Department of Biomedical Engineering Courses

About Course Numbers:

Each Carnegie Mellon course number begins with a two-digit prefix that designates the department offering the course (i.e., 76-xxx courses are offered by the Department of English). Although each department maintains its own course numbering practices, typically, the first digit after the prefix indicates the class level: xx-1xx courses are freshmen-level, xx-2xx courses are sophomore level, etc. Depending on the department, xx-6xx courses may be either undergraduate senior-level or graduate-level, and xx-7xx courses and higher are graduate-level. Consult the Schedule of Classes (https://enr-apps.as.cmu.edu/open/SOC/SOCServlet/) *each semester for course offerings and for any necessary pre-requisites or co-requisites.*

42-101 Introduction to Biomedical Engineering
Fall and Spring: 12 units
This course will provide exposure to basic biology and engineering problems associated with living systems and health care delivery. Examples will be used to illustrate how basic concepts and tools of science and amp; engineering can be brought to bear in understanding, mimicking and utilizing biological processes. The course will focus on four areas: biotechnology, biomechanics, biomaterials and tissue engineering and biosignal and image processing and will introduce the basic life sciences and engineering concepts associated with these topics.

42-200 Sophomore BME Research Project
Fall and Spring
Research projects for sophomores under the direction of a regular or adjunct BME faculty member. Arrangements may also be made via the Associate Head of BME for off-campus projects provided that a regular or adjunct BME faculty member agrees to serve as a co-advisor. The nature of the project, the number of units, and the criteria for grading are to be determined between the student and the research advisor. The agreement should be summarized in a two-page project description with sign-off by the research advisor and a copy submitted for review and filing with the BME Department. A final written report of the results is required. Units may vary from 9 to 12 according to the expected time commitment, with one unit corresponding to 1 hour of research per week. One (but not more than one) semester of research, if registered for at least 9 units, may be counted as a restricted elective course toward the BME additional major.

42-201 Professional Issues in Biomedical Engineering
Fall and Spring: 3 units
This course exposes students to many of the issues that biomedical engineers face. It provides an overview of professional topics including bioethics, regulatory issues, communication skills, teamwork, and other contemporary issues. Outside speakers and case studies will describe real world problems and professional issues in biotechnology and bioengineering, and progress toward their solution.

42-202 Physiology
Fall and Spring: 9 units
This course is an introduction to human physiology and includes units on all major organ systems. Particular emphasis is given to the musculoskeletal, cardiovascular, respiratory, digestive, excretory, and endocrine systems. Modules on molecular physiology tissue engineering and physiological modeling are also included. Due to the close interrelationship between structure and function in biological systems, each functional topic will be introduced through a brief exploration of anatomical structure. Basic physical laws and principles will be explored as they relate to physiologic function. Prerequisite or co-requisite: 03-121 Modern Biology, or permission of instructor.
Prerequisites: 03-151 or 03-121

42-203 Biomedical Engineering Laboratory
Fall and Spring: 9 units
This laboratory course is designed to provide students with the ability to make measurements on and interpret data from living systems. The experimental modules reinforce concepts from 42-101 Introduction to Biomedical Engineering and expose students to four areas of biomedical engineering: biomedical signal and image processing, biomaterials, biomechanics, and cellular and molecular biotechnology. Several cross-cutting modules are included as well. The course includes weekly lectures to complement the experimental component. Pre-med students should register for 03-206. Priority for enrollment will be given to students who have declared the Additional Major in Biomedical Engineering.
Prerequisites: 42-101 and (03-121 or 03-151)

42-300 Junior BME Research Project
Fall and Spring
Research projects for juniors under the direction of a regular or adjunct BME faculty member. Arrangements may also be made via the Associate Head of BME for off-campus projects provided that a regular or adjunct BME faculty member agrees to serve as a co-advisor. The nature of the project, the number of units, and the criteria for grading are to be determined between the student and the research advisor. The agreement should be summarized in a two-page project description with sign-off by the research advisor and a copy submitted for review and filing with the BME Department. A final written report of the results is required. Units may vary from 9 to 12 according to the expected time commitment, with one unit corresponding to 1 hour of research per week. One (but not more than one) semester of research, if registered for at least 9 units, may be counted as a restricted elective course toward the BME additional major.

42-302 Biomedical Engineering Systems Modeling and Analysis
Fall and Spring: 9 units
This course will prepare students to develop mathematical models for biological systems and for biomedical engineering systems, devices, components, and processes and to use models for data reduction and for system performance analysis, prediction and optimization. Models considered will be drawn from a broad range of applications and will be based on algebraic equations, ordinary differential equations and partial differential equations. The tools of advanced engineering mathematics comprising analytical, computational and statistical approaches will be introduced and used for model manipulation.
Prerequisites: 21-260 or 06-262 or 18-202

42-400 Senior BME Research Project
Fall and Spring
Research projects for seniors under the direction of a regular or adjunct BME faculty member. Arrangements may also be made via the Associate Head of BME for off-campus projects provided that a regular or adjunct BME faculty member agrees to serve as a co-advisor. The nature of the project, the number of units, and the criteria for grading are to be determined between the student and the research advisor. The agreement should be summarized in a two-page project description with sign-off by the research advisor and a copy submitted for review and filing with the BME Department. A final written report of the results is required. Units may vary from 9 to 12 according to the expected time commitment, with one unit corresponding to 1 hour of research per week. One (but not more than one) semester of research, if registered for at least 9 units, may be counted as a restricted elective course toward the BME additional major.

42-401 Foundation of BME Design
Fall: 6 units
This course sequence introduces Biomedical Engineering students to the design of useful biomedical products to meet a specific medical need. Students will learn to identify product needs, how to specify problem definitions and to use project management tools. Methods to develop creativity in design will be introduced. The course sequence is comprised of two parts: 42-401 is offered in the Fall semester and provides the students the opportunity to form project teams, select and define a project, create a development plan, and complete an initial prototype. 42-402 is offered in the Spring semester is a full semester course and completes the plan that was developed in the fall semester. This course culminates in the completion of multiple prototypes, a poster presentation, and a written report.
Prerequisite: 42-101

42-402 BME Design Project
Spring: 9 units
This course sequence introduces Biomedical Engineering students to the design of useful biomedical products to meet a specific medical need. Students will learn to identify product needs, how to specify problem definitions and to use project management tools. Methods to develop creativity in design will be introduced. The course sequence is comprised of two parts: 42-401 is offered in the Fall semester and provides the students the opportunity to form project teams, select and define a project, create a development plan, and complete an initial prototype. 42-402 is offered in the Spring semester is a full semester course and completes the plan that was developed in the fall semester. This course culminates in the completion of multiple prototypes, a poster presentation, and a written report.

42-437 Biomedical Optical Imaging
Fall: 9 units
Biophotonics, or biomedical optics, is a field dealing with the application of optical science and imaging technology to biomedical problems, including clinical applications. The course introduces basic concepts in electromagnetism and light tissue interactions, including optical properties of tissue, absorption, fluorescence, and light scattering. Imaging methods will be described, including fluorescence imaging, Raman spectroscopy, optical coherence tomography, diffuse optical spectroscopy, and photoacoustic tomography. The basic physics and engineering of each imaging technique are emphasized. Their relevance to human disease diagnostic and clinical applications will be included, such as breast cancer imaging and monitoring, 3D retinal imaging, ways of non-invasive tumor detection, as well as functional brain imaging in infants. NOTE: 42-437 is intended for undergraduates only. Pre-requisite: 33-107 Physics II for Engineering Students or permission of the instructor.
Prerequisite: 33-142

42-444 Medical Devices
Fall: 9 units
This survey course is an introduction to the engineering, clinical, legal, regulatory and business aspects of medical device performance and failure. Topics covered include a broad range of successful medical devices in clinical use, as well as historical case studies of devices that were withdrawn from the market as a consequence of noted failures. In-depth study of specific medical devices will include cardiovascular, orthopedic, and neurological disciplines. We will study best practices employed in the clinical setting, principles governing the design processes, and modes of failure as a risk to the patient population. Additional lectures will provide fundamental topics concerning biomaterials used for implantable medical devices (metals, polymers, ceramics), biocompatibility, imaging, patient risks and mechanisms of failure (wear, corrosion, fatigue, fretting, etc.). The level of technical content will require junior standing for MCS and CIT students, a degree in science or engineering for non-MCS or non-CIT graduate students, or permission of the instructor for all other students.

42-447 Rehabilitation Engineering
Fall: 9 units
Rehabilitation engineering is the systematic application of engineering sciences to design, develop, adapt, test, evaluate, apply, and distribute technological solutions to problems confronted by individuals with disabilities. This course surveys assistive technologies designed for a variety functional limitations - including mobility, communication, hearing, vision, and cognition - as they apply to activities associated with employment, independent living, education, and integration into the community. This course considers not only technical issues in device development, but also the psychosocial factors and market forces that influence device acceptance by individuals and the marketplace. Open only to students with junior standing who have had at least one engineering class or by permission of instructor.

42-610 Introduction to Biomaterials
Spring: 9 units
Understanding the fundamentals of biomaterials structure-function relationships pertaining to material functions and to cell and tissue environments will be a prime goal. The course will be composed of lectures, readings, projects and technical writing assignments. The synthesis, characterization and functional properties of organic and inorganic biomaterials and the processes involved in their use in tissue engineering and regenerative medicine will be discussed. Fundamental issues related to the utility of biomaterials, including biomechanics, transport, degradability, biointerfaces and biocompatibility, stability, fate in the body will be covered, along with some of the basic approaches to characterization. Clinical applications for biomaterials and new directions in design and synthesis to achieve better biocompatibility will be emphasized.

42-611 Biomaterials
Spring: 12 units
This class serves as an overview of the landscape of biomaterial engineering and research. This course will cover the application of materials in biological environments, focusing on structure-processing-property relationships, engineering design principles, and how the biological environment affects the material properties. This course will focus on applications of a variety of materials that interface with biological systems including natural biopolymers, synthetic polymers, metals, and ceramics. Topics include considerations in molecular design of biomaterials, fundamentals of thermodynamic and kinetics relationships, the application of bulk and surface properties in the design of medical devices, and understanding tissue-biomaterials interactions. This course will discuss practical applications of materials in drug delivery, tissue engineering, biosensors, and other biomedical technologies. Students will be assessed with homework assignments and quizzes. At the end of the class, in teams, students will apply the concepts they have learned to write and present a focused review on a biomaterial design/concept that excites them.

42-612 Tissue Engineering
Spring: 12 units
This course will train students in advanced cellular and tissue engineering methods that apply physical, mechanical and chemical manipulation of materials in order to direct cell and tissue function. Students will learn the techniques and equipment of bench research including cell culture, immunofluorescent imaging, soft lithography, variable stiffness substrates, application/measurement of forces and other methods. Students will integrate classroom lectures and lab skills by applying the scientific method to develop a unique project while working in a team environment, keeping a detailed lab notebook and meeting mandated milestones. Emphasis will be placed on developing the written and oral communication skills required of the professional scientist. The class will culminate with a poster presentation session based on class projects. Pre-requisite: Knowledge in cell biology and biomaterials, or permission of instructor

42-613 Polymeric Biomaterials
Spring: 12 units
This course will cover aspects of polymeric biomaterials in medicine from molecular principles to device scale design and fabrication. Topics include the chemistry, characterization, and processing of synthetic polymeric materials; cell-biomaterials interactions including interfacial phenomena, tissue responses, and biodegradation mechanisms; aspects of polymeric micro-systems design and fabrication for applications in medical devices. Recent advances in these topics will also be discussed.

42-614 Stem Cell Engineering
Intermittent: 9 units
This course will give an overview over milestones of stem cell research and will expose students to current topics at the frontier of this field. It will introduce students to the different types of stem cells as well as environmental factors and signals that are implicated in regulating stem cell fate. The course will highlight techniques for engineering of stem cells and their micro-environment. It will evaluate the use of stem cells for tissue engineering and therapies. Emphasis will be placed on discussions of current research areas and papers in this rapidly evolving field. Students will pick a class-related topic of interest, perform a thorough literature search, and present their findings as a written report as well as a paper review and a lecture. Lectures and discussions will be complemented by practical lab sessions, including: stem cell harvesting and culture, neural stem cell transfection, differentiation assays, and immunostaining, polymeric microcapsules as advanced culture systems, and stem cell integration in mouse brain tissue. The class is designed for graduate students and upper undergraduates with a strong interest in stem cell biology, and the desire to actively contribute to discussions in the class.

42-615 Biomaterial Host Interactions in Regenerative Medicine
Intermittent: 12 units
This course will provide students with hands-on experience in investigating host responses to synthetic and naturally biomaterials used in regenerative medicine applications. Students will gain experience in the analysis of host responses to these biomaterials as well as strategies to control host interaction. Biomaterial biocompatibility, immune interactions, tissue healing and regeneration will be addressed. Students will integrate classroom lectures with laboratory skills evaluating host-material interactions in a laboratory setting. Laboratory characterization techniques will include cell culture techniques, microscopic, cytochemical, immunocytochemical and histological analyses. Prior knowledge in physiology is helpful.

42-616 Bio-nanotechnology: Principles and Applications
Fall: 9 units
Have you ever wondered what is nanoscience and nanotechnology and their impact on our lives? In this class we will go through the key concepts related to synthesis (including growth methodologies and characterizations techniques) and chemical/physical properties of nanomaterials from zero-dimensional (0D) materials such as nanoparticles or quantum dots (QDs), one-dimensional materials such as nanowires and nanotubes to two-dimensional materials such as graphene. The students will then survey a range of biological applications of nanomaterials through problem-oriented discussions, with the goal of developing design strategies based on basic understanding of nanoscience. Examples include, but are not limited to, biomedical applications such as nanosensors for DNA and protein detection, nanodevices for bioelectrical interfaces, nanomaterials as building blocks in tissue engineering and drug delivery, and nanomaterials in cancer therapy. This class is open for both undergraduate (junior/senior) and graduate students.

42-620 Engineering Molecular Cell Biology
Fall: 12 units
Cells are not only basic units of living organisms but also fascinating engineering systems that exhibit amazing functionality, adaptability, and complexity. Applying engineering perspectives and approaches to study molecular mechanisms of cellular processes plays a critical role in the development of contemporary biology. At the same time, understanding the principles that govern biological systems provides critical insights into the development of engineering systems. The goal of this course is to provide basic molecular cell biology for engineering students with little or no background in cell biology, with particular emphasis on integrating engineering concepts throughout the entire learning process of modern molecular and cellular biology. This course will prepare advanced undergraduate or graduate students with the essential knowledge and mindset for future research endeavors involving engineering biological systems at molecular and cellular levels. This course, besides introducing the fundamental biological knowledge, aims to enhance students' comprehension and appreciation of (1) how engineering approaches have led to our current understanding of molecular and cell biology; (2) what the available engineering approaches are that allow manipulation and even creation of biological systems at molecular, cellular and tissue levels; (3) what the current challenges are in molecular and cell biology that could be solved one day by engineering innovation. Course topics include the engineering of cellular components (DNA, RNA, protein, cell membrane, mitochondria, extracellular matrix) and cellular processes (metabolism, proliferation, cell death, tissue formation). Pre-requisites: None. Prior completion of 03-121 Modern Biology is suggested but not required.

42-621 Principles of Immunoengineering and Development of Immunotherapy Drugs
Fall: 9 units
This course will provide context for the application of engineering principles to modulate the immune system to approaches problems in human health. Basic understanding of the components and function of the innate and adaptive immune system. Students will leave with a basic understanding of immunology and of the engineering techniques used to develop and characterize immunotherapy systems. Where appropriate, we will discuss how immunoengineering fits into other disciplines of engineering such as mechanical, chemical, and materials science. Because the purpose of immunoengineering is disease treatment, we will discuss, the therapy pipeline, development of clinical trials and the FDA approval process. Immunotherapy will also be assessed within different disease contexts including cancer, infectious disease, allergies, prosthetics and implants, neuro and musculoskeletal disorders.

42-622 Bioprocess Design
Spring: 9 units
This course is designed to link concepts of cell culture, bioseparations, formulation and delivery together for the commercial production and use of biologically-based pharmaceuticals; products considered include proteins, nucleic acids, and fermentation-derived fine chemicals. Associated regulatory issues and biotech industry case studies are also included. The format of the course is a mixture of equal parts lecture, open discussion, and participant presentation. Course work consists of team-oriented problem sets of an open-ended nature and indivudual-oriented industry case studies. The goals of the course work are to build an integrated technical knowledge base of the manufacture of biologically based pharmaceuticals and U.S. biotechnology industry. Working knowledge of cell culture and modern biology, biochemistry and differential equations is assumed. Pre-requisite: 42-321 Cellular and Molecular Biotechnology or both 03-232 Biochemistry and 06-422 Chemical Reaction Engineering, or instructor permission.
Prerequisites: 06-422 or 42-321 or 03-232

42-623 Cellular and Molecular Biotechnology
Fall: 9 units
This course will provide students with an introduction to biotechnology in an engineering context. The focus will be on using microorganisms to prepare therapeutically and technologically relevant biochemicals. Topics to be covered include cellular and microbial metabolism, recombinant DNA methodologies, bioreactor design, protein separation and purification, and systems approaches to biotechnology. Prerequisites: (42-202 Physiology OR 03-121 Modern Biology OR 03-232 Biochemistry) AND (06-262 Mathematical Methods of Chemical Engineering OR 21-260 Differential Equations) OR permission of instructor.

42-624 Biological Transport and Drug Delivery
Spring: 9 units
Analysis of transport phenomena in life processes on the molecular, cellular, organ and organism levels and their application to the modeling and design of targeted or sustained release drug delivery technologies. Coupling of mass transfer and reaction processes will be a consistent theme as they are applied to rates of receptor-mediated solute uptake in cells, drug transport and biodistribution, and drug release from delivery vehicles. Design concepts underlying advances in nanomedicine will be described.

42-625 Surgery for Engineers
Spring: 9 units
This course explores the impact of engineering on surgery. Students will interact with clinical practitioners and investigate the technological challenges that face these practitioners. A number of visits to the medical center are anticipated for hands on experience with a number of technologies utilized by surgeons to demonstrate the result of advances in biomedical engineering. These experiences are expected to include microvascular surgery, robotic surgery, laparoscopic, and endoscopic techniques. Tours of the operating room and shock trauma unit will be arranged. If possible observation of an operative procedure will be arranged (if scheduling permits). Invited surgeons will represent disciplines including cardiovascular surgery, plastic and reconstructive surgery, surgical oncology, trauma surgery, minimally invasive surgery, oral and maxillofacial surgery, bariatric surgery, thoracic surgery, orthopedic surgery, and others. The Primary Instructor is Howard Edington, M.D., MBA System Chairman of Surgery, Allegheny Health Network. This course meets once a week for 3 hours. Several sessions will be held at the Medical Center, transport provided. Pre-requisite: Physiology 42-202 and one of the introductory engineering courses, 42-101, 06-100, 12-100. 18-100, 19-101, 24-101, or 27-100 Priority for enrollment is given to BME Graduate students and additional majors, followed by BME minors.

42-626 Drug Delivery Systems
Fall and Spring: 9 units
The body is remarkable in its ability to sequester and clear foreign entities - whether they be "bad" (e.g. pathogens) or "good" (e.g. therapeutic drugs). This course will explore the design principles being used to engineer modern drug delivery systems capable of overcoming the body's innate defenses to achieve therapeutic effect. Specifically, we will study the chemistry, formulation, and mechanisms of systems designed to deliver nucleic acids, chemotherapeutics, and proteins across a variety of physiological barriers. Scientific communication plays a prominent role in the course, and students will have several opportunities to strengthen their communication skills through journal club presentations, proposal writing and constructive feedback. This is a graduate level course that is also open to undergraduate seniors.

42-630 Introduction to Neural Engineering
Spring: 12 units
Neural engineering sits at the interface between neuroscience and engineering, applying classical engineering approaches and principles to understand the nervous system and its function. Modern neural engineering techniques have been used to measure neural activity using tools based on light, electricity, and magnetism. The same tools for measurement can be redirected to modulate neural activity, and manipulate how an organism perceives, thinks, and acts. The course objectives are to familiarize students with a range of neural engineering approaches to investigating and intervening in the nervous system, emphasizing quantitative understanding and fundamental engineering concepts. The course will pair lectures and discussion with projects involving real neural data (Matlab-based exercises). Example projects could include finding visual responses in EEG data, or determining how groups of individual neurons interact based on spiking data. Overall, the goal is to give the student a deep understanding of select topics in neuroscience and the application of quantitative neural engineering approaches to these topics. This course is intended for advanced undergraduate and entering graduate students. Familiarity with linear algebra, signal processing, and introductory Matlab programming is helpful. This course is suitable for students coming from diverse backgrounds: (1) Students with non-engineering backgrounds seeking quantitative skills, and wanting to learn an engineering approach to neuroscience problems, and (2) students with engineering or other quantitative backgrounds who are seeking ways to apply their skills to scientific questions in neuroscience.

42-631 Neural Data Analysis
Fall: 12 units
The vast majority of behaviorally relevant information is transmitted through the brain by neurons as trains of actions potentials. How can we understand the information being transmitted? This class will cover the basic engineering and statistical tools in common use for analyzing neural spike train data, with an emphasis on hands-on application. Topics may include neural spike train statistics (Poisson processes, interspike intervals, Fano factor analysis), estimation (MLE, MAP), signal detection theory (d-prime, ROC analysis, psychometric curve fitting), information theory, discrete classification, continuous decoding (PVA, OLE), and white-noise analysis. Each topic covered will be linked back to the central ideas from undergraduate probability, and each assignment will involve actual analysis of neural data, either real or simulated, using Matlab. This class is meant for upper-level undergrads or beginning graduate students, and is geared to the engineer who wants to learn the neurophysiologist's toolbox and the neurophysiologist who wants to learn new tools. Those looking for broader neuroscience application (eg, fMRI) or more focus on regression analysis are encouraged to take 36-746. Those looking for more advanced techniques are encouraged to take 18-699. Prerequisites: undergraduate probability (36-225/227, or its equivalent), some familiarity with linear algebra and Matlab programming

42-632 Neural Signal Processing
Spring: 12 units
The brain is among the most complex systems ever studied. Underlying the brain's ability to process sensory information and drive motor actions is a network of roughly 10^11 neurons, each making 10^3 connections with other neurons. Modern statistical and machine learning tools are needed to interpret the plethora of neural data being collected, both for (1) furthering our understanding of how the brain works, and (2) designing biomedical devices that interface with the brain. This course will cover a range of statistical methods and their application to neural data analysis. The statistical topics include latent variable models, dynamical systems, point processes, dimensionality reduction, Bayesian inference, and spectral analysis. The neuroscience applications include neural decoding, firing rate estimation, neural system characterization, sensorimotor control, spike sorting, and field potential analysis. Prerequisites: 18-290; 36-217, or equivalent introductory probability theory and random variables course; an introductory linear algebra course; senior or graduate standing. No prior knowledge of neuroscience is needed.

42-638 Introduction to Biophotonics
Spring: 9 units
Biophotonics, or biomedical optics, is a field dealing with the application of optical science and imaging technology to biomedical problems, including clinical applications. The course introduces basic concepts in electromagnetism and light tissue interactions, including optical properties of tissue, absorption, fluorescence, and light scattering. Imaging methods will be described, including fluorescence imaging, Raman spectroscopy, optical coherence tomography, diffuse optical spectroscopy, and photoacoustic tomography. The basic physics and engineering of each imaging technique are emphasized. Their relevance to human disease diagnostic and clinical applications will be included, such as breast cancer imaging and monitoring, 3D retinal imaging, ways of non-invasive tumor detection, as well as functional brain imaging in infants. Pre-requisite: College level physics covering electromagnetism and optics or permission of the instructor.

42-639 Introduction to Neural Engineering
Intermittent: 12 units
Neural engineering sits at the interface between neuroscience and engineering, applying classical engineering approaches and principles to understand the nervous system and its function. Modern neural engineering techniques have been used to measure neural activity using tools based on light, electricity, and magnetism. The same tools for measurement can be redirected to modulate neural activity, and manipulate how an organism perceives, thinks, and acts. The course objectives are to familiarize students with a range of neural engineering approaches to investigating and intervening in the nervous system, emphasizing quantitative understanding and fundamental engineering concepts. The course will pair lectures and discussion with projects involving real neural data (Matlab-based exercises). Example projects could include finding visual responses in EEG data, or determining how groups of individual neurons interact based on spiking data. Overall, the goal is to give the student a deep understanding of select topics in neuroscience and the application of quantitative neural engineering approaches to these topics. This course is intended for advanced undergraduate and entering graduate students. Familiarity with linear algebra, signal processing, and introductory Matlab programming is helpful. This course is suitable for students coming from diverse backgrounds: (1) Students with non-engineering backgrounds seeking quantitative skills, and wanting to learn an engineering approach to neuroscience problems, and (2) students with engineering or other quantitative backgrounds who are seeking ways to apply their skills to scientific questions in neuroscience.

42-640 Image-Based Computational Modeling and Analysis
Spring: 12 units
Biomedical modeling and visualization play an important role in mathematical modeling and computer simulation of real/artificial life for improved medical diagnosis and treatment. This course integrates mechanical engineering, biomedical engineering, computer science, and mathematics together. Topics to be studied include medical imaging, image processing, geometric modeling, visualization, computational mechanics, and biomedical applications. The techniques introduced are applied to examples of multi-scale biomodeling and simulations at the molecular, cellular, tissue, and organ level scales.

42-641 Rehabilitation Engineering
Fall: 9 units
Rehabilitation engineering is the systematic application of engineering sciences to design, develop, adapt, test, evaluate, apply, and distribute technological solutions to problems confronted by individuals with disabilities. This course focuses on assistive technologies - technologies designed for use in the everyday lives of people with disabilities to assist in the performance of activities of daily living. The course surveys assistive technologies designed for a variety of functional limitations - including mobility, communication, hearing, vision, and cognition - as they apply to activities associated with employment, independent living, education, and integration into the community. This course considers not only technical issues in device development, but also the psychosocial factors and market forces that influence device acceptance by individuals and the marketplace. The class is designed for graduate students and upper undergraduates.

42-643 Microfluidics
Intermittent: 12 units
This course offers an introduction to the emerging field of microfluidics with an emphasis on chemical and life sciences applications. During this course students will examine the fluid dynamical phenomena underlying key components of "lab on a chip" devices. Students will have the opportunity to learn practical aspects of microfluidic device operation through hands-on laboratory experience, computer simulations of microscale flows, and reviews of recent literature in the field. Throughout the course, students will consider ways of optimizing device performance based on knowledge of the fundamental fluid mechanics. Students will explore selected topics in more detail through a semester project. Major course topics include pressure-driven and electrokinetically-driven flows in microchannels, surface effects, micro-fabrication methods, micro/nanoparticles for biotechnology, biochemical reactions and assays, mixing and separation, two-phase flows, and integration and design of microfluidic chips. Pre-requisites: 24-231 or 06-261 or 12-355 or instructor permission.

42-645 Cellular Biomechanics
Intermittent: 9 units
This course discusses how mechanical quantities and processes such as force, motion, and deformation influence cell behavior and function, with a focus on the connection between mechanics and biochemistry. Specific topics include: (1) the role of stresses in the cytoskeleton dynamics as related to cell growth, spreading, motility, and adhesion; (2) the generation of force and motion by moot molecules; (3) stretch-activated ion channels; (4) protein and DNA deformation; (5) mechanochemical coupling in signal transduction. If time permits, we will also cover protein trafficking and secretion and the effects of mechanical forces on gene expression. Emphasis is placed on the biomechanics issues at the cellular and molecular levels; their clinical and engineering implications are elucidated. 3 hrs. lec. Prerequisite: Instructor permission. Prerequisites: None. Corequisites: None. Cross Listed Courses: 24-655 Notes: None. Reservations:

42-648 Cardiovascular Mechanics
Spring: 12 units
The primary objective of the course is to learn to model blood flow and mechanical forces in the cardiovascular system. After a brief review of cardiovascular physiology and fluid mechanics, the students will progress from modeling blood flow in a.) small-scale steady flow applications to b.) small-scale pulsatile applications to c.) large-scale or complex pulsatile flow applications. The students will also learn how to calculate mechanical forces on cardiovascular tissue (blood vessels, the heart) and cardiovascular cells (endothelial cells, platelets, red and white blood cells), and the effects of those forces. Lastly, the students will learn various methods for modeling cardiac function. When applicable, students will apply these concepts to the design and function of selected medical devices (heart valves, ventricular assist devices, artificial lungs).

42-649 Introduction to Biomechanics
Fall: 12 units
The purpose of this course is to achieve a broad overview of the application of mechanics to the human body. This includes solid, fluid, and viscoelastic mechanics applied to single cells, the cardiovascular system, lungs, muscles, bones, and human movement. The physiology of each system will be reviewed as background prior to discussing mechanics applications within that system. Prior knowledge/experience in statics, fluid mechanics, and biology are helpful.

42-650 Introduction to Biomedical Imaging
Fall: 9 units
The field of medical imaging describes methods of seeing the interior of the human body, as well as visual representation of tissue and organ function. The materials covered in this course will give an overview of existing medical imaging devices used in a clinical and pre-clinical setting. The course presents the principles of medical imaging technologies, explaining the mathematical and physical principles, as well as describing the fundamental aspects of instrumentation design. Students will gain a thorough understanding of how these methods are used to image morphological and physiological features. Imaging methods will include Ultrasound, X-ray, computed tomography (CT), and magnetic resonance imaging (MRI), as well as optical methods. For each method, the fundamental imaging principles will be discussed, and examples of clinical applications will be presented. No prior knowledge of imaging methods is required.

42-652 Nano-Bio-Photonics
Spring: 12 units
Light can penetrate biological tissues non-invasively. Most of the available bio-optic tools are bulky. With the advent of novel nanotechnologies, building on-chip integrated photonic devices for applications such as sensing, imaging, neural stimulation, and monitoring is now a possibility. These devices can be embedded in portable electronic devices such as cell phones for point of care diagnostics. This course is designed to convey the concepts of nano-bio-photonics in a practical way to prepare students to engage in emerging photonic technologies. The course starts with a review of electrodynamics of lightwaves. The appropriate choice of wavelength and material platform is the next topic. Then optical waveguides and resonators are discussed. Resonance-based sensing is introduced followed by a discussion of the Figure of Merits (FOMs) used to design on-chip sensors. Silicon photonics is introduced as an example of a CMOS-compatible platform. On-chip spectroscopy is the next topic. The second part covers nano-plasmonics for bio-detection and therapy. The design methods are discussed, followed by an overview of nanofabrication and chemical synthesis, and then a discussion of applications. The last part of this course will be dedicated to a review of recent applications such as Optogenetic neural stimulation, Calcium imaging, Cancer Imaging and Therapy. Senior or graduate standing required. This course is cross-listed with 18416. Although students in 18-616 and 18-416 will share the same lectures and recitations, students in 18-616 will receive distinct course projects. Students in 18-416 and 18-616 will be graded on separate curves. Prerequisite: 21-260

42-655 Biostatistics
Spring: 9 units
This course introduces statistical methods for making inferences in engineering, biology and medicine. Students will learn how to select the most appropriate methods, how to apply these methods to actual data, and how to read and interpret computer output from a commonly used statistical package. The topics covered are descriptive statistics; elementary probability; discrete and continuous random variables and their distributions; hypothesis testing involving interval (continuous and discrete) and categorical (nominal and ordinal) variables, for two and three or more treatments; simple and multiple linear regression; time-series analysis; clustering and classification; and time-to-event (survival) analysis. Students will also learn how to write the statistical component of a "Results" section for a scientific paper and learn about the limitations of the statistical analyses. Basic familiarity with probability and probability distribution preferred but not required.

42-656 Introduction to Machine Learning for Biomedical Engineers
Fall: 9 units
This course introduces fundamental concepts, methods and applications in machine learning and datamining. We will cover topics such as parametric and non-parametric learning algorithms, support vector machines, neural networks, clustering, clustering and principal components analysis. The emphasis will be on learning high-level concepts behind machine learning algorithms, and applying them to biomedical-related problems. This course is intended for advanced undergraduate and graduate students in Biomedical Engineering or related disciplines. Students should have experience with high-level programming language such as Python/Matlab, basic familiarity with probability, statistics and linear algebra, and should be comfortable with manipulating vectors and matrices.

42-660 Bioinstrumentation
Spring: 12 units
This course aims to build concepts and skills in electronics for the design and construction of instruments for biomedical applications. The course uses a flipped, fast-paced format to cover a range of electronic components and circuits, including resistors, capacitors, transistors, sensors, actuators, amplifiers, signal filters, and microcontrollers, through lectures, tutorials, weekly lab projects, and term projects. Students, with or without a background in electronics, will gain hands-on skills to build functional instruments for physiological measurements such as temperature, gas concentration, blood pressure, and EKG signals.
Prerequisites: 42-101 and 42-202

42-661 Surgery for Engineers
Spring: 9 units
This course explores the impact of engineering on surgery. Students will interact with clinical practitioners and investigate the technological challenges that face these practitioners. A number of visits to the medical center are anticipated for hands on experience with a number of technologies utilized by surgeons to demonstrate the result of advances in biomedical engineering. These experiences are expected to include microvascular surgery, robotic surgery, laparoscopic, and endoscopic techniques. Tours of the operating room and shock trauma unit will be arranged. If possible observation of an operative procedure will be arranged (if scheduling permits). Invited surgeons will represent disciplines including cardiovascular surgery, plastic and reconstructive surgery, surgical oncology, trauma surgery, minimally invasive surgery, oral and maxillofacial surgery, bariatric surgery, thoracic surgery, orthopedic surgery, and others. The Primary Instructor is Howard Edington, M.D., MBA System Chairman of Surgery, Allegheny Health Network. This course meets once a week for 3 hours. Several sessions will be held at the Medical Center, transport provided. Pre-requisite: Physiology 42-202 and one of the introductory engineering courses, 42-101, 06-100, 12-100. 18-100, 19-101, 24-101, or 27-100 Priority for enrollment is given to BME Graduate students and additional majors, followed by BME minors.
Prerequisites: 42-202 and (27-100 or 24-101 or 19-101 or 18-100 or 12-100 or 42-101 or 06-100)

42-663 Computational Methods in BME
Spring: 12 units
This goal of this course is to enable students with little or no programming background to solve simple computational problems in science and engineering. Emphasis will be placed on enabling students to use currently available numerical methods (rather than developing anew) to solve engineering problems. Upon completing the course, the successful student will be able to use basic knowledge regarding computer architecture, data types, binary arithmetic, and programming, to solve sample quantitative problems in engineering. Topics will include: solving linear systems of equations, model fitting using least squares techniques (linear and nonlinear), data interpolation, numerical integration and differentiation, solving differential equations, and data visualization. Specific example computations in each topic above will be drawn from problems in physics, chemistry, as well as signal and image processing, and biomedical engineering. Students will work independently in groups for a final project. Matlab will be used as the programming language/environment for this class, although different languages such as C, Java, and Python will be briefly discussed (time permitting). May count as practicum for practicum-option MS. Pre-requisite: Calculus, multivariate calculus, linear algebra, and differential equations

42-665 Brain-Computer Interface: Principles and Applications
Spring: 9 units
This course provides an introduction and comprehensive review of the concepts, principles and methods of Brain-computer interface (BCI) technology. BCIs have emerged as a novel technology that bridges the brain with external devices. BCIs have been developed to decode human intention, leading to direct brain control of a computer or device, bypassing the neuromuscular pathway. Bi-directional brain-computer interfaces not only allows device control, but also opens the door for modulating the central nervous system through neural interfacing. Using various recorded brain signals that reflect the "intention" of the brain, BCI systems have shown the capability to control external devices, such as computers and robots. Neural stimulation using electrical, magnetic, optical and acoustic energy has shown capability to better understanding of the brain functions and intervene with central nervous systems. This course teaches the fundamentals how a BCI system works and various building blocks of BCIs, from signal acquisition, signal processing, feature extraction, feature translation, neurostimulation, to device control, and various applications. Examples of noninvasive BCIs are discussed to provide an in-depth understanding of the noninvasive BCI technology. Open to seniors or graduate students in engineering or science programs, or upon instructor's approval (for exceptional juniors, e.g.).

42-666 Neuroengineering Practicum
Fall: 9 units
This course will examine topics and issues related to ethics, professional conduct, conflicts, plagiarism, copyright, authorship, research design considerations, IRB, IACUC, intellectual properties, review process, regulatory science and FDA process, professional presentations, and technical writing in neuroengineering. Students will discuss neuro-ethical implications of neural technologies and learn about the process of bringing such technologies to market, including intellectual property and FDA approval considerations. Students will discuss essential career development skills for a neuroengineering R and D career in academia and industry. An important component of the course is to develop students' communications skills including developing an effective research proposal, as well as effective oral presentations of the ideas developed in the proposal and technical report. The essentials for successful proposal writing will be discussed in case studies, in the form of fellowship applications. Each student will be required to develop a research proposal based upon students' own research or an emerging research topic in neuroengineering. Each student will also be required to develop a research statement on her/his own research interest. It is expected that students will improve her/his writing skills for proposal/research statement development with case studies, group discussions, and individualized feedbacks on students' own writing and presentation. This course will help students to develop practical skills addressing real world problems in neuroengineering.

42-667 Biofabrication and Bioprinting
Spring: 12 units
This laboratory course is designed to introduce students to and give them hands-on experience using methods that are used to fabricate scaffolds that are often used in tissue engineering, drug delivery, and some medical devices. Methods that will be taught include plastic FDM (filament deposition methods) to 3d print thermoplastic materials and molds for casting soft hydrogel materials, as well as 3d Bioprinting of soft hydrogel materials into a support bath material. This course will include a lecture component to introduce students to the concepts needed to design and fabricate the scaffolds. Lecture topics will include (but are not limited to): chemical and physical properties of biomaterials, CAD, and post-processing methods. There are no pre-requisite courses; however prior introductory lab experience is suggested.

42-668 "Fun"-damentals of MRI and Neuroimaging Analysis
Spring: 9 units
Neuroimaging gives us many ways to learn how the brain operates through various functions and disease states without having to perform any invasive surgery. This course will cover the methodology and analysis of structural magnetic resonance imaging (MRI) and functional MRI in humans and animals. Through lecture, discussion and analysis of sample data, students will understand the (A) history of MRI, (B) physics of MRI, (C) utilization with MRI and other devices used to interpret biological tissue, (D) how to design an fMRI experiment, and (E) analysis techniques in MRI. At the end of the course, students will have strong fundamental MRI and fMRI skillset and gain programming skills in MATLAB and learn other tools like SPM to process MRI and fMRI datasets in appropriate software packaging.

42-669 Energy Applications in Biology and Medicine
Spring: 12 units
This course covers a wide range of energy-based applications in biology and medicine, such as cancer treatments by cryosurgery (freezing), thermal ablation (heating), photodynamic therapy (light-activated drugs), and irreversible electroporation (a non-thermal electrical application). This course also covers thermal regulation in humans and other mammals, as well as cryopreservation (low-temperature preservation) of tissues and organs for the benefit of organ banking and transplant medicine. The course combines lectures and individual assignments relating to the underlying principles of engineering, with teamwork on open-ended projects relating to concurrent challenges at the convergence of engineering and medical sciences. The course plan assumes a mastery of the fundamentals of heat transfer at the undergraduate level.

42-670 Special Topics: Biomaterial Host Interactions in Regenerative Medicine
Fall: 12 units
Special Topics: This course will provide students with hands-on experience in investigating host responses to synthetic and naturally biomaterials used in regenerative medicine applications. Students will gain experience in the analysis of host responses to these biomaterials as well as strategies to control host interaction. Biomaterial biocompatibility, immune interactions, tissue healing and regeneration will be addressed. Students will integrate classroom lectures with laboratory skills evaluating host-material interactions in a laboratory setting. Laboratory characterization techniques will include cell culture techniques, microscopic, cytochemical, immunocytochemical and histological analyses. Prerequisite: junior or senior standing in Biomedical Engineering or consent of the instructor.

42-671 Precision Medicine for Biomedical Engineers
Fall: 9 units
This course explores the opportunities for engineers in precision medicine of complex medical disorders. Students will interact with clinical practitioners and investigate the technological challenges that face these practitioners. The course will focus on common complex conditions and diseases such as inflammatory bowel disease (IBD), pancreatitis, diabetes mellitus and obesity, rheumatoid arthritis, multiple sclerosis, pain syndrome and pharmacogenetics. Improvement in care of these conditions requires a reverse engineering approach, and new tools because of the complexity and unpredictability of clinical course and best treatments on a case-by-case basis. Currently, the cost of medications for these conditions in Pittsburgh alone is and gt;1 billion, with a large percent of patients receiving less than optimal treatment because of lack of precision medicine tools. The course includes introduction to medical genetics, biomarkers of disease, health records, disease modeling, outcome predictions, therapies, remote monitoring and smart applications. Special lectures on health economics and career opportunities are also planned. Each session will include didactic lectures, workshops and development of applications. Specific engineering topics which may be relevant to each of these specialties as well as topics which span many specialties (for example biodetectors, computational biology, bioinformatics, UI/UX, gaming ideas to connect patients to products, integrated applications) will be presented by various faculty members of the CMU biomedical engineering and other dept. and UPMC/UPitt faculty. Students will gain experience exploring genetic variants associated with common diseases, including the opportunity to explore their own DNA. Instructors: David C. Whitcomb, MD, PhD (UPMC) Philip Empey, PharmD, PhD (UPMC)

42-672 Fundamentals of Biomedical Imaging and Image Analysis
Spring: 12 units
This course introduces fundamentals of biological and medical imaging modalities and related image analysis techniques. It is organized into three units. The first unit introduces fundamental principles of biological imaging modalities, such as fluorescence microscopy, super-resolution microscopy, and electron microscopy. These modalities are used to visualize and record biological structures and processes at the molecular and cellular levels. The second unit introduces fundamental principles of imaging modalities, such as magnetic resonance imaging, x-ray computed tomography, and ultrasound. These modalities are used to visualize and record medical structures and processes at the tissue and organ levels. Recent developments in convergence of biological and medical imaging are briefly discussed. The third section introduces fundamentals of computational techniques used for analyzing and understanding biological and medical images, such as deconvolution, registration, segmentation, tracking, and pattern recognition. The introduction to these topics will draw on concepts and techniques from several related fields, including physics, statistics, signal processing, computer vision, and machine learning. As part of the course, students will complete several independent projects. Students will also have the opportunity to visit laboratories to see some of the actual biomedical imaging devices in action. Prerequisites: 18-290 Signals and Systems or permission of the instructor. Proficiency in basic programming is expected. Knowledge of image processing, computer vision, and/or MATLAB is helpful but not essential.

42-673 Special Topics: Stem Cell Engineering
Intermittent: 9 units
Special Topics: This course will give an overview over milestones of stem cell research and will expose students to current topics at the frontier of this field. It will introduce students to the different types of stem cells as well as environmental factors and signals that are implicated in regulating stem cell fate. The course will highlight techniques for engineering of stem cells and their micro-environment. It will evaluate the use of stem cells for tissue engineering and therapies. Emphasis will be placed on discussions of current research areas and papers in this rapidly evolving field. Students will pick a class-related topic of interest, perform a thorough literature search, and present their findings as a written report as well as a paper review and a lecture. Lectures and discussions will be complemented by practical lab sessions, including: stem cell harvesting and culture, neural stem cell transfection, differentiation assays, and immunostaining, polymeric microcapsules as advanced culture systems, and stem cell integration in mouse brain tissue. The class is designed for graduate students and upper undergraduates with a strong interest in stem cell biology, and the desire to actively contribute to discussions in the class.

42-674 Special Topics: Engineering for Survival: ICU Medicine
Intermittent: 9 units
Special Topics: Engineering for Survival: ICU Medicine The overall learning objective of this class is to expose students to acute care medicine and the fundamentals of acute illness. The lectures review the structure and function of different body systems. Typical modes of failure (disease) are then described and illustrated with examples using actual de-identified cases based on over 30 years of experiences in the intensive care unit (ICU) by Dr. Rosenbloom. Field trips are made to a local critical care and emergency medicine simulation facility at the University of Pittsburgh. An optional opportunity to participate in ICU rounds is also available. Requirements: Junior standing and higher

42-675 Fundamentals of Computational Biomedical Engineering
Fall: 12 units
This goal of this course is to enable students with little or no programming background to use computational methods to solve basic biomedical engineering problems. Students will use MATLAB to solve linear systems of equations, model fit using least squares techniques (linear and nonlinear), interpolate data, perform numerical integration and differentiation, solve differential equations, and visualize data. Specific examples for each topic will be drawn from different areas of biomedical engineering, such as bioimaging and signal processing, biomechanics, biomaterials, and cellular and biomolecular technology.

42-676 Bio-nanotechnology: Principles and Applications
Fall: 9 units
Have you ever wondered what is nanoscience and nanotechnology and their impact on our lives? In this class we will go through the key concepts related to synthesis (including growth methodologies and characterizations techniques) and chemical/physical properties of nanomaterials from zero-dimensional (0D) materials such as nanoparticles or quantum dots (QDs), one-dimensional materials such as nanowires and nanotubes to two-dimensional materials such as graphene. The students will then survey a range of biological applications of nanomaterials through problem-oriented discussions, with the goal of developing design strategies based on basic understanding of nanoscience. Examples include, but are not limited to, biomedical applications such as nanosensors for DNA and protein detection, nanodevices for bioelectrical interfaces, nanomaterials as building blocks in tissue engineering and drug delivery, and nanomaterials in cancer therapy. This class is open for both undergraduate (junior/senior) and graduate students.

42-678 Medical Device Innovation and Realization
Spring: 12 units
The increasing pace of medical discoveries and emerging technologies presents a unique and exciting time for medical devices. Medical devices range from biomaterials that stimulate the body to repair itself to drug eluting stints to robotic surgical systems. Because they seek to improve and prolong human health, there are unique requirements and challenges for medical device development compared to most other industries. This class will look at how medical device innovation is currently practiced as well as the drivers which govern it, such as the FDA, intellectual property, reimbursement, and funding. By the end of this course, students should be able to: (1) obtain a broad understanding of medical devices; (2) identify new product opportunities; (3) understand the drivers that affect medical device development; and (4) develop strategies to address those drivers within the overall medical device development plan.

42-681 Disease Models for Therapeutic Discovery
Spring: 9 units
One of the key challenges in the fields of tissue engineering and disease modelling is a disconnect between the use of robust bioengineering tools and our limited understanding of pathobiology. The future of these fields depends on biomedical engineers using their technical skill sets to study normal physiology and disease mechanisms. In this class, we will explore current state-of-the-art methods for creating tissue and disease models, including: 2D/3D tissue cultures, bioreactors, organs-on-a-chip, microfluidic models, disease-in-a-dish models (with discussions on coupling multiple tissue systems), animal models of disease, and CRISPR/CAS9. The first few weeks of the semester will focus on learning the state-of-the-art methods with 1 exam as an assessment. The rest of the class will focus on specific disease modules with journal reviews and experts sharing their research on disease models with the class. For assessment, students will read 1 journal article each week and provide a brief critique. In addition, they will write a grant and present to the class methods for creating a disease model of their choice. At the end of the class, students will be able to critically assess and design models of normal and pathobiological disease mechanisms. Prior knowledge of basic physiology is required.

42-682 Bioinstrumentation
Intermittent: 12 units
This course aims to build concepts and skills in electronics for the design and construction of instruments for biomedical applications. The course uses a flipped, fast-paced format to cover a range of electronic components and circuits, including resistors, capacitors, transistors, sensors, actuators, amplifiers, signal filters, and microcontrollers, through lectures, tutorials, weekly lab projects, and term projects. Students, with or without a background in electronics, will gain hands-on skills to build functional instruments for physiological measurements such as temperature, gas concentration, blood pressure, and EKG signals.

42-683 Introduction to Machine Learning for Biomedical Engineers
Fall: 9 units
This course introduces fundamental concepts, methods and applications in machine learning and datamining. We will cover topics such as parametric and non-parametric learning algorithms, support vector machines, neural networks, clustering, clustering and principal components analysis. The emphasis will be on learning high-level concepts behind machine learning algorithms, and applying them to biomedical-related problems. This course is intended for advanced undergraduate and graduate students in Biomedical Engineering or related disciplines. Students should have experience with high-level programming language such as Matlab, basic familiarity with probability, statistics and linear algebra, and should be comfortable with manipulating vectors and matrices.

42-684 Principles of Immunoengineering and Development of Immunotherapy Drugs
Fall: 9 units
This course will provide context for the application of engineering principles to modulate the immune system to approaches problems in human health. Basic understanding of the components and function of the innate and adaptive immune system. Students will leave with a basic understanding of immunology and of the engineering techniques used to develop and characterize immunotherapy systems. Where appropriate, we will discuss how immunoengineering fits into other disciplines of engineering such as mechanical, chemical, and materials science. Because the purpose of immunoengineering is disease treatment, we will discuss, the therapy pipeline, development of clinical trials and the FDA approval process. Immunotherapy will also be assessed within different disease contexts including cancer, infectious disease, allergies, prosthetics and implants, neuro and musculoskeletal disorders.

42-685 Biostatistics
Spring: 9 units
This course introduces statistical methods for making inferences in engineering, biology and medicine. Students will learn how to select the most appropriate methods, how to apply these methods to actual data, and how to read and interpret computer output from a commonly used statistical package. The topics covered are descriptive statistics; elementary probability; discrete and continuous random variables and their distributions; hypothesis testing involving interval (continuous and discrete) and categorical (nominal and ordinal) variables, for two and three or more treatments; simple and multiple linear regression; time-series analysis; clustering and classification; and time-to-event (survival) analysis. Students will also learn how to write the statistical component of a "Results" section for a scientific paper and learn about the limitations of the statistical analyses. Basic familiarity with probability and probability distribution preferred but not required.

42-687 AI Applications in BME
Spring: 12 units
This course provides hands-on experience in applying the fundamentals of artificial intelligence/machine learning (AI/ML) to problems in a variety of biomedical research areas and applications. Students will work in teams to design, develop, and evaluate an AI/ML system to achieve one or more of the following goals: identifying patterns in the data, modeling the input-output relationships and/or classifying data into distinct categories. The datasets for this course will be drawn from different BME-related areas provided by biomedical researchers, clinicians, and other publicly available sources. In addition to the project work, the course will discuss issues that are specific to the development and implementation of AI algorithms in medical settings. This includes FDA approval, human clinical trials, the Health Insurance Portability and Accountability Act, and medical ethics. This computational project-based course is available to any student who has completed Introduction to Machine Learning course.

42-688 Introduction to Neural Engineering
Intermittent: 12 units
Neural engineering sits at the interface between neuroscience and engineering, applying classical engineering approaches and principles to understand the nervous system and its function. Modern neural engineering techniques have been used to measure neural activity using tools based on light, electricity, and magnetism. The same tools for measurement can be redirected to modulate neural activity, and manipulate how an organism perceives, thinks, and acts. The course objectives are to familiarize students with a range of neural engineering approaches to investigating and intervening in the nervous system, emphasizing quantitative understanding and fundamental engineering concepts. The course will pair lectures and discussion with projects involving real neural data (Matlab-based exercises). Example projects could include finding visual responses in EEG data, or determining how groups of individual neurons interact based on spiking data. Overall, the goal is to give the student a deep understanding of select topics in neuroscience and the application of quantitative neural engineering approaches to these topics. This course is intended for advanced undergraduate and entering graduate students. Familiarity with linear algebra, signal processing, and introductory Matlab programming is helpful. This course is suitable for students coming from diverse backgrounds: (1) Students with non-engineering backgrounds seeking quantitative skills, and wanting to learn an engineering approach to neuroscience problems, and (2) students with engineering or other quantitative backgrounds who are seeking ways to apply their skills to scientific questions in neuroscience.

42-689 Introduction to Biomedical Imaging
Spring: 9 units
The field of medical imaging describes methods of seeing the interior of the human body, as well as visual representation of tissue and organ function. The materials covered in this course will give an overview of existing medical imaging devices used in a clinical and pre-clinical setting. The course presents the principles of medical imaging technologies, explaining the mathematical and physical principles, as well as describing the fundamental aspects of instrumentation design. Students will gain a thorough understanding of how these methods are used to image morphological and physiological features. Imaging methods will include Ultrasound, X-ray, computed tomography (CT), and magnetic resonance imaging (MRI), as well as optical methods. For each method, the fundamental imaging principles will be discussed, and examples of clinical applications will be presented. No prior knowledge of imaging methods is required.

42-690 BME in Everyday Life
Intermittent: 9 units
This course focuses on how biomedical engineering technologies are used in everyday life. The objective is to develop an understanding of the clinical need for these technologies, and past and current solutions to meet these clinical needs. Topics covered include artificial organs, tissue engineering, brain-control interfaces, and immunoengineering. For each medical condition being addressed, biology physiology, and anatomy concepts will be applied in the context of biomedical engineering technology. This course is suitable for non-engineering majors who have an interest in biomedical engineering.

42-691 Biomechanics of Human Movement
Spring: 12 units
This course provides an overview of the mechanical principles underlying human movement biomechanics and the experimental and modeling techniques used to study it. Specific topics will include locomotion, motion capture systems, force plates, muscle mechanics, musculoskeletal modeling, three dimensional kinematics, inverse dynamics, forward dynamic simulations, and imaging-based biomechanics. Homework and final class projects will emphasize applications of movement biomechanics in orthopedics, rehabilitation, and sports.
Prerequisites: 21-260 and 24-351

42-692 Special Topics: Nanoscale Manufacturing Using Structural DNA Nanotechnology
Fall: 12 units
This course provides an introduction to modern nanoscale manufacturing using structural DNAnanotechnology. This DNA-based approach to manufacturing has much in common with other fabrication methods in micro- and nano-engineering: computer aided design tools are necessary for device design and resulting structures can only be seen using advanced microscopy. However, instead of machining larger materials down to micro- and nanostructures, DNA origami is fabricated using a "bottom up" approach for self-assembling individual oligonucleotides into 2D and 3D nanostructures. Resulting structures can be designed to have novel mechanical and electrical properties and have applications as broad-ranging as medicine, biological computing, and energy systems. The course will include lectures, hands-on physical modeling, homework problems, 3D modeling of DNA origami using caDNAno and CANDO software, and student team projects and presentations.

42-693 Special Topics in Integrated Systems Technology: Micro/Nano Biomedical Devices
Fall: 12 units
Biomedical devices constantly call for innovations. Micro/nano fabrication not only miniaturizes devices and instruments, but also can enable new biomedical devices and significantly boost device performance. This course introduces fundamental micro/nano fabrication technologies and related materials of biomedical devices. The biomedical background and design principles of various biomedical devices will be presented. Both diagnostic and therapeutic devices will be discussed, including point-of-care diagnostic devices, biosensors, DNA sequencers, medical implants, prosthetic devices, drug delivery systems, medical robots, etc.

42-694 Engineering Principles of Medical Devices
Intermittent: 9 units
Medical devices are apparatuses widely used in diagnosis, treatment and prevention of human diseases. The invention and adoption of medical devices is one of the major driving forces for the revolution in modern healthcare. This course takes a systematic and quantitative approach for the design and implementation of medical devices. We will mainly focus on three major medical device categories: bioelectrical devices, biomechanical devices, and medical devices enabled by emerging technologies. For each category, domain knowledge and fundamental principles will be introduced, and detailed design, implementation, and performance analysis will be studied. Analytical equations and simulation tools will be used when appropriate. The course will prepare students with a solid foundation to further study, research, and work in medical device related fields. Pre-requisite or Co-requisite: 42-202 and (21-120 or 21-122 or 21-259) and (33-141 or 33-142) or permission of instructor

42-696 Special Topics: Wearable Health Technologies
Spring: 12 units
This course will provide an overview of emerging wearable health technologies and give students hands-on experience in solving ongoing technical challenges. The wearable sensing field is experiencing explosive growth, with exciting applications in medicine. New lightweight devices will make it easier to monitor health conditions in real time, automatically import data into health informatics systems, and provide haptic feedback with humans in the loop. We will review several aspects of these technologies, including hardware, software, user experience, communication networks, applications, and big data analytics. Students will be paired with a company for a semester-long project that tackles timely computational challenges. Programing experience, in any language, is a pre-requisite.

42-713 Applied Nanoscience and Nanotechnology
Fall and Spring: 12 units
Have you ever wondered what is nanoscience and nanotechnology and their impact on our lives? In this class we will go through the key concepts related to synthesis (including growth methodologies and characterizations techniques) and chemical/physical properties of nanomaterials from zero-dimensional (0D) materials such as nanoparticles or quantum dots (QDs), one-dimensional materials such as nanowires and nanotubes to two-dimensional materials such as graphene. The students will then survey a range of applications of nanomaterials through problem-oriented discussions, with the goal of developing design strategies based on basic understanding of nanoscience. Examples include, but are not limited to, biomedical applications such as nanosensors for DNA and protein detection, nanodevices for bioelectrical interfaces, nanomaterials as building blocks in tissue engineering and drug delivery, and nano materials in cancer therapy. Pre-requisite: Graduate standing. College level chemistry or physical chemistry, and thermodynamics.

42-737 Biomedical Optical Imaging
Fall: 12 units
Biophotonics, or biomedical optics, is a field dealing with the application of optical science and imaging technology to biomedical problems, including clinical applications. The course introduces basic concepts in electromagnetism and light tissue interactions, including optical properties of tissue, absorption, fluorescence, and light scattering. Imaging methods will be described, including fluorescence imaging, Raman spectroscopy, optical coherence tomography, diffuse optical spectroscopy, and photoacoustic tomography. The basic physics and engineering of each imaging technique are emphasized. Their relevance to human disease diagnostic and clinical applications will be included, such as breast cancer imaging and monitoring, 3D retinal imaging, ways of non-invasive tumor detection, as well as functional brain imaging in infants.

42-772 Special Topics: Applied Nanoscience and Nanotechnology
Fall: 12 units
Have you ever wondered what is nanoscience and nanotechnology and their impact on our lives? In this class we will go through the key concepts related to synthesis (including growth methodologies and characterizations techniques) and chemical/physical properties of nanomaterials from zero-dimensional (0D) materials such as nanoparticles or quantum dots (QDs), one-dimensional materials such as nanowires and nanotubes to two-dimensional materials such as graphene. The students will then survey a range of applications of nanomaterials through problem-oriented discussions, with the goal of developing design strategies based on basic understanding of nanoscience. Examples include, but are not limited to, biomedical applications such as nanosensors for DNA and protein detection, nanodevices for bioelectrical interfaces, nanomaterials as building blocks in tissue engineering and drug delivery, and nano materials in cancer therapy. Pre-requisite: Graduate standing. College level chemistry or physical chemistry, and thermodynamics.

42-774 Special Topics: Introduction to Biophotonics
Fall: 12 units
Biophotonics, or biomedical optics, is a field dealing with the application of optical science and imaging technology to biomedical problems, including clinical applications. The course introduces basic concepts in electromagnetism and light tissue interactions, including optical properties of tissue, absorption, fluorescence, and light scattering. Imaging methods will be described, including fluorescence imaging, Raman spectroscopy, optical coherence tomography, diffuse optical spectroscopy, and photoacoustic tomography. The basic physics and engineering of each imaging technique are emphasized. Their relevance to human disease diagnostic and clinical applications will be included, such as breast cancer imaging and monitoring, 3D retinal imaging, ways of non-invasive tumor detection, as well as functional brain imaging in infants. Pre-requisite: Graduate standing. College level physics covering electromagnetism and optics or permission of the instructor.

42-783 Neural Engineering Laboratory
Intermittent: 12 units
Neural engineering applies classic engineering approaches and principles to understand the nervous system and its function. The measurement of neural activity involves a number of basic tools that have evolved over decades to sense the activity of neurons (individual neurons, populations of neurons and nerve fibers) or activity that is related to neurons (such as the oxygenation of blood in the brain). To intervene in the nervous system, a comparable set of tools have evolved to change neural activity locally or globally, on short and long time scales. The successful application of these methods to measure and manipulate neural activity requires both a basic science and engineering understanding of the principles behind their action, along with practical experience in applying them in real-world settings. This laboratory course will pair lectures with laboratory exercises to gain a deep understanding of the tools we use to measure and manipulate neural activity, as well as the analytic approaches to this data. It will involve both building and diagnosing recording hardware, experimental data collection, data analysis in Matlab or Python, and scientific writing. Overall, the goal is to provide students with a deep understanding of the methods for acquiring experimental data in neuroscience. Familiarity with signal processing and introductory Matlab or Python programming is helpful. This course is suitable for students from diverse backgrounds: (1) Students with experimental backgrounds seeking a range of hands-on experience in different experimental settings and a deeper understanding of different experimental methods, and (2) students with engineering and other quantitative backgrounds seeking exposure to experimental data collection methods and practices.

42-880 Biomaterials
Fall: 9 units
This course is currently only for those enrolled in the 3D Biofabrication and Bioprinting Certificate program. Understanding the fundamentals of biomaterials structure-function relationships pertaining to material functions and to cell and tissue environments will be a prime goal. The course will be composed of lectures, readings, projects and technical writing assignments. The synthesis, characterization and functional properties of organic and inorganic biomaterials and the processes involved in their use in tissue engineering and regenerative medicine will be discussed. Fundamental issues related to the utility of biomaterials, including biomechanics, transport, degradability, biointerfaces and biocompatibility, stability, fate in the body will be covered, along with some of the basic approaches to characterization. Clinical applications for biomaterials and new directions in design and synthesis to achieve better biocompatibility will be emphasized.