlying sensorimotor transformations, population coding, motor learning and plasticity, decision-making, functional brain imaging, brain stimulation, and brain machine interfacing. Students will compare neural imaging techniques. The course will be supplemented with visits to medical campus labs and critical analysis of current literature.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.580.427. Microphysiological Systems and Laboratory. 3 Credits.**

This course focuses on the principle and application of biological and engineering fundamentals to design microphysiological systems such as organ/tissue chips, 3D-printed tissues, and organoids. This course will introduce the concept of human organ-on-a-chip and organoid engineering and discuss the latest developments in the field of drug development - the shift from animal testing toward human relevant, high content, high-throughput integrative testing strategies. Students will learn various biofabrication techniques such as microfluidics, microfabrication, and 3D bioprinting to create in vitro miniaturized 3D complex human tissue models that mimic the biochemical, electrical, and mechanical properties of organ or tissue function. This course will also cover a wide range of biomedical applications of microphysiological systems in disease modeling, drug screening, precision medicine, and space biology as well as technology commercialization efforts. This laboratory portion of the course consists of three experiments that will provide students with valuable hands-on experience in design, fabrication and applications of microphysiological systems, including organ-on-a-chip systems (tissue/organ chips), 3-D printed tissue constructs, and organoids. Experiments include 1) the basics of human induced pluripotent stem cell differentiation, 2) tissue/organ chip fabrication, and 3) functional phenotypic analysis and drug testing. Spring semester only. Recommended background: EN.580.441, EN.580.442 and EN.580.452

**Prerequisite(s):** EN.580.441 OR EN.580.442

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.428. Genomic Data Visualization. 3 Credits.**

As the primary mode through which analysts and audience members alike consume data, data visualization remains an important hypothesis generating and analytical technique in data-driven research to facilitate new discoveries. However, if done poorly, data visualization can also mislead, bias, and slow down progress. This hands-on course will cover the principles of perception and cognition relevant for data visualization and apply these principles to genomic data, focusing on large-scale single-cell and spatially-resolved omics datasets, using the R statistical programming language. Students will be expected to complete class readings, create weekly data visualizations as homework assignments, and make a major class presentation."

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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).

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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.553.421 OR EN.553.430 OR EN.560.348 )

**EN.580.432. Principles of Genomic Systems Engineering and Synthetic Biology. 4 Credits.**

Biomedical engineering has always involved interfacing with biological systems using non- or partially-biological devices. A current frontier is the ability to interface with biological systems from within using genetic systems. This course focuses on principles of engineering genetic systems. Students will learn how to design a genetic effector circuit, insert it cells and tissues, and assess its function. Specific concepts that will be covered include cellular engineering, gene editing, CRISPR, cloning, gene delivery, viral engineering, barcoding, genetic recording, spatial sequencing, and in situ sequencing.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**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 )

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.580.435. Applied Bioelectrical Engineering. 3 Credits.**

This course covers diverse applications of bioelectrical measurements, manipulation and therapy in engineering practice. Topics include functional electrical stimulation, deep brain stimulation, cardiac pacing and defibrillation, tissue ablation and electromanipulation of cells. Students will receive practical training in the simulation of electrical potentials and electric fields in volume conductors, using the finite element package COMSOL. It will be used throughout the course to explore theoretical concepts as well as in a class project. Recommended background: familiarity with MATLAB; cardiac, muscle and brain physiology; and cellular electrophysiology.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.437. Biomedical Data Design. 4 Credits.**

In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing biomedical 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: linear algebra, probability and statistics, numerical programming.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.580.438. Biomedical 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.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**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.030.205 Meets with EN.580.641

Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**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.030.205 Recommended EN.580.441/EN.580.641 Co-listed with EN.580.642

Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**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

Distribution Area: Engineering  
AS Foundational Abilities: Science and Data (FA2)

**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. Distribution Area: Engineering, Natural Sciences AS Foundational Abilities: Science and Data (FA2)

**EN.580.445. Gero-Engineering: Bioengineering a future for aging and longevity. 3 Credits.**

Applying modern bioengineering approaches to aging research can revolutionize how we think about and study aging. As our worldwide population grows older, staying free of chronic illness and other aging-related diseases has never been more important. Aging is complex and presents significant challenges to healthcare, quality of life, and health equity. However, to make significant strides and optimize human health across the lifespan, we must take unconventional approaches. Bioengineering is poised to have a significant impact on aging and longevity research by developing new concepts, innovative technologies, and AI/ML strategies to improve health and resilience. This course will build on emerging concepts in aging biology, mechano-biology, immuno-engineering, and data science. Specific topics will include: a) developing conceptual frameworks for aging and a bioengineering perspective for why we age differently; b) scales of aging (i.e., groups of genes to groups of people); c) hallmarks and biomarkers of aging; d) senescence; e) mechano-biology of aging; f) cellular reprogramming for engineered resilience; and g) the applications of data science, modeling, and AI/ML strategies to predict aging trajectories, health, and aging interventions. We will also discuss new frontiers of aging and areas that could benefit from emerging bioengineering perspectives that include reproductive longevity, democratizing longevity science: ethical and societal implications of aging and longevity interventions, and perturbation science: cells as sensors of health and disease. The goal is for students to gain a deep understanding of how biomedical engineering can reshape the future of aging and longevity. Students are expected to complete class readings, weekly assignments, class presentations, and group projects. Recommended background: data science principles, cellular and tissue engineering, and fundamentals of biomedical engineering.

Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**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.

Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**EN.580.448. Computational Genomics: Data Analysis. 3 Credits.**

The demand for computational genomics and biology in industry, academia, and government is rapidly growing. Genomic data have the potential to reveal causes of disease, novel drug targets, and relationships among genes and pathways in our cells. However, identifying meaningful patterns from high-dimensional genomic data has required development of new computational tools. This course gives a broad introduction to statistics, machine learning, and computational tools for modern computational genomics real-world problems. Assignments include project sets including programming, and a project component. Genomic applications will include single-cell RNA-sequencing, genome-wide association studies, epigenetics, spatial transcriptomics, heritability and genetic risk prediction, long-read RNA-sequencing, and ethics in genetics.

**Prerequisite(s):** EN.580.475

Distribution Area: Engineering  
AS Foundational Abilities: Science and Data (FA2)

**EN.580.449. Artificial Intelligence and Machine Learning (AI-ML) for Global Health. 3 Credits.**

The field of Artificial Intelligence has seen major breakthroughs in recent years, offering unprecedented possibilities in addressing major global health challenges, particularly in health equity and access. This foundational course in AI for Global Health aims to provide students with the theoretical basis and practical skills needed to apply machine learning techniques to healthcare innovations for global public health problems. The course does not require prior background in machine learning or global public health. It takes a unique approach by teaching foundational machine learning topics using case studies and real-life data from global health innovation projects across Africa, South Asia, and Latin America. Students will learn machine learning topics alongside weekly case studies involving datasets from projects on Malaria, Maternal Health, Neonatal Health, Primary Health Care, Cancer, and more. The course covers topics from basic machine learning to advanced techniques like convolutional neural networks, generative AI, and time series/sequence data. Labs and mini-projects will involve applying these methods to real datasets, culminating in a final challenge project based on a real-life multi-country implementation in East Africa. Prerequisites: Programming knowledge in a high-level language such as Python.

**EN.580.451. Immunoengineering Laboratory. 3 Credits.**

This half-semester flipped-content laboratory course will consist of modules that provide students with valuable hands-on experience in cell-based immunoengineering. Modules contain experiments including immune cell culture techniques, immunofluorescence labeling and imaging, inflammatory pathway stimulation, and immune-induced cytotoxicity. Students will collect and analyze their own experimental data, write-up results in publication structured reports, and engage in active discussion of current scientific literature. Requirement(s): Bloodborne Pathogens training to remain enrolled in this class. To access the tutorial, login to myLearning and enter the title in the Search box to locate the appropriate module.

**Prerequisite(s):** Students who have taken EN.580.453 prior to Fall 24 may not enroll.; Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); EN.580.221 Distribution Area: Engineering, Natural Sciences AS Foundational Abilities: Science and Data (FA2)

**EN.580.452. Cell and Tissue Engineering Lab. 3 Credits.**

This half-semester flipped-content laboratory course will consist of modules that provide students with valuable hands-on experience in cell and tissue engineering. Modules contain experiments including the basics of cell culture techniques, gene delivery, small molecule delivery, and tissue modeling. Students will collect and analyze their own experimental data, write-up results in publication structured reports, and engage in active discussion of current scientific literature. Students actively pursuing a Master's degree should prioritize the full semester 580.754 Cell & Tissue Engineering Lab. Pre-requisites: Students must have completed the online "Introductory Laboratory Safety" and "Bloodborne Pathogens" prior to registering for this class. To access these courses, log in to MyLearning and identify these tutorials.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); EN.580.221 Distribution Area: Engineering, Natural Sciences AS Foundational Abilities: Science and Data (FA2)



**EN.580.453. Immunoengineering Principles and Applications. 3 Credits.**

This course focuses on the application of engineering fundamentals to design cell/tissue-based systems for modulating immune response in treating disease. Concepts of immune cell development, surveillance, migration, and activation/inhibition will be introduced. Students will learn tissues in the body important for trafficking of immune players to local sites of therapeutic response. Engineering concepts required to alter immune cell or tissue function will be explored. Emphasis will be placed on synthetic biology methods such as viral or CRISPR-based techniques as well as necessary (pre/post) isolation and adoptive transfer techniques. In addition, animal models and various in vivo as well as ex vivo toolsets often used in the world of Immunology will be discussed.

**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)  
Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**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 ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)  
Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**EN.580.456. Neural and Rehabilitation Engineering. 3 Credits.**

**Prerequisite(s):** EN.580.243, EN.580.246, and EN.580.424

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.458. Computing the Transcriptome. 3 Credits.**

This course will introduce computational tools used in the field of transcriptomics to analyze the genes and transcripts expressed in a living cell. Lectures will cover different practical ways to analyze large data sets generated by high-throughput RNA sequencing (RNA-Seq) experiments, including alignment, assembly, and quantification. The students will learn how to use RNA-seq to answer questions such as: what is the complete set of human genes? How do we reconstruct the splice variants that are transcribed in different cell types and conditions? How do we compute which genes are differentially expressed between different RNA-seq datasets? Prerequisites: (1) Familiarity with Python or Perl, (2) the Unix command-line environment, and (3) a basic understanding of programming in R.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.460. Epigenetics at the Crossroads of Genes and the Environment. 2 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 four main topics of the course are: epigenetics and DNA methylation; gene-environmental interaction and its relationship to epigenetics; cancer epigenetics; potential energy landscapes for epigenetic analysis. The format is a Socratic-style seminar with three alternating components: (1) "Big Ideas" focused on general principles presented by the instructor and questions from the students; (2) "Methods Development" focused on the logic behind current laboratory and computational methods; and (3) "Current Literature" focused on how to extract believable information from current journal articles. There are also four computational lab projects. Recommended Background: Laboratory course in organic chemistry, biochemistry, or cell biology; introductory statistics; familiarity with R, Python, or MATLAB  
Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**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.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.463. Physics of Medical Imaging. 3 Credits.**

The course provides students with an intermediate understanding of the physics of medical imaging devices. For each modality, we will discuss the physical contrast mechanisms, data acquisition systems, image formation techniques, performance tradeoffs, and state-of-the-art technologies and applications. Lectures and in-class discussions will be complemented by tours of imaging research laboratories and clinical facilities. The technologies that will be discussed in the class include: X-ray Imaging: Generation, interaction, and detection of x-rays, radiation dose. Radiography, mammography, Computer Tomography (CT), and interventional applications of x-ray imaging. Nuclear medicine and molecular imaging: Gamma-ray emission and detection, radiotracer physics, and radiotracer development. Single-Photon Emission Tomography (SPECT), Positron Emission Tomography (PET), and small-animal systems. Biophotonics: Physics and basic properties of light: wave-particle duality, polarization, generation (sources) and detection (detectors). Light propagation properties and image formation: reflection, refraction, rays and waves, diffraction, image formation, and resolution. Light-matter interactions and imaging contrast: including absorption, single and multiple scattering (diffusion), fluorescence. Classic optical imaging modalities: camera, optical microscopy, tomography. Magnetic Resonance Imaging and Spectroscopy: Behavior of atomic nuclei in a magnetic field, generation of resonance signals, relaxation processes, spatial encoding techniques, gradient and radiofrequency (RF) systems, image contrast mechanisms. Advances and diverse applications of MRI in medicine. Proton MR Spectroscopy: Single-voxel and spectroscopic imaging techniques. Ultrasound physics: sound wave propagation, reflection, and attenuation in biological tissues.

**Prerequisite(s):** Students who have taken or are enrolled in EN.580.763 are not eligible to take EN.580.463.

**EN.580.464. Advanced Data Science for Biomedical Engineering. 4 Credits.**

This course will focus on some of the fundamental concepts, learning paradigms, and problems in modern data science. It will provide students with a precise characterization of problems and algorithms for learning from data, from problem formulations to data models to algorithms. We will cover supervised and unsupervised problems, as well as topics on modern aspects of the application of data science in the 21st century. This course is "advanced" in the sense that it will presume undergraduate-level courses in statistics, linear algebra, programming, and basic introductory classes to data science. It is ideal for undergraduate students wanting to specialize in data science.

**EN.580.468. Practical Human Neuroimaging. 3 Credits.**

Neuroimaging is widely used in basic research and clinical practice. This course will introduce the basic principles of magnetic resonance imaging (MRI) and provide students with hands-on experience manipulating, analyzing, and interpreting MRI data sets. We will focus on four types of MRI used to understand human neuroscience: structural imaging, functional imaging, diffusion imaging, and perfusion imaging. After taking this course students will have a practical understanding of working with a variety of MRI data sets. Recommended background: Linear Algebra and programming experience (Python, Matlab, or C).

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**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 Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>) Distribution Area: Engineering, Natural Sciences AS Foundational Abilities: Science and Data (FA2)

**EN.580.472. Honors Instrumentation. 4 Credits.**

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. Student must have taken EN.580.471.

**Prerequisite(s):** EN.580.471

Distribution Area: Engineering

**EN.580.473. Dynamic Modeling of Infectious Diseases in Patients and Populations. 2 Credits.**

Infectious diseases remain a major threat to health globally, and the risk of emerging pandemics like HIV/AIDS and SARS-CoV-2/COVID-19 persists. This course will equip students with the tools to effectively use models to guide clinical and public health decision making for infectious diseases. Topics covered include understanding the complex systems that govern disease transmission, designing and interpreting mathematical models of disease processes at individual patient and population scales, stochastic and deterministic model formulation, use of networks in disease modeling, computational approaches to model simulation, statistical inference methods for timeseries, and data science methods for dealing with common limitations of infectious disease data. Examples will be taken from a range of endemic and epidemic diseases and will include disease evolution and drug resistance. Students will develop and analyze models to inform disease prediction, development of therapeutics, implementation of vaccination, and other control programs. Recommended background: Students should have prior college-level coursework in calculus, linear algebra, probability, statistics, and differential equations. Being comfortable coding in a language such as Python, R, or Matlab is required. No specific academic background in biology or epidemiology is required, but a strong interest and willingness to learn is. Co-listed with EN.580.673

**Prerequisite(s):** Students may take EN.580.773 or EN.580.473 but not both.

Distribution Area: Engineering

**EN.580.474. 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.580.475. 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 OR EN.553.421)

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**EN.580.477. Biomedical Data Science Laboratory. 1 Credit.**

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. Recommended Course Background: Signals and Systems, Calculus III, Linear Algebra, Probability and Statistics

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

**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 various medical disciplines including critical care, neurology, immunology, cardiovascular care, and more. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: 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 or OR; data-driven optimal selection of patient interventions and therapies; and many more. In the first semester, students will assemble into teams of 5-6, and will work with their project mentors (clinical faculty in Johns Hopkins Medicine; Drs. Greenstein and Taylor) 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 both clinical and technical lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project as well as advisory meetings where faculty are available to provide project-specific guidance and assist students with challenges. HIPAA regulations, IRB protocols, and use of human subjects data will be covered. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will be charged with designing and validating their models and preparing results for publication by the end of the second semester. Auditing is not permitted. There is a required one-hour weekly meeting between the student project team and project team PI.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

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 various medical disciplines including critical care, neurology, immunology, cardiovascular care, and more. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: 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 or OR; data-driven optimal selection of patient interventions and therapies; and many more. In the first semester, students will assemble into teams of 5-6, and will work with their project mentors (clinical faculty in Johns Hopkins Medicine; Drs. Greenstein and Taylor) 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 both clinical and technical lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project as well as advisory meetings where faculty are available to provide project-specific guidance and assist students with challenges. HIPAA regulations, IRB protocols, and use of human subjects data will be covered. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will be charged with designing and validating their models and preparing results for publication by the end of the second semester. Auditing is not permitted. There is a required one-hour weekly meeting between the student project team and project team PI.

**Prerequisite(s):** (EN.580.480 OR EN.580.680)

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

Writing Intensive

**EN.580.483. Annotate a Genome. 3 Credits.**

The course will present practical and specific understanding of approaches for genome interpretation. Topics will include Common Variants, Rare and Novel Variants, Personal Genomics and the Environment, Ethical considerations in personal genomics, Structural Variation, Pharmacogenetic variants, and Genetic Trait Associations. Students will learn bioinformatic methods to predict the impact of variants and to rapidly pull published information about variants identified in a genome. Students will work in teams to do exercises and programming projects on personal genomics datasets. Recommended Background: prior coursework in Genetics, Intermediate Programming Distribution Area: Quantitative and Mathematical Sciences AS Foundational Abilities: Science and Data (FA2)

**EN.580.485. Computational Medicine: Cardiology. 2 Credits.**

A quantitative, model-oriented investigation of the cardiovascular system. The course will focus on cardiac electrophysiology, mechanics, and hemodynamics using multi-scale physiology-driven models. Distribution Area: Engineering, Natural Sciences AS Foundational Abilities: Science and Data (FA2)

**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 Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>) Distribution Area: Engineering, Natural Sciences AS Foundational Abilities: Science and Data (FA2)

**EN.580.488. Foundations of Computational Biology and Bioinformatics. 3 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

Distribution Area: Engineering, Natural Sciences  
AS Foundational Abilities: Science and Data (FA2)

**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

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.492. Critical Thinking in Science. 3 Credits.**

How do we know if a scientific claim is true? This course will explore ways of thinking critically and skeptically about scientific and medical claims, through close readings of scientific papers and the evidence within them. The course will also discuss scientific misinformation, how it spreads, and how to counteract it. Topics will include a wide range of findings, ranging from basic scientific questions to claims about the benefits of diet and medical treatments. Scientific questions will include topics in genomics such as the effects of microbes on cancer, horizontal gene transfer, and others. Medical topics will include the anti-vaccine movement, common treatments for pain, methods to extend lifespan, and claims about the benefits of vitamins and supplements. Each week, the course will address different topics by reading papers from the scientific literature and discussing them in class. Extensive class participation will be expected of all students through presentations as well as discussion.

**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 ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>) Distribution Area: Engineering AS Foundational Abilities: Science and Data (FA2)

**EN.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. To access the tutorial, login to myLearning and enter ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>) Distribution Area: Engineering AS Foundational Abilities: Science and Data (FA2)



**EN.580.495. Neural Signals and Computation. 3 Credits.**

This course will go over the computational pipelines for recording and analyzing neural data at the population level. The first half of the course will cover core data processing steps, including spike-sorting and fluorescence imaging segmentation. The latter half will cover computational approaches to modeling neural populations, including dimensionality reduction and dynamical systems models. Both data-driven and theory-driven models will be considered, including sparse coding, predictive coding, RNNs, and others. Recommended Background: Linear Algebra, Probability and Statistics, Python or MATLAB programming.

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.580.497. Advanced Design Projects. 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 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 Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

**EN.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 Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms.

**EN.580.511. BME Research for Visiting Students. 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 Customized Academic Learning using the Customized Academic Learning 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 Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms.

**EN.580.561. Advanced Focus Area Research. 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 ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>); You must request Customized Academic Learning using the Customized Academic Learning form found in Student Self-Service: Registration > Online Forms. Distribution Area: Engineering, Quantitative and Mathematical Sciences AS Foundational Abilities: Science and Data (FA2)

**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.

**Prerequisite(s):** You must request Customized Academic Learning using the Customized Academic Learning 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.580.608. 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.580.610. Intro to Business for Healthcare Innovation & Design. 3 Credits.**

This course comprises two distinct, but related, components. The first is a broad introduction to the terms, concepts, and values of business and management. Particular emphasis will be placed on the economic, financial, and corporate contexts of our business culture, and how they impact the organization, strategy, and decision-making of business firms. The second component is an introduction to the sociological and economic forces that shape the development and diffusion of new technologies. This part is primarily designed to provide a framework for determining the commercial viability of new medical devices and the best path for realizing their value, including how to develop a compelling value proposition, analyze markets and competitors, and protect intellectual property. Throughout, the course utilizes individual exercises, case analyses, and team projects. CBID MSE Students Only

**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.580.614. Evidence Generation for the Medical Device Innovator. 2 Credits.**

This course introduces engineering students to a holistic framework to create and implement an evidence generation strategy for translating their invention/ innovation to the marketplace- including regulatory, reimbursement, and overall clinical trial strategy. Students will apply the topics towards their ongoing master's team project to develop and present their overall evidence generation plan for market access.

**EN.580.618. Identification and Validation of Global Health Needs. 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.580.625. 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). This course will meet on the School of Medicine campus. Recommended Background: general introduction to Neuroscience. Undergraduates with knowledge in Neuroscience welcome.

**EN.580.627. Deep Learning for Medical Imaging. 3 Credits.**

Recent advances in machine learning and deep convolutional neural networks in particular, coupled with computational capabilities offered by modern GPUs and increased data availability, have enabled application of deep learning (DL) techniques in medical imaging. Such applications extend beyond image analysis, with increased presence of DL in early stages of the image formation process, including image preprocessing, tomographic image reconstruction, and image postprocessing informed by the requirements of specific clinical tasks. This course will introduce the foundations of deep learning methods used in medical imaging for both image formation and analysis through hands-on assignments and projects in image denoising, tomographic reconstruction, artifacts correction, image segmentation, feature detection/classification, and single/multi-modality registration. Recommended course background: Python and Linear Algebra

**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. In addition to lectures, students will also participate in section meetings. Section meetings will be offered at designated times/locations throughout the course term and will culminate with final course-wide project presentations. Recommended Course Background: Matlab or Python. This course can be taken in conjunction with EN.580.433 which covers computational physiological medicine.

**EN.580.632. Principles of Genomic Systems Engineering and Synthetic Biology. 4 Credits.**

Biomedical engineering has always involved interfacing with biological systems using non- or partially-biological devices. A current frontier is the ability to interface with biological systems from within using genetic systems. This course focuses on principles of engineering genetic systems. Students will learn how to design a genetic effector circuit, insert it cells and tissues, and assess its function. Specific concepts that will be covered include cellular engineering, gene editing, CRISPR, cloning, gene delivery, viral engineering, barcoding, genetic recording, spatial sequencing, and in situ sequencing. Recommended background: Cellular and Molecular Biology, Methods in Nucleic Acid Sequencing  
Distribution Area: Engineering, Natural Sciences

**EN.580.635. Applied Bioelectrical Engineering. 3 Credits.**

This course covers diverse applications of bioelectrical measurements, manipulation and therapy in engineering practice. Topics include functional electrical stimulation, deep brain stimulation, cardiac pacing and defibrillation, tissue ablation and electromanipulation of cells. Students will receive practical training in the simulation of electrical potentials and electric fields in volume conductors, using the finite element package COMSOL. It will be used throughout the course to explore theoretical concepts as well as in a class project. Recommended background: familiarity with MATLAB; cardiac, muscle and brain physiology; and cellular electrophysiology.

**EN.580.637. Microphysiological Systems. 3 Credits.**

This course focuses on the principle and application of biological and engineering fundamentals to design microphysiological systems such as organ/tissue chips, 3D-printed tissues, and organoids. This course will introduce the concept of human organ-on-a-chip and organoid engineering and discuss the latest developments in the field of drug development - the shift from animal testing toward human relevant, high content, high-throughput integrative testing strategies. Students will learn various biofabrication techniques such as microfluidics, microfabrication, and 3D bioprinting to create in vitro miniaturized 3D complex human tissue models that mimic the biochemical, electrical, and mechanical properties of organ or tissue function. This course will also cover a wide range of biomedical applications of microphysiological systems in disease modeling, drug screening, precision medicine, and space biology as well as technology commercialization efforts. This laboratory portion of the course consists of three experiments that will provide students with valuable hands-on experience in design, fabrication and applications of microphysiological systems, including organ-on-a-chip systems (tissue/organ chips), 3-D printed tissue constructs, and organoids. Experiments include 1) the basics of human induced pluripotent stem cell differentiation, 2) tissue/organ chip fabrication, and 3) functional phenotypic analysis and drug testing. Spring semester only. Recommended background: EN.580.441, EN.580.442 and EN.580.452  
Distribution Area: Engineering

**EN.580.638. Biomedical 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 (Regenerative 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  
Distribution 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 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. 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.

Distribution Area: Engineering, Natural Sciences

**EN.580.645. Business of Healthcare Innovation & Design II. 3 Credits.**

This course builds upon the introductory business course for graduate students at the Center for Bioengineering Innovation and Design (CBID) and introduces students to several key topics relevant to translating an early-stage medical technology to the marketplace. Students will learn to assess and articulate the value proposition of their innovation, develop business models, and detailed business plans, including regulatory, reimbursement, IP, and overall market access strategy. Topics will be taught as a combination of lectures and hands on workshops, with most of the content will be applied directly to the ongoing innovation projects at CBID as part of the course deliverables.

**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.

Distribution 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.

Distribution Area: Engineering, Natural Sciences

**EN.580.649. Artificial Intelligence and Machine Learning (AI-ML) for Global Health. 3 Credits.**

The field of Artificial Intelligence has seen major breakthroughs in recent years, offering unprecedented possibilities in addressing major global health challenges, particularly in health equity and access. This foundational course in AI for Global Health aims to provide students with the theoretical basis and practical skills needed to apply machine learning techniques to healthcare innovations for global public health problems. The course does not require prior background in machine learning or global public health. It takes a unique approach by teaching foundational machine learning topics using case studies and real-life data from global health innovation projects across Africa, South Asia, and Latin America. Students will learn machine learning topics alongside weekly case studies involving datasets from projects on Malaria, Maternal Health, Neonatal Health, Primary Health Care, Cancer, and more. The course covers topics from basic machine learning to advanced techniques like convolutional neural networks, generative AI, and time series/sequence data. Labs and mini-projects will involve applying these methods to real datasets, culminating in a final challenge project based on a real-life multi-country implementation in East Africa. Prerequisites: Programming knowledge in a high-level language such as Python.

**EN.580.656. Neural and Rehabilitation Engineering. 3 Credits.**

This course introduces biomedical engineering students to the challenges of engineering solutions for persons functioning with neural and physical disabilities in order to apply that knowledge to the development of a new, improved device to be used for measurements or treatments of an impairment or disability. Our objectives include: gaining a basic appreciation of disabilities such as loss of limb function (amputation) or sensory loss and correspondingly develop engineering solutions for helping persons with disabilities function – with prosthesis and neuroprosthesis/brain-machine interface as the central theme. Topics include: prosthesis design and its advances such as soft or hybrid prosthesis, computer-aided design and 3D printing, detection and analysis of muscle, nerve and brain signals to control the prosthesis, use of machine intelligence and AI to control the prosthesis, design of sensors and bio/neuro-inspired ways to analyze the sensor signals, methods to provide sensory feedback, use of motion tracking and virtual reality for human motion and performance, understand the nerve and brain architecture and the signals to detect sensory perceptions and use of these brain signals to build a brain-machine interface. This course can be partnered with EN.580.471/.771 Principles of Design of Medical Instrumentation. Recommended background: Circuits/Electronics, Signals, Systems & Controls, and Neuroscience coursework. Distribution Area: Engineering

**EN.580.658. Computing the Transcriptome. 3 Credits.**

This course will introduce computational tools used in the field of transcriptomics to analyze the genes and transcripts expressed in a living cell. Lectures will cover different practical ways to analyze large data sets generated by high-throughput RNA sequencing (RNA-Seq) experiments, including alignment, assembly, and quantification. The students will learn how to use RNA-seq to answer questions such as: what is the complete set of human genes? How do we reconstruct the splice variants that are transcribed in different cell types and conditions? How do we compute which genes are differentially expressed between different RNA-seq datasets? Prerequisites: (1) Familiarity with Python or Perl, (2) the Unix command-line environment, and (3) a basic understanding of programming in R.

Distribution Area: Engineering

**EN.580.664. Advanced Data Science for Biomedical Engineering. 4 Credits.**

This course will focus on some of the fundamental concepts, learning paradigms, and problems in modern data science. It will provide students with a precise characterization of problems and algorithms for learning from data, from problem formulations to data models to algorithms. We will cover supervised and unsupervised problems, as well as topics on modern aspects of the application of data science in the 21st century. This course is "advanced" in the sense that it will presume undergraduate-level courses in statistics, linear algebra, programming, and basic introductory classes to data science. It is ideal for graduate students who desire to work in this space.

**EN.580.668. Practical Human Neuroimaging. 3 Credits.**

Neuroimaging is widely used in basic research and clinical practice. This course will introduce the basic principles of magnetic resonance imaging (MRI) and provide students with hands-on experience manipulating, analyzing, and interpreting MRI data sets. We will focus on four types of MRI used to understand human neuroscience: structural imaging, functional imaging, diffusion imaging, and perfusion imaging. After taking this course students will have a practical understanding of working with a variety of MRI data sets. Recommended background: Linear Algebra and programming experience (Python, Matlab, or C).

Distribution Area: Engineering

**EN.580.673. Dynamic Modeling of Infectious Diseases in Patients and Populations. 2 Credits.**

Infectious diseases remain a major threat to health globally, and the risk of emerging pandemics like HIV/AIDS and SARS-CoV-2/COVID-19 persists. This course will equip students with the tools to effectively use models to guide clinical and public health decision making for infectious diseases. Topics covered include understanding the complex systems that govern disease transmission, designing and interpreting mathematical models of disease processes at individual patient and population scales, stochastic and deterministic model formulation, use of networks in disease modeling, computational approaches to model simulation, statistical inference methods for timeseries, and data science methods for dealing with common limitations of infectious disease data. Examples will be taken from a range of endemic and epidemic diseases and will include disease evolution and drug resistance. Students will develop and analyze models to inform disease prediction, development of therapeutics, implementation of vaccination, and other control programs. Recommended background: Students should have prior college-level coursework in calculus, linear algebra, probability, statistics, and differential equations. Being comfortable coding in a language such as Python, R, or Matlab is required. No specific academic background in biology or epidemiology is required, but a strong interest and willingness to learn is. Co-listed with EN.580.473  
Distribution Area: Engineering

**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 I. 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), FRAP, 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.  
Distribution Area: Engineering

**EN.580.679. Principles and Applications of Modern X-ray Imaging and Computed Tomography. 3 Credits.**

This course provides students with an intermediate-level understanding of the physics, engineering, algorithms, and applications (clinical, pre-clinical, and industrial) of 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 assessment, 3D image reconstruction (including analytical, iterative, and deep-learning approaches), and quantitative image data analysis. Guest lectures from clinical experts introduce applications in diagnostic and image-guided procedures. The students conduct experimental and computational projects involving acquisition and processing of x-ray CT data. Recommended background: Signals and Systems or an equivalent course and familiarity with Matlab.  
Distribution 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 various medical disciplines including critical care, neurology, immunology, cardiovascular care, and more. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: 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 or OR; data-driven optimal selection of patient interventions and therapies; and many more. In the first semester, students will assemble into teams of 5-6, and will work with their project mentors (clinical faculty in Johns Hopkins Medicine; Drs. Greenstein and Taylor) 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 both clinical and technical lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project as well as advisory meetings where faculty are available to provide project-specific guidance and assist students with challenges. HIPAA regulations, IRB protocols, and use of human subjects data will be covered. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will be charged with designing and validating their models and preparing results for publication by the end of the second semester. Auditing is not permitted. There is a required one-hour weekly meeting between the student project team and project team PI.

**EN.580.681. Precision Care Medicine. 3 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 various medical disciplines including critical care, neurology, immunology, cardiovascular care, and more. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: 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 or OR; data-driven optimal selection of patient interventions and therapies; and many more. In the first semester, students will assemble into teams of 5-6, and will work with their project mentors (clinical faculty in Johns Hopkins Medicine; Drs. Greenstein and Taylor) 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 both clinical and technical lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project as well as advisory meetings where faculty are available to provide project-specific guidance and assist students with challenges. HIPAA regulations, IRB protocols, and use of human subjects data will be covered. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will be charged with designing and validating their models and preparing results for publication by the end of the second semester. Auditing is not permitted. There is a required one-hour weekly meeting between the student project team and project team PI.

**Prerequisite(s):** EN.580.480 OR EN.580.680

**EN.580.683. Annotate a Genome. 3 Credits.**

The course will present practical and specific understanding of approaches for genome interpretation. Topics will include Common Variants, Rare and Novel Variants, Personal Genomics and the Environment, Ethical considerations in personal genomics, Structural Variation, Pharmacogenetic variants, and Genetic Trait Associations. Students will learn bioinformatic methods to predict the impact of variants and to rapidly pull published information about variants identified in a genome. Students will work in teams to do exercises and programming projects on personal genomics datasets. Recommended Background: prior coursework in Genetics, Intermediate Programming Distribution Area: Quantitative and Mathematical Sciences

**EN.580.688. Foundations of Computational Biology and Bioinformatics. 3 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.580.689. Modern Optical Microscopy: Theory and Practice. 3 Credits.**

This course will teach the fundamental theory in optical microscopy, including propagation of electromagnetic wave, and Fourier optic. The course will also teach how the theoretical framework is practiced and applied in modern microscopy, by in-class demonstration and hands-on lab projects. Background knowledge: Fourier transform, linear algebra.

**Prerequisite(s):** Students may only earn credit for EN.580.489 or EN.580.689.

Distribution Area: Engineering

**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 ASEN in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

**EN.580.695. Neural Signals and Computation. 3 Credits.**

This course will go over the computational pipelines for recording and analyzing neural data at the population level. The first half of the course will cover core data processing steps, including spike-sorting and fluorescence imaging segmentation. The latter half will cover computational approaches to modeling neural populations, including dimensionality reduction and dynamical systems models. Both data-driven and theory-driven models will be considered, including sparse coding, predictive coding, RNNs, and others. Recommended Background: Linear Algebra, Probability and Statistics, Python or MATLAB programming.

Distribution Area: Engineering

**EN.580.697. Biomedical Data Design. 4 Credits.**

In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing biomedical 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: linear algebra, probability and statistics, 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.**

Project work for second year CBID students only.

**EN.580.705. Musculoskeletal Biology and Disease. 2 Credits.**

The musculoskeletal system (MSK), including bone, cartilaginous tissues, skeletal muscle, tendon, ligament, intervertebral disc, and others, is the structural framework to provide physical support. MSK tissues also form the articulating joints to facilitate movement. In addition, MSK tissues have endocrine functions and communicate with other tissues to affect organism homeostasis and overall physiological health. MSK disorders such as osteoporosis, osteoarthritis, and disc degeneration cause long-term pain, physical disability, psychological distress, and reduced quality of life. In addition to adverse health outcomes, MSK disorders also lead to work disability, declines in productivity, and increases in health care spending.

**EN.580.707. Algorithms for Analysis of Genomic Sequence Data. 3 Credits.**

This course is aimed at introducing students to the concepts of computational bioinformatics and genomics. Emphasis will be placed on algorithms and data structures for genomic data. The course will cover how genomic and transcriptomic data are produced, data file formats, and basic tools for processing the data. It will also include algorithms used in the alignment and assembly of genomic sequence data, with hands-on computational examples, followed by topics in genome sequence analysis and annotation.

**EN.580.710. Ethical Challenges in Biomedical Engineering. 2 Credits.**

This course will address the mores of scholarship and responsible practices in conducting biomedical research. Discussions will be focused on the grey areas encountered in considering and determining the best conduct for performing biomedical research and will emphasize how decisions depend on multiple factors and contexts. Issues to be discussed will span the main focus areas in the Biomedical Engineering Department: Cell and Tissue Engineering, Imaging, Genomics, Computational Medicine, Biomedical Data Science, and Neuroscience. Each week a short lecture will be presented by a faculty member, followed by breakdown into small groups for discussion and debate. Course restricted to BME PhD Students Only.

**EN.580.711. Quantitative Methods in BME. 1 Credit.**

This course is designed to introduce students to the diverse quantitative approaches that are used to tackle BME research and design questions. It allows students to identify areas of interest by exposing them to quantitative methods that they had not been exposed to and also to identify connections between on the surface disparate areas of BME. The topics range from methods used in bioinformatics, neuroengineering, immunoengineering, imaging, and cell and tissue engineering.

**EN.580.713. Translating Healthcare AI: Essential Concepts. 3 Credits.**

Developing AI interventions for healthcare requires skills not only to train AI models but also to evaluate them. Evaluating AI for healthcare relies on concepts such as dataset shifts, missing data, statistical inference, frameworks for study design and validity of evidence. This course will integrate concepts required for evaluation and scientific reporting of AI interventions for healthcare into a project-based learning environment. Students are required to have prior training and/or experience with machine learning or deep learning model development.

**EN.580.720. Immunomodulatory Biomaterials: Design, Synthesis, and Applications. 3 Credits.**

The objective of this course is to teach students the chemistry, immunology, and materials engineering fundamentals necessary to develop novel materials that modulate immune responses for the treatment and prevention of diseases. This course will present many of the small molecule and polymer chemistry strategies used to synthesize state-of-the-art biomaterials. The concepts of spatio-temporal delivery of therapeutics, biomaterials degradation, biocompatibility, and various structure-function relationships between biomaterials and the immune system will be introduced. The role played by adaptive and innate immunity in the development and persistence of cancer, infectious diseases, and autoimmunity will be explored. Emphasis will be placed on the design elements that have been, and could be, engineered into immunomodulatory materials to improve human health outcomes.

Recommended background: Organic Chemistry I

Distribution Area: Engineering, Natural Sciences

**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. BME seniors permitted with instructor approval.

**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.**

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. 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 course will require students to attend seminars hosted by JHU's Institute for Computational Medicine (ICM) once a month in addition to weekly discussions of recent scholarly advances in computational medicine and conversations with invited seminar speakers. Seminars are hosted on the first Tuesday of each month at 4:00 pm.

**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.580.742. 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. Class material assumes strong familiarity with the following topics: cell biology, physics with electromagnetics (or electrical circuits), chemistry, differential equations. Computer programming experience is required: all assignments include Matlab programming.

**EN.580.743. Advanced Topics in Genomic Data Analysis. 3 Credits.**

Genomic data is becoming available in large quantities, but understanding how genetics contributes to human disease and other traits remains a major challenge. Machine learning and statistical approaches allow us to automatically analyze and combine genomic data, build predictive models, and identify genetic elements important to disease and cellular processes. This course will cover current uses of statistical methods and machine learning in diverse genomic applications including new genomic technologies. Students will present and discuss current literature. Topics include personal genomics, integrating diverse genomic data types, new technologies such as single cell sequencing and CRISPR, and other topics guided by student interest. The course will include a project component with the opportunity to explore publicly available genomic data. Recommended Course Background: coursework in data science or machine learning.

**EN.580.745. Gero-Engineering: Bioengineering a future for aging and longevity. 3 Credits.**

Applying modern bioengineering approaches to aging research can revolutionize how we think about and study aging. As our worldwide population grows older, staying free of chronic illness and other aging-related diseases has never been more important. Aging is complex and presents significant challenges to healthcare, quality of life, and health equity. However, to make significant strides and optimize human health across the lifespan, we must take unconventional approaches. Bioengineering is poised to have a significant impact on aging and longevity research by developing new concepts, innovative technologies, and AI/ML strategies to improve health and resilience. This course will build on emerging concepts in aging biology, mechano-biology, immuno-engineering, and data science. Specific topics will include: a) developing conceptual frameworks for aging and a bioengineering perspective for why we age differently; b) scales of aging (i.e., groups of genes to groups of people); c) hallmarks and biomarkers of aging; d) senescence; e) mechano-biology of aging; f) cellular reprogramming for engineered resilience; and g) the applications of data science, modeling, and AI/ML strategies to predict aging trajectories, health, and aging interventions. We will also discuss new frontiers of aging and areas that could benefit from emerging bioengineering perspectives that include reproductive longevity, democratizing longevity science: ethical and societal implications of aging and longevity interventions, and perturbation science: cells as sensors of health and disease. The goal is for students to gain a deep understanding of how biomedical engineering can reshape the future of aging and longevity. Students are expected to complete class readings, weekly assignments, class presentations, and group projects. Recommended background: data science principles, cellular and tissue engineering, and fundamentals of biomedical engineering.

Distribution Area: Engineering, Natural Sciences

**EN.580.746. Imaging Science Seminar. 1 Credit.**

Fall semester only. 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.580.747. 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.580.752. Advanced Topics in Regenerative and Immune Engineering. 4 Credits.**

This course is designed as part of the core curriculum for the RIE track for 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 research course provides students with the opportunity to obtain experience in advanced project design and implementation in topics of Translational Cell and Tissue Engineering. This course offers students an opportunity to gain research experience on an independent project and apply their knowledge to a team project with student-defined experimental goals. Students will coordinate their research aims, progress, and outcomes under the guidance of faculty over the course of the semester. This course is appropriate for students who have previously taken the full laboratory course, EN.580.452 or EN.580.754.

**Prerequisite(s):** EN.580.452 OR EN.580.754

**EN.580.754. Cell & Tissue Engineering Lab. 4 Credits.**

This flipped-content laboratory course will consist of modules that provide students with valuable hands-on experience in cell and tissue engineering. Modules contain experiments including the basics of cell culture techniques, gene transfection, metabolic glycoengineering, and cell encapsulation. Students will collect and analyze their own experimental data, write-up results in publication structured reports, and engage in active discussion of current scientific literature. An independent group project based in cellular engineering principles will be designed and presented by the students as a capstone for the course. Students who previously completed 580.452 Cell & Tissue Engineering Lab may NOT register for this class. Textbook Info None. Prerequisites: Students must have completed the online "Introductory Laboratory Safety" and "Bloodborne Pathogens" prior to registering for this class. To access these courses, log in to MyLearning and identify these tutorials.

**EN.580.763. Physics of Medical Imaging. 3 Credits.**

The course provides students with an intermediate understanding of the physics of medical imaging devices. For each modality, we will discuss the physical contrast mechanisms, data acquisition systems, image formation techniques, performance tradeoffs, and state-of-the-art technologies and applications. Lectures and in-class discussions will be complemented by tours of imaging research laboratories and clinical facilities. The technologies that will be discussed in the class include: X-ray Imaging: Generation, interaction, and detection of x-rays, radiation dose. Radiography, mammography, Computer Tomography (CT), and interventional applications of x-ray imaging. Nuclear medicine and molecular imaging: Gamma-ray emission and detection, radiotracer physics, and radiotracer development. Single-Photon Emission Tomography (SPECT), Positron Emission Tomography (PET), and small-animal systems. Biophotonics: Physics and basic properties of light: wave-particle duality, polarization, generation (sources) and detection (detectors). Light propagation properties and image formation: reflection, refraction, rays and waves, diffraction, image formation, and resolution. Light-matter interactions and imaging contrast: including absorption, single and multiple scattering (diffusion), fluorescence. Classic optical imaging modalities: camera, optical microscopy, tomography. Magnetic Resonance Imaging and Spectroscopy: Behavior of atomic nuclei in a magnetic field, generation of resonance signals, relaxation processes, spatial encoding techniques, gradient and radiofrequency (RF) systems, image contrast mechanisms. Advances and diverse applications of MRI in medicine. Proton MR Spectroscopy: Single-voxel and spectroscopic imaging techniques.

**Prerequisite(s):** Students who have taken or are enrolled in EN.580.463 are not eligible to take EN.580.763.

**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 concepts 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 focus on 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 Laboratory Safety Introductory Course in the Search Box to access the proper course. Click here to access the Laboratory Safety Introductory Course (<https://johnshopkins.csod.com/ui/lms-learning-details/app/curriculum/66847e20-c695-4e54-a6be-8c94465b8a70/>)

**EN.580.772. Advanced Projects in Biomedical 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):** EN.580.471 OR EN.580.771

**EN.580.781. Biomedical Engineering Seminar. 1 Credit.**

In this course, scientists from other institutions present cutting edge research that is relevant to biomedical engineering. Each session takes 1 hour for the seminar together with Q&A.

**EN.580.782. Biomedical Engineering Seminar. 1 Credit.**

In this course, scientists from other institutions present cutting edge research that is relevant to biomedical engineering. Each session takes 1 hour for the seminar together with Q&A.

**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. No Audits.

**EN.580.801. Research in Biomedical Engineering. 1 - 10 Credits.**

Graduate Students only

**EN.580.802. Research in Biomedical Engineering. 1 - 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.580.806. CBID Summer Research. 9 Credits.**

Independent project work for second year CBID students only.

**EN.580.810. Biomedical Engineering Teaching Practicum. 1 Credit.**

Graduate biomedical engineering students will assist the core course instructors in developing curriculum, lesson planning, class and homework assignments, assessments, grading policies and overall classroom management in an effort to gain practical training in the student's major area of study. Permission required.

Distribution Area: Engineering, Natural Sciences

**EN.580.812. Biomedical Graduate Research. 9 Credits.**

Student participation in on-going research activities. Research is conducted under the supervision of a BME faculty member.

**EN.580.821. Applied Research and Grant Methodology. 3 Credits.**

The goal of this course is to guide a student through the process of designing a scientific project as well as evaluating others' projects (i.e., providing "peer review"). Course requirements include attending lectures describing successive stage of project design; providing iterative oral and written reports on your own research proposal/project; as well providing feedback on your colleagues' (i.e., your fellow students in the class) projects and proposals. A final research proposal to be presented in the format of a NIH-style grant application will provide evidence that a student is capable of designing an advanced research project by identifying a significant biomedical problem, developing innovative approaches to solve it, and then designing a practical, relevant, and implementable research plan. This course is often taken in conjunction with – and based upon – an independent project being done by the student in a research laboratory but students without a laboratory position are welcome to take this course based on a hypothetical research project of their choosing.

**EN.580.843. Independent Study: Advances in Immunoengineering. 2 Credits.**

This independent study will investigate the diverse and complex fields of engineering and immunology and how it is transforming patient treatment in cancer, autoimmunity, regeneration, and transplantation.