EN.585 (APPLIED BIOMEDICAL ENGINEERING)

Courses

EN.585.601. Physiology for Applied Biomedical Engineering I. 3 Credits.

This course is the first semester of a two-semester sequence designed to provide the physiological background necessary for advanced work in biomedical engineering. A quantitative, model-oriented approach to physiology systems is stressed. using video lectures, virtual reality, readings, computer simulations, and literature-based research, students will learn about basic cell structure and function membrane transport mechanisms, electrical properties of excitable tissue, muscular tissue (skeletal, smooth, and cardiac), the cardiovascular system, and the respiratory system.

EN.585.602. Physiology for Applied Biomedical Engineering II. 3 Credits.

This two-semester sequence is designed to provide the physiological background necessary for advanced work in biomedical engineering. A quantitative model-oriented approach to physiological systems is stressed. First-term topics include the cell and its chemistry, transport and the cell membrane, properties of excitable tissue and muscle, the cardiovascular system, and the respiratory system. The second term course covers anatomy of the nervous system, structure and functions of the auditory and visual systems, motor systems, the kidney and gastrointestinal tract, and the neural and neuroendocrine control of the circulation.

EN.585.607. Molecular Biology. 3 Credits.

The course is intended to serve as a fundamental introduction to cell and molecular biology. Topics generally included are basic chemistry and biochemistry of the cell; structure, function, and dynamics of macromolecules; cell organization; enzyme kinetics; membranes and membrane transport; biochemistry of cellular energy cycles, including oxidative phosphorylation; replication, transcription, and translation; regulation of gene expression; and recombinant DNA technology. Where appropriate, biomedical application and devices based on principles from cell and molecular biology are emphasized.

EN.585.612. Biomechanical Engineering in Sports. 3 Credits.

This course explores strategies and technologies used in the biomechanical analysis of individuals and teams in sports in order to minimize the risk of injury and improve performance. This course focuses on the intersection of anatomy, physiology, kinesiology, and mechanical engineering in order to discover, model, characterize and optimize sports performance and injury determinants. Sports applications will be studied, evaluating specific movements, injuries, technologies, techniques and strategies that are used in the associated professional fields. Topics covered will include the forces in equilibrium, forces causing motion, deformable mechanics as well as the biomechanics of running, the biomechanics of baseball, the biomechanics of golf, contact sports injury biomechanics, human performance monitoring and data analysis for player performance, and technologies and techniques in sports biomechanics. Students will be asked to survey and critique sports biomechanics research literature, characterize and model sports movements through sensors and data analysis, design clinical programs to train and evaluate sport-specific movements, solve simple biomechanics problems, and implement data analysis principles on sports performance datasets.Prerequisites: A background in physics, biomechanics, or mechanical engineering is required. Introduction to biomechanics (585.631) is recommended. A physiology course is also recommended. Experience in programing (e.g., working in MATLAB/Python) is recommended.

EN.585.613. Medical Sensors & Devices. 3 Credits.

This course covers the basic and advanced principles, concepts, and operations of medical sensors and devices. The origin and nature of measurable physiological signals are studied, including chemical, electrochemical, optical, and electromagnetic signals. The principles and devices to make the measurements, including a variety of electrodes and sensors, will be discussed first. This will be followed by a rigorous presentation of the design of appropriate electronic instrumentation. Therapeutic instrumentation such as pacemakers, defibrillators, and prosthetic devices will be reviewed. The final part of this course will cover emerging frontiers of cellular and molecular instrumentation and the use of micro- and nanotechnology in these biotechnology fields. The lectures will be followed by realistic experimentation in two laboratory sessions where students will obtain hands-on experience with electronic components, sensors, biopotential measurements, and testing of therapeutic instrumentation.

EN.585.615. Mathematical Methods. 3 Credits.

The course covers mathematical techniques needed to solve advanced problems encountered in applied biomedical engineering. Fundamental concepts are presented with emphasis placed on applications of these techniques to biomedical engineering problems. Topics include solution of ordinary differential equations using the Laplace transformation, Fourier series and integrals, solution of partial differential equations including the use of Bessel functions and Legendre polynomials and an introduction to complex analysis. Prerequisite(s): Familiarity with multi-variable calculus, linear algebra, and ordinary differential equations.

EN.585.616. Principles of Medical Instrumentation and Devices. 3 Credits.

Biomedical sensors and devices are an integral part of modern medicine and they are becoming increasingly important with the growing need for objectivity and accessibility in diagnostics and therapeutics. The science and technology that goes into the plethora of sensors, although highly interdisciplinary, mainly derives from basic principles in physics and electrical engineering. This course will (re)introduce these principles and illustrate the application of these principles in a number of classes of medical sensors. It will also review some of the basic ideas and constraints that go into making of a medical device and finally touch upon a few nontechnical principles in applications of medical devices. Course Note(s): Desirable background knowledge includes introductory level electrical engineering, circuit design, college level differential and integral calculus, and introductory human physiology.

EN.585.617. Rehabilitation Engineering. 3 Credits.

This course is an introduction to a field of engineering dedicated to improving the lives of people with disabilities. Rehabilitation engineering is the application of engineering analysis and design expertise to overcome disabilities and improve quality of life. A range of disabilities and assistive technologies will be investigated. The relationship between engineering innovation, the engineering design process, the human-technology interface, and the physical medicine and rehabilitation medical community will be explored. This course will require a semester long design project that addresses an unmet technological need. Students will choose a project with the instructor's approval. An engineering solution will be developed over the course of the semester through specification development, design reviews, and interacting with appropriate members of the medical community. There is a required visit to a local rehabilitation facility. For students who complete a software training module, access to a 3D printer will be available with assistance from an experienced designer. Prerequisite(s): An undergraduate engineering degree or permission of the instructor.

EN.585.619. Regulation of Medical Devices. 3 Credits.

Biomedical engineers are uniquely involved in many aspects of product development, from the inception of the idea to its delivery in the marketplace. This course will cover one major aspect of that process—the objectives and mechanisms of the FDA regulatory system governing the clinical use of medical devices in the United States, including regulatory pathways and device classification. Students will both analyze and discuss management of risk, and they will design controls related to cardiovascular, orthopedic, and neurological devices. By the end of the course, students will have a deep understanding of how the regulatory process is involved in every phase of medical device development.

EN.585.621. Advances in Pulmonary Therapeutics. 3 Credits.

Pulmonary diseases like chronic obstructive pulmonary disease cause a significant burden on the healthcare systems all over the world. For a biomedical engineer, it is therefore important to learn about state-of-the-art diagnostic and therapeutic technologies in pulmonary medicine. This online course introduces pathologies of the pulmonary system along with related preclinical and clinical research methodologies. Modules are designed to cover integration of respiratory physiology with molecular biology, biophysics, pathophysiology, medicine, and biomedical engineering. A combination of video lectures, virtual workshops, literature reviews, student presentations, and problem sets will be used in order to foster critical thinking skills required to address current challenges in respiratory medicine.

EN.585.631. Introduction to Biomechanics. 3 Credits.

This course will explore the human body, modeled as a mechanical system, and fundamental mechanical engineering principles that can be applied to answer questions about its structure and function. In this course, students will be introduced to tools, methods and models used in the biomechanics field. Topics covered will include deformable solid mechanics of the bone and soft tissues, fluid mechanics, statics and dynamics in musculoskeletal biomechanics applications, experimental biomechanics models, computational biomechanics models, and biomechanical sensors and signals. Students will be asked to survey and critique biomechanics research literature, solve simple biomechanics problems, and identify classical biomechanics fields and emerging biomechanics frontiers.Prerequisites:A background in physics or mechanical engineering as well as experience working in MATLAB is encouraged.

EN.585.635. Ethics in Biomedical Engineering Research and Management. 3 Credits.

Bioengineering focuses on the development and application of new technologies in biology and medicine. These technologies often have powerful effects on living systems at the microscopic and macroscopic level. They can provide great benefit to society, but they also can be used in dangerous or damaging ways. These effects may be positive or negative, and so it is critical that bioengineers understand the basic principles of ethics when thinking about how the technologies they develop can and should be applied. On a personal level, every bioengineer should understand the basic principles of ethical behavior in the professional setting. The goal of this semester course is to present the issues of professional conduct in the practice of engineering, research, publication, public and private disclosures, and in managing professional and financial conflicts. The course seeks to teach these concepts through didactic presentations, case studies, presentations of methods for problem solving in ethical matters, and classroom debates on contemporary ethical issues. Investigation of cases includes documentation of students' initial thoughts on issues, then systematic reflection on these thoughts through introduction of multiple perspectives, thought papers and in-class discussions. Case studies cover a wide variety of application areas, including genetic engineering, xenotransplantation, using animals in research, rights of patients and research subjects, and BME technology development.

EN.585.649. Artificial Intelligence and Machine Learning for Global Health. 3 Credits.

EN.585.661. Medical Device Marketing and Market Position Establishment. 3 Credits.
Prerequisite(s): (EN.585.405[C] AND EN.585.406[C] AND EN.585.425[C]) AND (EN.585.629[C] OR EN.585.641[C])

EN.585.682. Neuropharmacology. 3 Credits.

EN.585.685. Methods in Neurobiology. 3 Credits.

Neurobiology is the study of cells of the nervous system and the organization of these cells into functional circuits that process information and mediate behavior. In this course we will explore molecular and cellular aspects of neuronal physiology, their organization into higher systems and approach methodologies used to analyze CNS function at different levels. Such techniques will include recent progress in whole brain imaging, advances in fluorescence microscopy and optogenetics, the basics of single-cell sequencing and the use of cellular, organoids or animal models in neuroscience. We will also discuss deviations from neuronal physiology such as during aging or after onset of CNS related pathologies, including neurodegenerative diseases and approaches to cell reprogramming and regeneration in order to recover cellular function.At the end of this course, students will have a broader understanding on techniques used to study neuronal function at a molecular, cellular and systemic level and will have the basics insights to infer which tools are more appropriate depending on the application.

Prerequisite(s): EN.585.601 OR EN.585.602 Physiology for Applied Biomedical Engineering I or II

EN.585.702. Medical Device Innovation and Design. 3 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.585.703. Applied Medical Image Processing. 3 Credits.

Developments in medical image acquisition systems such as magnetic resonance imaging (MRI), computed tomography (CT), and ultrasound have resulted in a large number of clinical images with rich information regarding structure and function of different organs in the human body. A challenging task would be to extract clinically relevant information from the raw images that can be used to identify disease at an early stage or to monitor response to treatment. This course briefly introduces the underlying physical foundation of different image modalities followed by presentation of concepts and techniques that are used to process and extract information from medical images. Topics that are covered include medical image formats, enhancement, segmentation, registration, and visualization. MATLAB scripting language will be introduced and used to implement basic algorithms.

Prerequisite(s): EN.585.615 Mathematical Methods for Applied Biomedical Engineering or EN.535.641 Mathematical Methods for Engineers is required, or written permission from the instructor. EN.585.704 Principles of Medical Imaging is recommended. Preliminary knowledge of probability, linear algebra, and human anatomy is strongly recommended.

EN.585.704. Principles of Medical Imaging. 3 Credits.

The objective of this online course is to critically compare different modalities of medical imaging by exploring the electromagnetic spectrum and the acoustic spectrum. By the end of this course, students will be able to demonstrate understanding of each modality's strengths, limitations, and applications. For each modality, we will examine the mathematical and physical foundations of the corresponding spectrum, image formation, image interpretation, image quality, and image processing. We will also evaluate and summarize current and future research trends in medical imaging.

Prerequisite(s): EN.585.615 Mathematical Methods for Applied Biomedical Engineering or EN.535.641 Mathematical Methods for Engineers, or permission from the instructor. An introductory background in physics (electromagnetism) is recommended.

EN.585.708. Biomaterials. 3 Credits.

This course covers the fundamentals of the synthesis, properties, and biocompatibility of metallic, ceramic, polymeric, and biological materials that come in contact with tissue and biological fluids. Emphasis is placed on using biomaterials for both hard and soft tissue replacement, organ replacement, coatings and adhesives, dental implants, and drug delivery systems. New trends in biomaterials, such as electrically conductive polymers, piezoelectric biomaterials, and sol-gel processing are discussed, and the recent merging of cell biology and biochemistry with materials is examined. Case studies and in-class scenarios are frequently used to highlight the current opportunities and challenges of using biomaterials in medicine.

EN.585.709. Biomechanics of Cells and Stem Cells. 3 Credits.

The class starts with introductory lectures on the place of cell mechanics in the broader areas of cell biology, physiology, and biophysics, where the general topics of cell structure, motility, force generation, and interaction with the extracellular matrix are considered. The importance of the cell mechanical properties as indicators of the cell performance under normal and pathological conditions is emphasized. Major experimental techniques, such as micropipette aspiration, atomic force microscopy, and magnetic cytometry, to probe cell mechanical properties are presented. Linear elastic and viscoelastic models are introduced and applied to the interpretation of the mechanical experiments with endothelial cells and fibroblasts. Then the class discusses cell adhesion, spreading, and motility focusing on the experiments and models to estimate traction forces (stresses) produced by the cell. Finally, the effects of various mechanical factors (applied strains or forces, stiffness and viscoelastic properties, surface topography) on stem cell lineage commitment are discussed. Students also read and make presentations on original journal papers covering additional topics, which exposes them to the professional literature and hones their communication skills.

EN.585.710. Biochemical Sensors. 3 Credits.

This course covers the fundamental principles and practical aspects of chemical sensing of physiological signals. The focus of the course is on the electrochemistry and biophysical chemistry of biological sensing elements and their integration with signal transducers. Other topics covered include design and construction of practical sensors, processing and interpretation of signal outputs, and emerging technologies for biosensing.

EN.585.717. Rehabilitation Engineering II. 3 Credits.

This 2-course sequence is an introduction to a field of engineering dedicated to improving the lives of people with disabilities. Rehabilitation engineering is the application of engineering analysis and design expertise to overcome disabilities and improve quality of life. A range of disabilities and assistive technologies will be discussed and investigated. The relationship between engineering innovation, the engineering design process, the human-technology interface, and the physical medicine and rehabilitation medical community will be explored. This course sequence will require a 2-semester long design project that addresses an unmet technological need. Students will choose a project with the instructors' approvals. An engineering solution will be developed over the two courses through specification development, design reviews, and interacting with appropriate members of the medical community. Either live or virtual interaction with a rehab clinic is required. Access to a 3D printer will be available with assistance from an experienced designer.

EN.585.718. Biological Solid & Fluid Mechanics. 3 Credits.

The nonlinear mechanics of the arterial walls is analyzed as an important example of biological solid mechanics. After the introduction of the necessary background on matrices and tensors, the stresses and strains in the arterial wall are defined. Then, the fundamental concept of the strain energy function and its particular forms used in the vascular mechanics are introduced. The experiments (biaxial stretch and inflation-extension) aimed at the estimation of the wall material properties are discussed. In addition to the properties of the normal arterial wall, the mechanics in vascular diseases are studied. First, the stresses and stiffness in atherosclerotic arteries are analyzed, and then the effects of hypertension are discussed. In the second part of the class, the fluid mechanics of blood is studied, including the velocity profiles and shear stress distribution. The non-Newtonian features of blood rheology are presented as well. In the last part of the class, the cells in the blood circulation are considered with the main focus on the red blood cells. The micropipette experiment to estimate the elastic moduli of the red blood cell wall is studied in detail. The recent studies of the red blood cell circulation under pathological conditions (cancer, malaria) are discussed also. In all sections, the latest results of the computational modeling are used to support the main goals of the course. In addition to the regular (weekly) assignments, the students will be given original journal papers to discuss as a group. Finally, the students will be working on a computational project related to one of the major topics of the course.

EN.585.719. Sparse Representations in Computer Vision and Machine Learning. 3 Credits.

Sparse and redundant representations constitute 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.

Prerequisite(s): Mathematical Methods or equivalent

EN.585.720. Orthopedic Biomechanics. 3 Credits.

This course serves as an introduction to the field of orthopedic biomechanics for the biomedical engineer. Structure and function of the musculoskeletal system in the intact and pathologic states will be reviewed. Further discussion will focus on the design of orthopedic implants for the spine and the appendicular skeleton. Biomechanical principles of fracture repair and joint reconstruction will also be addressed. Peerreviewed journal publications will be used to explore the latest developments in this field.

Prerequisite(s): EN.585.601 or EN.585.602 Physiology for Applied Biomedical Engineering I or II (or equivalent).

EN.585.723. Functional Neuroimaging and Neural Sensors. 3 Credits.

Through lectures, small group activities, and independent research, this course illustrates the fundamental technologies used for neuroimaging and sensing neural systems across a range of domains including clinical and consumer devices. Topics include neurophysiological basis for neural sensing; electrical, hemodynamic, and optical property-based functional neuroimaging; invasive and noninvasive neural sensing; neural sensing for clinical applications and consumer devices; and an overview of the regulatory landscape for neural sensing systems. By the end of this course, students will be able to explain strengths, limitations, and potential future trajectories of a range of neuroimaging and neural sensing technologies. Small group work will focus on current and future research trends in functional neuroimaging.

EN.585.724. Neural Prosthetics: Science, Technology, and Applications. 3 Credits.

This course covers the physiological bases, applications, and ethical considerations of emerging neuroprosthetic devices, covering a wide range of neural interfaces. Examples include cochlear implants, retinal implants for vision restoration, and brain-computer interfaces for delivering haptic feedback. Homework assignments will involve processing neural recordings, neural stimulation modeling, collecting and analyzing your own psychophysical data, and writing reviews of recent research publications. Working knowledge of MATLAB or a similar programming language is strongly recommended.

EN.585.725. Biomedical Engineering Practice and Innovation. 3 Credits.

This course will cover hands-on experimental and design work primarily in the areas of physiology, cell and tissue engineering, and biomedical instrumentation. In addition to teaching and allowing students to perform state-of-the art experimental techniques, this course will emphasize the business end of biomedical engineering innovation including identification of engineered needs and FDA regulation.

Prerequisite(s): EN.585.601 Physiology for Applied Biomedical Engineering I OR EN.585.602 Physiology for Applied Biomedical Engineering II AND EN.585.615 Mathematical Methods

EN.585.726. Biomimetics in Biomedical Engineering. 3 Credits.

Biomimetics refers to human-made processes, substances, devices, or systems that imitate nature. This course focuses on substances prepared and engineered to meet biomedical uses. It is designed to provide students with: (1) an understanding of the biomimetic process of self-assembly, (2) an introduction to bioengineering biological materials and novel biomimetic materials that include forms and structures useful to bioprocesses, and (3) an understanding of how different instruments may be used for imaging, identification, and characterization of biological and biomimetic materials. Detailed knowledge of biological structure hierarchy is essential for most areas of biomedical engineering, and biological materials are becoming an increasingly important resource in creating new biomimetic materials that possess targeted biological structural and functional properties.

EN.585.729. Cell and Tissue Engineering. 3 Credits.

Cell and tissue engineering are dynamic and rapidly growing fields within biomedical engineering. This course will examine fundamental biological processes and medical engineering tools essential to regenerative medicine both at the singlecell and the whole-organism levels. Topics include stem cell engineering, cell−matrix and cell−scaffold interactions, cell−cell interactions and tissue morphogenesis, wound healing, and in vitro organogenesis. Prerequisite(s): Knowledge of basic molecular and cellular biology, physiology, and math through ordinary differential equations is required. Students can either take 585.729 OR 580.641/642 unless they have permission from their advisor.

EN.585.732. Advanced Signal Processing for Biomedical Engineers. 3 Credits.

One of the defining topics for biomedical engineering, signal processing is playing an increasingly important role in modern times, mostly due to the ever-increasing popularity of portable, wearable, implantable, wireless, and miniature medical sensors/ devices. The primary function of all the medical devices is acquisition and analysis of some kind of physiological data, often in a semi continuous real-time manner. From a medical stand point, the benefits that the devices offer pertain to complementing the physician in diagnosis, prognosis, and therapeutics. High-quality signal processing algorithm is a vital part of this process. On the research side, accurate signal processing plays a fundamentally important role in a medical device's validation and translation from bench to bedside. Mastering this important topic can equip the student with skills that can be immediately applied in real-life technological innovations. This new online course will primarily focus on advanced topics in signal processing, including linear and nonlinear analysis of primary electro-physiological signals. Topics will include more traditional Auto-regressive Moving Average Analysis, spectral analysis, and singular value decomposition as well as advanced methods such as entropy computation, dimensionality estimation, state-space reconstruction, recurrence time analysis, parameter estimation, etc. Students will be challenged to write their own algorithms to reproduce select published research results.

Prerequisite(s): EN.585.615 Mathematical Methods for Applied Biomedical Engineering; EN.535.641 Mathematical Methods for Engineers; or written permission from the instructor. Knowledge of MATLAB is strongly recommended.

EN.585.734. Biophotonics. 3 Credits.

Biophotonics is an emerging multidisciplinary field, embracing all light-based technologies applied to life sciences and medicine. This course introduces fundamental principles of biophotonics and their application to real-world devices for diagnostics, patient monitoring and therapy. In a series of "at-home" laboratory exercises, students will design optical systems for evaluation of optical properties of biological media and learn computational methods to simulate light transport in such media. Experimental kits based on smartphone technology and 3D printing are distributed to each student to enable "hands-on" laboratory measurements in spectroscopy and imaging to reinforce the principles learned in the lectures. Clinical and point-of-care applications of modern biophotonic devices including fluorescence spectroscopy, scattering spectroscopy, optical coherence tomography, advanced microscopy, cellphone-based sensors and photodynamic therapy will be covered in detail. Students will also learn the process of transitioning biophotonic devices from the laboratory to the clinical setting, highlighting the critical steps required for a successful transition. For each application, students will understand how the device works, how the observed optical signature is related to fundamental tissue properties, and how the system performance is assessed through quantitative analysis. These skills will be developed throughout the course and used to evaluate devices not covered in the course as part of a project. In the project, students will apply the principles covered in this course to these selected devices.

EN.585.735. 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.585.739. Models of the Neuron. 3 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.

EN.585.741. MR Imaging in Medicine. 3 Credits.
Advances in magnetic resonance Imaging (MRI) have resulted in developing techniques such as functional brain imaging, diffusion imaging, delayed contrast enhanced imaging, and tagged imaging. These techniques offer insights into the brain and cardiac structure and function. With increased availability of these techniques in clinical MRI machines, they are now entering clinical practice for the evaluation of neuro and cardiovascular 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 functional MRI, diffusion weighted imaging and techniques for mapping white matter fiber bundles, and cardiac cine and tagged imaging. Attention is also drawn to possible artifacts and pitfalls.
Prerequisite(s): EN.585.615 Mathematical Methods for Applied Biomedical Engineering or EN.535.641 Mathematical Methods for Engineers or a written permission from the instructor.

EN.585.742. Regenerative 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.Prerequisite(s): Knowledge of basic molecular and cellular biology, physiology, and math through ordinary differential equations is required.
Prerequisite(s): EN.585.601 Applied Physiology I or EN.585.602 Applied Physiology II or EN.585.607 Molecular Biology

EN.585.743. Modeling Approaches to Cell and Tissue Engineering. 3 Credits.
Through lectures, quizzes, mathematical /computational projects, and assignments, this course presents the main modeling approaches, such as cell- and rule-based methods, to cell and tissue engineering. This course covers the topics of cancer (tumor development and treatment), bone (bone fracture healing and use of implants), and skeletal muscle regeneration (after major volume losses). In each case, a multicellular system us considered where several groups of cells divide, migrate, differentiate and dye. In addition, these cells interact with the microenvironment, including the extracellular matrix whose mechanical properties, stiffness, and stress relaxation time have effects on the cell's fate. This course will be an effective tool for design and optimization of scaffolds, implants, and materials in regenerative medicine.

EN.585.744. Biomedical Applications of Glycoengineering. 3 Credits.
Glycoengineering refers to the improvement of glycosylated molecules through manipulating their glycans ("glycans" is a broad term referring to sugars attached to proteins or lipids that includes all types of carbohydrates including monosaccharides, oligosaccharides, and polysaccharides). This course will cover the basic glycobiology of sugars and then focus on the manipulation of glycans for therapeutic purposes. Specific biomedical applications covered include the role of glycoengineering in the production and efficacy of therapeutic proteins (e.g., monoclonal antibodies); the impact of dietary sugars on human health; and the prospects for carbohydrate-based therapies for intractable human diseases such as metastatic cancer and neurological disorders such as Alzheimer's disease. Suggested prerequisites include university level cellular biology, molecular biology, or biochemistry courses.

EN.585.746. Biochemical and Cellular Engineering. 3 Credits.
This course provides a foundation of molecular and biochemical principles required for engineering cells accompanied by a survey of biomedical applications of biochemically engineered cells with a focus on medical uses. Class lectures provide an overview of molecular biology and biochemistry fundamentals that include 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 also cover the effects of physical (e.g., shear stress, strain), biochemical (e.g., cytokines, growth factors), and other (e.g., electrical) stimuli on cell function, emphasizing gene regulation, signal transduction, metabolic engineering, polymeric biomaterials, and drug and gene delivery. Finally, lectures will cover biomedical applications of engineered cells ranging from viral-based systems, prokaryote manipulation (e.g., in the context of the microbiome), to cell-based therapies (e.g., CAR T cell and other immunotherapies). An ongoing emphasis in course lectures will be to provide illustrative examples of how "Nature" engineers cells and how these lessons can be applied by biomedical engineers for clinical translation applications. In addition to lectures provided by course instructors, students will work in teams on a course project on a topic of their choosing (subject to course instructor approval) that involves an oral presentation as well as a written report.Recommended prerequisites: Background in undergraduate level cell biology, biochemistry, and/or organic chemistry.

EN.585.747. Advances in Cardiovascular Medicine. 3 Credits.
This course is designed to provide in-depth instruction in cardiovascular physiology and pathophysiology, exploring the body's own intrinsic feedback responses to cardiovascular perturbations as well as extrinsic engineering interventions related to the prevention, diagnosis, and/or treatment of those perturbations. Course topics are approached through a systems engineering lens, examining how both intrinsic control systems and extrinsic interventions support the nuanced, complex, and interdependent functions of the cardiovascular system. Students will also research and present on selected current advances in cardiovascular engineering.
Prerequisite(s): EN.585.601 Physiology for Applied Biomedical Engineering I; EN.585.602 Physiology for Applied Biomedical Engineering II or written permission from the instructor.

EN.585.751. Immunoengineering. 3 Credits.

Immunoengineering is a quickly growing field where engineering principles are used to better understand the dynamics of the immune system and enhance the efficacy of current immunotherapeutics. This course will provide relevant background in our understanding of various immune responses including to pathogens, self, allergens, cancer, and biomaterials. An in-depth engineering perspective and approach will be taken in the analysis of these responses and the development of novel therapeutics. Topics include systems immunology, genetic engineering, nanotechnology, hydrogels, biomaterials, vaccines, cancer immunotherapy, autoimmunity, tissue engineering, stem cells, viruses, bacteria, etc.

EN.585.761. Bioentrepreneurship. 3 Credits.

Through lectures, discussion, and business planning, students will learn how to assess the feasibility of a life sciences startup venture. Over the course of the semester students will evaluate financial and market opportunities, build financial projections and author a business plan. Students will debate a wide range of important issues facing entrepreneurs. As a class, students will identify opportunity, assess the skills and talents of successful entrepreneurs, and investigate models and approaches that help leaders navigate the uncertainties of entrepreneurship and creating new life science ventures. Projects relating to imaging, instrumentation, or translational tissue engineering would be eligible for inclusion.

EN.585.762. Computational Methods in Biomedical Engineering. 3 Credits.

This course will teach the theory and application of computational techniques for modeling the systems of the human body, with a significant focus on musculoskeletal biomechanics. We will begin with MATLAB examples using differential equations to explain, model, and predict biological phenomena including action potential propagation, viscoelasticity, bone remodeling, and other physiologic processes. Further discussion will center around advanced computational techniques including inverse kinematics, inverse dynamics, and computed muscle control for modeling macroscopic human movement in OpenSim; non-linear finite element analysis of human tissue in a commercial solver; and other cutting edge computational methods from the scientific literature. We aim to provide students with the theoretical foundation and applied skills to excel in the field of biological modeling and simulation.
Prerequisite(s): A physiology course, such as EN.585.601: Physiology for Applied Biomedical Engineering I or EN.585.602: Physiology for Applied Biomedical Engineering II, is required. An advanced math class, such as EN.585.615: Mathematical Methods or EN.535.641: Mathematical Methods for Engineers, is also required.

EN.585.770. Global Health Engineering. 3 Credits.

Most biomedical engineers trained in low-resource settings are absorbed into the labor market as clinical engineers supporting hospitals. Once in hospitals, it has been difficult for these engineers to engage in scalable healthcare strengthening activity because they received siloed training that prevents them from adequately addressing the complex context of healthcare delivery. Additionally, many administrators and clinicians are not able to adequately engage clinical engineers because they are unaware of the scope of their activity and their role in healthcare delivery and healthcare strengthening. This course explores the scope of activity required of clinical engineers and their collaborators in poorly resourced healthcare settings. The objective of the course is to develop the core competencies required for clinical engineers to significantly impact the design and management of medical devices and healthcare systems. Topics include an analysis of the continuous engagement model for clinical engineering in low-resource settings, and the application of biomedical engineering design principles to quality management plans, device management plans, and capacity management plans.Prerequisite: Students should have completed one course within their focus area

EN.585.771. Biomedical Data Science. 3 Credits.

Biomedical Data Science is a course designed to equip students with the basics of data science tools for data engineering, data analysis, and building artificial intelligence models in python.

EN.585.779. Principles and Applications of Modern X-ray Imaging and Computed Tomography. 3 Credits.

EN.585.781. Frontiers in Neuroengineering. 3 Credits.

Neuroscientists and neuroengineers are using state-of-the-art tools for understanding the mysteries of the brain. A suite of new approaches is allowing researchers to tap into the brain activity and to measure the electrical, molecular, cellular, and structural changes that underlie complex behaviors as well as neurological disorders such as Alzheimer's and Parkinson's disease. This technological burst, spurred by the recent BRAIN (Brain Research for Advancing Innovative Neurotechnologies) Initiative by the US government, affords a unique educational opportunity at Johns Hopkins-especially with the recently inaugurated Kavli Neuroscience Discovery Institute. This multi-instructor course will give students an opportunity to learn the latest advances in the field of neuroengineering from the best experts on campus who are currently contributing their pioneering research in this field.Prerequisite(s): Written permission from the instructor is required. Completion of all required core courses, as well as the core courses for your chosen focus area, is strongly recommended.

EN.585.783. Introduction to Brain-Computer Interfaces. 3 Credits.
Recent advances in neural interfacing and neural imaging technology and the application of various signal processing methodologies have enabled us to better understand and then utilize brain activity for interacting with computers and other devices. In this course, we will explore these technologies and approaches for acquiring and then translating brain activity into useful information. We will also discuss the components of a brain-computer interface system, including invasive and noninvasive neural interfaces, the clinical and practical applications for a variety of users, and the ethical considerations of interfacing with the brain. Students will investigate the benefits and limitations of commonly used signal processing and machine learning methods (which include independent component analysis, Bayesian inference, dimensionality reduction, and information theoretic approaches), and then apply these methods on real neural data. We aim to equip students with the foundational knowledge and skills to pursue opportunities in the emerging field of brain-computer interfacing.
Prerequisite(s): EN.585.615 Mathematical Methods for Applied Biomedical Engineering; EN.535.641 Mathematical Methods for Engineers; or a written permission from the instructor. EN.585.732 Advanced Signal Processing for Biomedical Engineers and a good knowledge of MATLAB are strongly recommended.

EN.585.785. Computational Medicine: Cardiology. 3 Credits.
The goal of this course is to investigate the cardiovascular system using a quantitative, model-oriented approach. The course will address the unique cardiac features that allow for cardiac electrical conduction and the resulting blood flow in the circulatory system through a series of lectures, selected readings, and assignments. Topics are organized in two segments: (1) Electrophysiology focused on the biophysics of single-cell to organ systems in health and disease, (2) Cardiovascular mechanics and CNS regulation of blood circulation. Students will complete two research-based projects throughout the semester that each investigate emerging engineering technologies that are beginning to reshape the standards of clinical care.

EN.585.788. Foundations of Computational Biology and Bioinformatics. 3 Credits.
This course provides students with a foundation in the basics of statistical and algorithmic approaches developed in computational biology and bioinformatics over the past 30 years, with emphasis on the need to extend these approaches to emerging problems in the field. Each week will consist of an in-person lecture and an in-person practical session where students will collaborate in groups on assigned work based on the lecture material. Lectures for this course will also be available for download/viewing. Group final projects are the capstone for this course.

EN.585.795. Projects in Medical Sensors and Devices. 3 Credits.
This course aims to provide practical, hands-on design experience to complement the pedagogical lecture-based online learning. Students with limited experience will design basic sensors and device solutions with practical biomedical use. Experienced students will utilize their basic knowledge of biomedical sensors, electronics, and measurements to design and build practical medical devices. Five examples are presented: 1) Build a biomedical signal amplifier in one laboratory to record own electrocardiogram. Then, advanced students will be challenged to develop an abnormal heart rhythm monitoring device using a microcontroller or mobile device. 2) Students will design a touch or force sensor and a measurement circuit in another laboratory. Advanced students will mount this sensor on their feet to detect footstep and assess gait, and are challenged to develop an algorithm to detect falls (a serious problem with the elderly). 3) Develop a gaming solution for people with disability (e.g., paralyzed). The basic project will be to experiment with sensors to detect movements (e.g. foot, head or eye) that can serve as an alternative sensor to a gaming interface like a mouse or a joystick. 4) The fourth hands-on project will challenge students with the problem of detecting sleep apnea (e.g. cessation of breathing attributed to sudden infant death syndrome). 5) The fifth, and final project, will be to understand the principles of brain-machine interface (BMI), and contribute to a team effort to design or use a brain wave monitoring device to control a computer or a prosthetic hand. Student teams will break down the BMI into its design component and research solutions that may have clinical and non-clinical uses, discover the state of the art and learn about the emerging frontiers in academia and industry. The course will be structured to have 5 online and remote tutorial sessions on each of the five projects as well as in-person laboratory work.

EN.585.800. Independent Study I. 3 Credits.
This course is an individually tailored, supervised project that offers the student research experience through work on a special problem related to the student's specialty of interest. The research problem can be addressed experimentally or analytically. A written report is produced on which the grade is based. The applied biomedical engineering project proposal form must be completed prior to registration. Prerequisite(s): Permission of the instructor required.

EN.585.801. Independent Study II. 3 Credits.
The course permits the student to investigate possible research fields or pursue topics of interest through reading or nonlaboratory study under the direction of a faculty member. The applied biomedical engineering directed studies program proposal form must be completed prior to registration. Prerequisite(s): Permission of the instructor required.
Prerequisite(s): EN.585.800 Independent Study I