APPLIED BIOMEDICAL ENGINEERING

The part-time Applied Biomedical Engineering program aims to educate and train practicing scientists and engineers to be able to carry out engineering-oriented research and development in the biomedical sciences. In addition to diverse student backgrounds, the program's most valuable strength lies in the active faculty currently involved in research and development.

Courses are offered at the Applied Physics Laboratory, Homewood campus, and online. Various electives are offered through the full-time Department of Biomedical Engineering and the School of Medicine.

Program Committee

Eileen Haase, Program Chair
Senior Lecturer, Biomedical Engineering
JHU Whiting School of Engineering

Brock Wester, Vice Program Chair
Senior Professional Staff
JHU Applied Physics Laboratory

Anil Maybhate
Lecturer, Applied Biomedical Engineering
JHU Whiting School of Engineering

Larry Schramm
Professor of Biomedical Engineering
Johns Hopkins School of Medicine

Artin Shoukas
Professor Emeritus
Johns Hopkins School of Medicine

Leslie Tung
Professor of Biomedical Engineering
Johns Hopkins School of Medicine

Programs

- Applied Biomedical Engineering, Master of Science (http://e-catalog.jhu.edu/engineering/engineering-professionals/applied-biomedical-engineering/applied-biomedical-engineering-master-science/)
- Applied Biomedical Engineering, Post-Master's Certificate (http://e-catalog.jhu.edu/engineering/engineering-professionals/applied-biomedical-engineering/applied-biomedical-engineering-post-masters-certificate/)

Courses

EN.585.601. Physiology for Applied Biomedical Engineering I. 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.585.602. 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 secondterm 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.585.613. 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.585.631. 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.585.642. Network Science for Biomedical Engineers. 3 Credits.
Network science has emerged as a powerful tool for the study of systems which can be modeled as complex networks. In this course we will introduce the mathematical foundations of network science, with applications to biological networks. Students will learn to employ graph theoretic metrics for the analysis and characterization of complex network models. We will also study recent advancements in network science, including extensions to dynamical networks, multilayer networks and graph signal processing and their biomedical applications. After completing this course, students will be equipped with network science tools to analyze biological networks.

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.

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.
With an emphasis on the physical principles behind modern medical imaging, this online course will cover topics such as mathematical and physical foundations of imaging; image construction and interpretation and image quality and image processing. Individual modules will cover various imaging modalities to provide an advanced understanding of the physics of the signal and its interaction with biological tissue; image formation or reconstruction; modality-specific issues for image quality; clinical applications; and biological effects and safety. Final modules will briefly touch on image analysis and describe applications for clinical diagnosis and/ or treatment.
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.585.718. 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.585.720. 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 and EN.585.602 Physiology for Applied Biomedical Engineering I and II (or equivalent).

EN.585.721. Neural Data Science for Biomedical Engineers. 3 Credits.
In recent years, data science has revolutionized how we make sense and extract information from data. With recent advancements in neuroscience and availability of data, large amounts of data are available for scientists to analyze. In this course we aim to provide data science tools for the challenges encountered in neuroscience datasets, including noise, high dimensions, and lack of ground truth. We will introduce preprocessing pipelines for neural data from multiple modalities, methods for noise reduction, dimensionality reduction, hypothesis testing, spectral analysis, multivariate analysis, and graph theory. At the end of this course, students will be ready to analyze neural data from various recording techniques.

EN.585.724. Neural Prosthetics: Science, Technology, and Applications. 3 Credits.
This course addresses the scientific bases, technologies, and chronic viability of emerging neuroprosthetic devices. Examples include cochlear and retinal implants for sensory restoration, cortical and peripheral nervous system and brain-computer interface devices for deriving motor control and enabling afferent feedback, rehabilitative and therapeutic devices such as deep brain stimulators for Parkinson’s disease, functional electrical stimulation systems for spinal cord injuries, and cognitive prosthetic systems for addressing brain trauma. Regulatory (FDA) challenges with emerging technologies and ethical considerations will also be addressed.

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, EN.585.602 and EN.585.615

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.

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.
This course introduces the fundamental principles of biophotonics and their applications to real-world devices. In a combination of laboratory and classroom 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. Modern optical measurement techniques including fluorescence spectroscopy, optical coherence tomography, and confocal microscopy will be covered in detail.

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.585.747. Advances in Cardiovascular Medicine. 3 Credits.
This course is designed to provide in-depth instruction in cardiovascular physiology (building on the background provided in EN.585.601 Physiology for Applied Biomedical Engineering I) and cardiovascular responses to pathophysiological and environmental stressors. A quantitative, model-oriented approach to physiological responses is stressed. Students will research and present current advances in cardiovascular devices and procedures.
Prerequisite(s): EN.585.601 Physiology for Applied Biomedical Engineering I; EN.585.602 Physiology for Applied Biomedical Engineering II

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. Bioentrenpreneurship. 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.585.770. 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.585.781. 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.585.786. Psychophysiology. 3 Credits.
The measurement of psychophysiology, the physiological manifestations of psychological states, is practiced by collecting self-reports, by taking readings from instruments, and by assessing behaviors. In this course, we focus on the psychophysiological instrumentation employed in the study of emotion. Each module of this course is concerned with a locus or system of interest (including the face and eyes, and cardiopulmonary and integumentary systems), and is presented in three acts. In Act 1, we first review relevant affect science and physiology. Next, in Act 2, we examine the sensors to measure physiological changes attributable to affect. Concluding each module in Act 3, we discuss interpretation of these measurements. We close the course by considering topics in integrative psychophysiology: fusion across loci and systems, and the study of dyadic interaction.
Prerequisite(s): EN.585.613 Medical Sensors and Devices or EN.585.616 Principles of Medical Instrumentation and Devices are strongly recommended.

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