BIOMEDICAL ENGINEERING

http://www.bme.jhu.edu

The faculty and students of the Johns Hopkins Department of Biomedical Engineering, founded more than 50 years ago, are engineering the future of medicine. Consistently ranked the #1 BME program in the nation, we are pushing the boundaries of discovery and innovation, pioneering new and emerging disciplines of biomedical engineering that in turn drive our academic programs.

Biomedical engineering is an interdisciplinary endeavor, and new discoveries and technological advances require a variety of experimental and computational approaches. Our unique positioning within the Johns Hopkins Whiting School of Engineering and the Johns Hopkins School of Medicine provides students and faculty with opportunities to engage with other leading engineers, scientists, and physicians. Together, we are developing the disruptive technologies that will transform the practice of medicine and improve human health. Many of these technologies are currently used in the clinic to diagnose and treat diseases, from cardiac arrhythmias and sepsis to Alzheimer's and cancer. Examples of Hopkins BME advances include new drug delivery methods, diagnostic imaging devices, artificial organs and orthopedic implants, prosthetic devices, and patient-specific quantitative models of disease.

Johns Hopkins BME is training the next generation of leaders in biomedical engineering through academic programs at three levels:

1. an undergraduate program, leading to a B.S. degree
2. three master's programs, leading to an MSE degree in biomedical engineering, with course-based or thesis-based options; an MSE in bioengineering innovation and design; or dual MSE and MS degrees from Johns Hopkins BME and Tsinghua University in Beijing, China, respectively
3. a doctoral program, leading to a Ph.D. degree

At both the undergraduate and graduate levels, we are transforming the BME educational landscape through BME 2.0, an integrative learning experience in which every student is an active participant in our discovery, innovation, and translation efforts. Supported by our personalized advising program, students at all levels will specialize in one of several cutting-edge biomedical engineering focus areas derived from our research expertise. These focus areas include:

- biomedical data science
- computational medicine
- genomics and systems biology
- imaging and medical devices
- immunoengineering
- neuroengineering
- translational cell and tissue engineering

Through project-based courses and hands-on learning experiences, our students will apply their knowledge in these areas to solve real-world clinical, design, and engineering problems. Combined with advanced research and design opportunities, these experiences ensure that our graduates are well prepared for careers in industry, medicine, or research.

Facilities

Situated on both the Homewood and School of Medicine campuses, our research and educational spaces are equipped to support a broad range of interdisciplinary discovery and innovation efforts.

At the School of Medicine campus, faculty members maintain laboratories supplied with a wide variety of equipment in the Traylor, Ross, Rangos, Miller, and Smith research buildings. This location fosters a close association with other basic biomedical science programs and provides access to the clinical environment of one of the nation's top-ranked hospitals.

The Homewood campus is home to Clark Hall, a dedicated BME space that features research laboratories, classrooms, and conference spaces. Clark Hall also houses the BME Design Studio, a premiere workspace where students can design and develop solutions to clinical and global health challenges. To maintain close ties with clinical collaborators, the Design Studio is connected around-the-clock to similar BME student design spaces located on the School of Medicine campus. BME students at all levels, from freshman to graduate students, are able to work in our design spaces and research labs, ensuring that they can begin practicing the discipline on their very first day at Hopkins.

Additional Johns Hopkins BME amenities include physiology teaching laboratories, microscope facilities, a microfabrication laboratory, tissue culture rooms, a fully-staffed mechanical shop, conference and seminar spaces that allow broadcasting throughout the university, and state-of-the-art 3-D printing facilities designed to support a broad range of prototyping needs.

Our faculty and students also have access to ample resources through our affiliations with several of the Johns Hopkins institutes and centers that have emerged from Hopkins BME research activities. Hotbeds for interdisciplinary scientific collaborations, these centers and institutes, all of which are directed or co-directed by Hopkins BME faculty, include the Institute for Computational Medicine, Center for Imaging Science, Carnegie Center for Surgical Innovation, Translational Tissue Engineering Center, Kavli Neuroscience Discovery Institute, Mathematical Institute for Data Science, and Center for Hearing and Balance. Hopkins BME is also home to the Center for Bioengineering Innovation and Design, which oversees our renowned graduate design program. In addition to these affiliated centers and institutes, our faculty have ongoing collaborations with scientists and physicians throughout the various Johns Hopkins divisions, including the Applied Physics Lab, School of Public Health, Krieger School of Arts and Sciences, and Carey Business School.

The profoundly interdivisional nature of Johns Hopkins BME provides students with access to a wide range of university resources, including computing laboratories, libraries, and core facilities for microscopy, flow cytometry, sequencing and genetics, creating CRISPR/Cas9-based transgenic strains, and more. These amenities allow our students to produce the innovative technologies and groundbreaking research discoveries that result in patents, start-up companies, high-impact publications, and a better standard of health care for people across the globe.

Undergraduate Programs

The mission of the undergraduate programs is to provide state-of-the-art biomedical engineering education to students in order that they may continue their education in graduate, medical, and professional schools or pursue careers in industry. To this end, our responsibility is as much to the future as it is to the present. Through a strong research and educational environment, we strive to empower our students to explore and define their own frontiers as well as instill the ethical principles that will foster rewarding professional endeavors. The B.S. in Biomedical Engineering degree program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org under the General Criteria and Program Criteria for Bioengineering and Biomedical and Similarly Named Engineering Programs.

The biomedical engineering program normally leads to the Bachelor of Science degree and requires at least 129 credits. The B.S. program is recommended for students who plan careers in engineering or who plan to attend graduate school in engineering. If a student wishes to take a more flexible program with less emphasis on engineering, a B.A. program is also available. Either the B.S. or the B.A. program can meet the needs of a student who plans graduate study in a nonengineering area.

The undergraduate program provides a strong foundation in mathematics, engineering, and science. It emphasizes preparation for advanced study in an area related to biomedical engineering and is broad enough to accommodate students who plan graduate work in biology, medicine, engineering, biophysics, physiology, or biomedical engineering.

Program Objectives

Our fundamental aim is to instill a passion for learning, scientific discovery, innovation and entrepreneurial spirit, and societal impact in an extraordinary group of students who, because of their experiences in our program, will:

- Continue to utilize and enhance their engineering and biological training to solve problems related to health and healthcare that are globally relevant and based on ethically sound principles,
- Demonstrate leadership in their respective careers in biomedical engineering or interrelated areas of industry, government, academia, and clinical practice, and
- Engage in life-long learning by continuing their education in graduate or professional school or through opportunities for advanced career or professional training.
- Practice and advocate for equitable access to the field and the technology it produces by advancing diversity, inclusivity, and accessibility for all in their profession.

Student Outcomes

Each student plans a curriculum suited to their goals with the assistance of a faculty advisor. Upon completion of the B.S. in biomedical engineering, students will demonstrate:

- an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
- an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
- an ability to communicate effectively with a range of audiences
- an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
- an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
- an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
- an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

The program also encourages individual study and research and gives academic credit for them. Students are welcome to work in laboratories on the Homewood campus or at the Medical Institutions in East Baltimore.

Programs

- Bioengineering Innovation and Design, Master of Science in Engineering (https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/biomedical-engineering/innovation-design-master-science-engineering/)
- Biomedical Engineering, Bachelor of Arts (https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/biomedical-engineering/biomedical-engineering-bachelor-arts/)
- Biomedical Engineering, Bachelor of Science (https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/biomedical-engineering/biomedical-engineering-bachelor-science/)
- Biomedical Engineering, Master of Science in Engineering (https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/biomedical-engineering/biomedical-engineering-master-science-engineering/)
- Biomedical Engineering, PhD through the School of Medicine (https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/biomedical-engineering/biomedical-engineering-phd/)

For current course information and registration go to https://sis.jhu.edu/classes/

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

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.
Course provides a rigorous foundation in cell structures and pathways relevant to medicine and bioengineering. Interactive lectures will cover molecular components (biological membranes, proteins, DNA, RNA, glycoproteins); electro-chemical gradients across membranes; structure and functions of the cell nucleus and genome; secretory and endocytic pathways; biomechanics, contractility and cell motility; cell adhesions, tissues and the extracellular matrix; signaling structures and networks; stem cells, cell division and cell specialization; heredity, mutations and phenotypes. This course will feature bioengineering principles including shape, localization, timing and feedback in biological systems. Students also take the 1-credit Structural Biology of Cells Lab.
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, thestruggle 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 willcontemplate 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. Theseries of guest lectures will be delivered by practitioners and leaders in the movement for racialjustice. 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 awaywith a) a broad understanding of the drivers of structural racism, b) models of advocacy inadvancing policy change, c) individual and institutional core competencies for anti-racistpractices. 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, communityorganizing, and social activism.
Distribution Area: Social and Behavioral Sciences

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.580.237. Neuro Data Design I. 3 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. This version of Neuro Data Design is designed for students with less coding experience who wish to develop their writing skills.
Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.580.238. Neuro Data Design II. 3 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. This version of Neuro Data Design is designed for students with less coding experience who wish to develop their writing skills.
Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.580.241. Statistical Physics. 2 Credits.
Basic principles of statistical physics and thermodynamics of biological systems. Topics included quantitative statistical formulation of entropy and its application in thermodynamic optimizationand conversion principles, the Gibbs/Boltzmann distribution, mixing, and phase transitions.Recommended Background: AS.110.108-109, AS.030.101-102, AS 171.101-102 or equivalent.
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, controlability, and PID controller design. Recommended course background: AS.110.201 Linear Algebra, AS.110.302 Differential Equations, or EN.553.291 Linear Algebra and Differential Equations.
Prerequisite(s): EN.580.243
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 introducted by saturation and cooperativity, information content and combinatorial regulation, and instabilities leading to cell fate specification. Recommended Course Background: Linear Algebra, Systems and Controls and programming.
Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.580.298. Advanded 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 be meet biweekly with course faculty through a Desk Review format. Students are expected to work in teams between desk reviews and present progress updates as well as short- and long-term action plans at each desk review. A final presentation is expected at the end of the semester that will involve course faculty as well as a clinical sponsor (called a committee meeting in Design Teams). Additionally, each team must identify a domain expert from the WSE faculty that agrees to attend the final presentation and at least 2 desk reviews. This faculty will focus on guiding and assessing the team’s technical achievements within the context of biomedical instrumentation.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

EN.580.311. 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.580.402. 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.580.418. 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
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class.
Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

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 458083 in the Search box to locate the appropriate module.
Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.580.425. Radiology for Engineers. 3 Credits.
This course provides engineering students with an introductory understanding of the principles and practice of radiology – including a spectrum of specialties in diagnostic radiology as well as procedures in interventional radiology and digital pathology. The course includes lectures, working with real image data, and visits to clinical areas at Johns Hopkins Hospital. Each segment of the course emphasizes clinical perspective on imaging (including scanner technology and image analysis) in relation to anatomy, physiology, and pathology. Each segment is led by an expert in a particular discipline in collaboration with the course director. Recommended course background: 580.472, 601.455The course is open to senior BME undergraduates. Enrollment is limited by permission from the course director. Audits are not allowed.
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.030.205Meets 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.030.205Recommended EN.580.441/EN.580.641Co-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.580.447. 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 458083 in the Search box to locate the appropriate module.;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 458083 in the Search box to locate the appropriate module.;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 458083 in the Search box to locate the appropriate module.
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 458083 in the Search box to locate the appropriate module.
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.580.457. Introduction to Rehabilitation Engineering: Design Lab. 3 Credits.
Students have the opportunity to apply the knowledge they have gained in the fall semest4er of EN.580.456 and their prior coursework to the development of a new, improved device to be used for measurement or treatment of an impairment or disability. In doing so, they will learn the biomedical engineering design process and its application to persons with disabilities. Working in groups of four to five, teams will work on a project derived from a needs analysis based on their visits to rehabilitation centers in the fall semester. Project will require instructor approval before the beginning of the spring semester. Each project will consist of a proposal for design of a new device or solution to a problem faced by persons with disabilities, preliminary "virtual" (e.g., CAD), and actual proof of concept working prototype.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;EN.580.456
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 458083 in the Search box to locate the appropriate module.
Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

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.580.475. 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.580.479. 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
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 areas of medicine including critical care medicine. The scope of such problems is vast and solutions can improve the delivery of patient care. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 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, students will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. HIPAA regulations 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, validating and deploying their model and an application that delivers the computational method for solving the underlying healthcare problem to the user. The goal is to generate results and one or more manuscripts to be submitted for publication by the end of the second semester.
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 anesthesiology and critical care medicine. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 3-4, and will work with their project mentors (clinical faculty in the ACCM Department; Drs. Winslow and Sarma) to develop a project work plan. In the remainder of the course, they will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will also be charged with designing, validating and deploying a web-application that delivers the computational method for solving the underlying healthcare problem to the user. HIPAA regulations, use of human subjects data, and requirements for FDA Class II and Medical Device Data Systems approval will be covered.
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 for 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 458083 in the Search box to locate the appropriate module.
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.580.493. Imaging Instrumentation. 4 Credits.
This course is intended to introduce students to imaging instrumentation. The class will be lab-oriented, giving hands-on experience with data collection and processing using a configurable optical system. Specific topics will include the programming and control of electromechanical elements, imaging data acquisitions, image formation and processing (e.g. 3D reconstruction), and imaging system analysis and optimization.Recommended Course Background: EN.580.222 Systems and Controls or EN.520.214 Signals and Systems. Programming experience highly desirable.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
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, or permission of the instructor.
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 be meet biweekly with course faculty through a Desk Review format. Students are expected to work in teams between desk reviews and present progress updates as well as short- and long-term action plans at each desk review. A final presentation is expected at the end of the semester that will involve course faculty as well as a clinical sponsor (called a committee meeting in Design Teams). Additionally, each team must identify a domain expert from the WSE faculty that agrees to attend the final presentation and at least 2 desk reviews. This faculty will focus on guiding and assessing the team's technical achievements within the context of biomedical instrumentation.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)

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

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

EN.580.561. Advanced Focus Area Research. 3 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. "Advanced Focus Area Research" is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors.Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through "MyLearning" including Bloodborne Pathogens, HIPAA, and any other online training as needed.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.
Distribution Area: Engineering, Quantitative and Mathematical Sciences
AS Foundational Abilities: Science and Data (FA2)

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

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

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

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

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

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

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

EN.580.610. 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 (Regnerative and Immune Engineering) track of the BME masters program. The course is also appropriate for Cell & Tissue Engineering Ph.D. students and may be taken by advanced undergraduate students upon permission of the instructor. Prerequisites: Graduate standing with background in cell biology and biochemistry or EN.580.221 or AS20.305 and AS.020.306 (or equivalent) and AS.030.205 or permission of the instructor.

EN.580.642. Tissue Engineering. 3 Credits.
This course focuses on the application of engineering fundamentals to designing biological tissue substitutes. Concepts of tissue development, structure and function will be introduced. Students will learn to recognize the majority of histological tissue structures in the body and understand the basic building blocks of the tissue and clinical need for replacement. The engineering components required to develop tissue-engineered grafts will be explored including biomechanics and transport phenomena along with the use of biomaterials and bioreactors to regulate the cellular microenvironment. Emphasis will be placed on different sources of stem cells and their applications to tissue engineering. Clinical and regulatory perspectives will be discussed. Co-listed with EN.580.442.
Recommended Course Background: EN.580.221 or AS.020.305 and AS.020.306, AS.030.205, EN.580.441/EN.580.641
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 lat three decades that focus on stem cell- and cell-free, biomaterial-based approaches to regenerate functional tissues will be presented and analyzed. Practical (regulatory/commercial) considerations that restrict the translation of therapies to the clinic will be discussed. Undergraduate by permission only. Recommend Course Background: EN.580.442 or EN.580.642.

EN.580.644. Biomedical Applications of Glycoengineering. 3 Credits.
This course provides an overview of carbohydrate-based technologies in biotechnology and medicine. The course will begin by briefly covering basics of glycobiology and glycochemistry followed by detailed illustrative examples of biomedical applications of glycoengineering. A sample of these applications include the role of sugars in preventative medicine (e.g., for vaccine development and probiotics), tissue engineering (e.g., exploiting natural and engineered polysaccharides for creating tissue or organs de novo in the laboratory), regenerative medicine (e.g., for the treatment of arthritis or degenerative muscle disease), and therapy (e.g., cancer treatment). A major part of the course grade will be based on class participation with each student expected to provide a “journal club” presentation of a relevant paper as well as participate in a team-based project designed to address a current unmet clinical need that could be fulfilled through a glycoengineering approach. Recommended Course Background: EN.580.221 Molecules and Cells or equivalent (molecular and cell biology), college level calculus and calculus-based general physics.
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.
The primary objective of this course is to introduce biomedical engineering students to the challenges of engineering solutions for persons functioning with disabilities. In order to achieve this goal, other objectives include: gaining a basic appreciation of the modalities used to treat impairments, the opportunities for application of engineering to improve treatment delivery, understanding the science and engineering applied to helping persons with disabilities function in the everyday world and an basic knowledge of the legal, ethical issues and employment opportunities in rehabilitation engineering. By the conclusion of this class, students should be able to: understand the breadth and scope of physical impairment and disability, including its associated pathophysiology; characterize the material and design properties of current evaluation tools for assessment of impairments and adaptations for disability; characterize the material and design properties of current modalities of treatment of impairments and adaptations for disability; apply engineering analysis and design principles to critique current solutions for persons with disabilities in order to suggest improvements.
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), FRAT, FRET and FCS. The recent development in tissue optics, biomedical optical imaging/spectroscopy techniques (such as OCT, multiphoton fluorescence and harmonics microscopy, Structured Illumination, light scattering, diffuse light imaging and spectroscopy, optical molecular imaging, photo-acoustic imaging) will also be discussed. Representative biomedical applications of translational biomedical photonics technologies will be integrated into the corresponding chapters.
Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
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 areas of medicine including critical care medicine. The scope of such problems is vast and solutions can improve the delivery of patient care. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 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, students will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. HIPAA regulations 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, validating and deploying their model and an application that delivers the computational method for solving the underlying healthcare problem to the user. The goal is to generate results and one or more manuscripts to be submitted for publication by the end of the second semester.

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 anesthesiology and critical care medicine. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 3-4, and will work with their project mentors (clinical faculty in the ACCM Department; Drs. Winslow and Sarma) to develop a project work plan. In the remainder of the course, they will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will also be charged with designing, validating and deploying a web-application that delivers the computational method for solving the underlying healthcare problem to the user. HIPAA regulations, use of human subjects data, and requirements for FDA Class II and Medical Device Data Systems approval will be covered.
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 eletromagnetic 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 458083 in the Search box to locate the appropriate module.

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.580.709. Sparse Representations in Computer Vision and Machine Learning. 3 Credits.
Sparse and redundant representations constitutes a fascinating area of research in signal and image processing. This is a relatively young field that has been taking form for the last 15 years or so, with contributions from harmonic analysis, numerical algorithms and machine learning, and has been vastly applied to myriad of problems in computer vision and other domains. This course will focus on sparsity as a model for general data, generalizing many different other constructions or priors. This idea - that signals can be represented with just "a few" coefficients - leads to a long series of beautiful (and surprisingly, solvable) theoretical and numerical problems, and many applications that can benefit directly from the new developed theory. In this course we will survey this field, starting with the theoretical foundations, and systematically covering the knowledge that has been gathered in the past years. This course will touch on theory, numerical algorithms, and applications in image processing and machine learning. Recommended course background: Linear Algebra, Signals and Systems, Numerical Analysis.

EN.580.710. 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.580.720. 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.580.725. Radiology for Engineers. 3 Credits.
This course provides engineering students with an introductory understanding of the principles and practice of radiology – including a spectrum of specialties in diagnostic radiology as well as procedures in interventional radiology and digital pathology. The course includes lectures, working with real image data, and visits to clinical areas at Johns Hopkins Hospital. Each segment of the course emphasizes clinical perspective on imaging (including scanner technology and image analysis) in relation to anatomy, physiology, and pathology. Each segment is led by an expert in a particular discipline in collaboration with the course director. Recommended course background: 580.472, 601.455Restricted to BME MSE and BME PhD students only. Others by instructor permission. Audits are not allowed.
Distribution Area: Engineering, Natural Sciences

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.580.746. 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 fo the BME masters program. Topics will be selected based on current methods, basic research, and clinical translation of regenerative medicine and immune engineering technologies. Background Knowledge: EN.580.641, EN.580.642, and EN.580.751 or graduate standing and permission of the instructor.

EN.580.753. Cell and Tissue Engineering Lab Advanced Project. 1 Credit.
This one credit laboratory course provides students with the opportunity to obtain experience in advanced project design and implementation in conjunction with the graduate-level Cell & Tissue Laboratory course (EN.580.754). It is appropriate for students who have previously taken the undergraduate version of this course to fulfill the core curriculum requirement of the RIE (Regenerative and Immune Engineering) track of the BME master's program. Graduate students may also take this course will permission of the instructor to pursue additional 'advanced topics' laboratory modules. The work will be completed over the course of the semester in conjunction with the "advanced topics" component of the regular graduate level version of the lab course.

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

EN.580.772. 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.580.805. BME MSE Independent Study. 1 Credit.
Independent Study

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.
Prerequisite(s): EN.500.601

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.

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

Cross-Listed Courses

Applied Mathematics & Statistics

EN.553.450. Computational Molecular Medicine. 4 Credits.
Computational systems biology has emerged as the dominant framework for analyzing high-dimensional “omics” data in order to uncover the relationships among molecules, networks and disease. In particular, many of the core methodologies are based on statistical modeling, including machine learning, stochastic processes and statistical inference. We will cover the key aspects of this methodology, including measuring associations, testing multiple hypotheses, and learning predictors, Markov chains and graphical models. In addition, by studying recent important articles in cancer systems biology, we will illustrate how this approach enhances our ability to annotate genomes, discover molecular disease networks, detect disease, predict clinical outcomes, and characterize disease progression. Whereas a good foundation in probability and statistics is necessary, no prior exposure to molecular biology is required (although helpful).
Prerequisite(s): Students may receive credit for EN.553.450 or EN.553.650, but not both.;(EN.553.420 OR EN.553.421 OR EN.553.620) AND (EN.553.430 OR EN.553.431 OR EN.553.630) OR equivalent courses in probability and statistics.
Distribution Area: Engineering, Quantitative and Mathematical Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.553.650. Computational Molecular Medicine. 4 Credits.
Computational systems biology has emerged as the dominant framework for analyzing high-dimensional “omics” data in order to uncover the relationships among molecules, networks and disease. In particular, many of the core methodologies are based on statistical modeling, including machine learning, stochastic processes and statistical inference. We will cover the key aspects of this methodology, including measuring associations, testing multiple hypotheses, and learning predictors, Markov chains and graphical models. In addition, by studying recent important articles in cancer systems biology, we will illustrate how this approach enhances our ability to annotate genomes, discover molecular disease networks, detect disease, predict clinical outcomes, and characterize disease progression. Whereas a good foundation in probability and statistics is necessary, no prior exposure to molecular biology is required (although helpful). Recommended Course Background: EN.553.620 AND EN.553.630.
Prerequisite(s): Students may receive credit for EN.550.450/EN.553.450 or EN.553.650, but not both.
Distribution Area: Engineering, Quantitative and Mathematical Sciences

Computer Science

EN.601.350. Genomic Data Science. 3 Credits.
This course will use a project-based approach to introduce undergraduates to research in computational biology and genomics. During the semester, students will take a series of large data sets, all derived from recent research, and learn all the computational steps required to convert raw data into a polished analysis. Data challenges might include the DNA sequences from a bacterial genome project, the RNA sequences from an experiment to measure gene expression, the DNA from a human microbiome sequencing experiment, and others. Topics may vary from year to year. In addition to computational data analysis, students will learn to do critical reading of the scientific iterature by reading high-profile research papers that generated groundbreaking or controversial results. Recommended Course Background: Knowledge of the Unix operating system and programming expertise in a language such as Perl or Python.
Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)

EN.601.461. Computer Vision. 3 Credits.
This course provides an overview of fundamental methods in computer vision from a computational perspective. Methods studied include: camera systems and their modelling, computation of 3-D geometry from binocular stereo, motion, and photometric stereo, and objectrecognition, image segmentation, and activity analysis. Elements of machine vision and biological vision are also included.
Prerequisite(s): Students may receive credit for only one of EN.600.361, EN.600.461, EN.600.661, EN.601.461, EN.601.661.;(EN.553.310 OR EN.553.311 OR ((EN.553.420 OR EN.553.421) AND (EN.553.430 OR EN.553.431)) AND (AS.110.201 OR AS.110.212 OR EN.553.291 OR EN.553.295)) AND (EN.500.112 OR EN.500.113 OR EN.500.114 OR EN.601.220 AS.250.205)
Distribution Area: Engineering, Quantitative and Mathematical Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.601.476. Machine Learning: Data to Models. 3 Credits.
How can robots localize themselves in an environment when navigating? Which factors predict whether patients are at greatest-risk for complications in the hospital? Can we reconstruct the brain’s "connectome" from fMRI data? Many such big data questions can be answered using the paradigm of probabilistic models in machine learning. This is the second course on machine learning which focuses on probabilistic graphical models. You will learn about directed and undirected graphical models, inference methods, sampling, structure learning algorithms, latent variables, and temporal models. There will be regular assignments, which include theory and some programming. Students will analyze real data for their final project, applying methods discussed in class and writing up a report of their results. Students may receive credit for EN.600.476 or EN.600.676, but not both.
Prerequisite(s): EN.600.475/EN.601.475 OR EN.600.675/EN.601.675 or equivalent.;Students may receive credit for only one of EN.600.476, EN.601.476, EN.601.676.
Distribution Area: Engineering, Quantitative and Mathematical Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.601.676. Machine Learning: Data to Models. 3 Credits.
Same material as EN.601.476, for graduate students. How can robots localize themselves in an environment when navigating? Which factors predict whether patients are at greatest-risk for complications in the hospital? Can we reconstruct the brain’s "connectome" from fMRI data? Many such big data questions can be answered using the paradigm of probabilistic models in machine learning. This is the second course on machine learning which focuses on probabilistic graphical models. You will learn about directed and undirected graphical models, inference methods, sampling, structure learning algorithms, latent variables, and temporal models. There will be regular assignments, which include theory and some programming. Students will analyze real data for their final project, applying methods discussed in class and writing up a report of their results. Recommended Background: EN.600.475 or EN.601.675 or equivalent. Students may receive credit for EN.600.476 or EN.600.676, but not both.
Prerequisite(s): Students may receive credit for only one of EN.600.476, EN.601.476, EN.601.676.
Distribution Area: Engineering, Quantitative and Mathematical Sciences

Electrical & Computer Engineering

EN.520.315. Intro. to Bio-Inspired Processing of Audio-Visual Signals. 3 Credits.
An introductory course to basic concepts of information processing of human communication signals (sounds, images) in living organisms and by machine. Recommended Course Background: EN.520.214 (or EN.580.222) or consent of the instructor.
Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)

EN.520.418. Modern Convex Optimization. 3 Credits.
Convex optimization is at the heart of many disciplines such as machine learning, signal processing, control, medical imaging, etc. In this course, we will cover theory and algorithms for convex optimization. The theory part includes convex analysis, convex optimization problems (LPs, QPs, SOCPS, SDPs, Conic Programs), and Duality Theory. We will then explore a diverse array of algorithms to solve convex optimization problems in a variety of applications, such as gradient methods, sub-gradient methods, accelerated methods, proximal algorithms, Newton's method, and ADMM. A solid knowledge of Linear Algebra is needed for this course.
Prerequisite(s): (AS.110.201 OR AS.110.212 OR EN.553.291) AND (EN.500.113 OR EN.500.133 OR EN.540.382)
Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)

EN.520.445. Audio Signal Processing. 3 Credits.
This course gives a foundation in current audio and speech technologies, and covers techniques for sound processing by processing and pattern recognition, acoustics, auditory perception, speech production and synthesis, speech estimation. The course will explore applications of speech and audio processing in human computer interfaces such as speech recognition, speaker identification, coding schemes (e.g. MP3), music analysis, noise reduction. Students should have knowledge of Fourier analysis and signal processing.It is recommended that students take EN.520.344 Digital Signal Processing prior to taking this class.
Prerequisite(s): EN.520.344
Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)

EN.520.618. Modern Convex Optimization. 3 Credits.
Convex optimization is at the heart of many disciplines such as machine learning, signal processing, control, medical imaging, etc. In this course, we will cover theory and algorithms for convex optimization. The theory part includes convex analysis, convex optimization problems (LPs, QPs, SOCPS, SDPs, Conic Programs), and Duality Theory. We will then explore a diverse array of algorithms to solve convex optimization problems in a variety of applications, such as gradient methods, sub-gradient methods, accelerated methods, proximal algorithms, Newton's method, and ADMM. A solid knowledge of Linear Algebra is needed for this course.
Distribution Area: Engineering

EN.520.622. Principles of Complex Networked Systems. 3 Credits.
By employing fundamental concepts from diverse areas of research, such as statistics, signal processing, biophysics, biochemistry, cell biology, and epidemiology, this course introduces a multidisciplinary and rigorous approach to the modeling and computational analysis of complex interaction networks. Topics to be covered include: overview of complex nonlinear interaction networks and their applications, graph-theoretic representations of network topology and stoichiometry, stochastic modeling of dynamic processes on complex networks and master equations, Langevin, Poisson, Fokker-Plank, and moment closure approximations, exact and approximate Monte Carlo simulation techniques, time-scale separation approaches, deterministic and stochastic sensitivity analysis techniques, network thermodynamics, and reverse engineering approaches for inferring network models from data.

EN.520.665. Machine Perception. 3 Credits.
This course will cover topics such as Marr-Hildreth and Canny edge detectors, local representations (SIFT, LBP), Markov random fields and Gibbs representations, normalized cuts, shallow and deep neural networks for image and video analytics, shape from shading, Make 3D, stereo, and structure from motion.
Distribution Area: Engineering

General Engineering

EN.500.112. Gateway Computing: JAVA. 3 Credits.
This course introduces fundamental programming concepts and techniques, and is intended for all who plan to develop computational artifacts or intelligently deploy computational tools in their studies and careers. Topics covered include the design and implementation of algorithms using variables, control structures, arrays, functions, files, testing, debugging, and structured program design. Elements of object-oriented programming. algorithmic efficiency and data visualization are also introduced. Students deploy programming to develop working solutions that address problems in engineering, science and other areas of contemporary interest that vary from section to section. Course homework involves significant programming. Attendance and participation in class sessions are expected.
Prerequisite(s): Students may only receive credit for one of the following courses: EN.500.112 OR EN.500.113 OR EN.500.114 OR EN.500.132 OR EN.500.133 OR EN.500.134
Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)

EN.500.113. Gateway Computing: Python. 3 Credits.
This course introduces fundamental programming concepts and techniques, and is intended for all who plan to develop computational artifacts or intelligently deploy computational tools in their studies and careers. Topics covered include the design and implementation of algorithms using variables, control structures, arrays, functions, files, testing, debugging, and structured program design. Elements of object-oriented programming. algorithmic efficiency and data visualization are also introduced. Students deploy programming to develop working solutions that address problems in engineering, science and other areas of contemporary interest that vary from section to section. Course homework involves significant programming. Attendance and participation in class sessions are expected.
Prerequisite(s): Students may only receive credit for one of the following courses: EN.500.112 OR EN.500.113 OR EN.500.114 OR EN.500.132 OR EN.500.133 OR EN.500.134
Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)

EN.500.114. Gateway Computing: Matlab. 3 Credits.
This course introduces fundamental programming concepts and techniques, and is intended for all who plan to develop computational artifacts or intelligently deploy computational tools in their studies and careers. Topics covered include the design and implementation of algorithms using variables, control structures, arrays, functions, files, testing, debugging, and structured program design. Elements of object-oriented programming. algorithmic efficiency and data visualization are also introduced. Students deploy programming to develop working solutions that address problems in engineering, science and other areas of contemporary interest that vary from section to section. Course homework involves significant programming. Attendance and participation in class sessions are expected.
Prerequisite(s): Students may only receive credit for one of the following courses: EN.500.112 OR EN.500.113 OR EN.500.114 OR EN.500.132 OR EN.500.133 OR EN.500.134
Distribution Area: Engineering

Mechanical Engineering

EN.530.410. Biomechanics of the Cell. 3 Credits.
Mechanical aspects of the cell are introduced using the concepts in continuum mechanics. Discussion of the role of proteins, membranes and cytoskeleton in cellular function and how to describe them using simple mathematical models.
Distribution Area: Engineering, Natural Sciences

EN.530.448. Biosolid Mechanics. 3 Credits.
This class will introduce fundamental concepts of statics and solid mechanics and apply them to study the mechanical behavior bones, blood vessels, and connective tissues such as tendon and skin. Topics to be covered include the structure and mechanical properties of tissues, such as bone, tendon, cartilage and cell cytoskeleton; concepts of small and large deformation; stress; constitutive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity; and experimental methods for measuring mechanical properties, Recommended Course Background: AS.110.201 and AS.110.302, as well as a class in statics and mechanics.
Distribution Area: Engineering

EN.530.616. Introduction to Linear Systems Theory. 3 Credits.
A beginning graduate course in multi-input multi-output, linear, time-invariant systems. Topics include state-space and input-output representations; solutions and their properties; multivariable poles and zeros; reachability, observability and minimal realizations; stability; system norms and their computation; linearization techniques. Students cannot take EN.530.616 if they have already taken the equivalent course EN.520.601. No audit option, but contact the instructor if you want to informally sit in on the course.Recommended course background are undergraduate courses in linear algebra, differential equations, and an undergraduate level course in control systems. Students cannot take EN.530.616 if they have already taken EN.520.601.
Prerequisite(s): Recommended course background are undergraduate courses in linear algebra, differential equations, and an undergraduate level course in control systems. Students cannot take EN.530.616 if they have already taken EN.520.601

Robotics

EN.620.745. Seminar in Computational Sensing and Robotics. 1 Credit.
Seminar series in robotics. Topics include: Medical robotics, including computer-integrated surgical systems and image-guided intervention. Sensor based robotics, including computer vision and biomedical image analysis. Algorithmic robotics, robot control and machine learning. Autonomous robotics for monitoring, exploration and manipulation with applications in home, environmental (land, sea, space), and defense areas. Biorobotics and neuromechanics, including devices, algorithms and approaches to robotics inspired by principles in biomechanics and neuroscience. Human-machine systems, including haptic and visual feedback, human perception, cognition and decision making, and human-machine collaborative systems.Cross-listed Mechanical Engineering, Computer Science, Electrical and Computer Engineering, and Biomedical Engineering.

For current faculty and contact information go to http://www.bme.jhu.edu/people/completefacultylist.php