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 & 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: 3 units
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. Prerequisite or co-requisite: 42-101 Introduction to Biomedical Engineering

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: 03-121 or 03-151

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. Prerequisites: 42-101 Introduction to Biomedical Engineering and 03-121 Modern Biology. 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 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.

42-302 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 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 18-202 or 06-262

42-341 Introduction to Biomechanics
Fall: 9 units
This course covers the application of solid and fluid mechanics to living tissues. This includes the mechanical properties and behavior of individual cells, the heart, blood vessels, the lungs, bone, muscle and connective tissues as well as methods for the analysis of human motion.
Prerequisites: 06-261 or 12-355 or 24-231

42-400 Senior 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.

42-401 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: Senior standing in Biomedical Engineering. Co-requisite: 42-101.
Prerequisites: 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 and is expected to be completed along with the Fall semester course. This course culminates in the completion of multiple prototypes, a poster presentation, and a written report. Prerequisite: 42-401

42-411 Engineering Biomaterials  
Fall: 9 units  
This course will cover structure-processing-property relationships in biomaterials for use in medicine. This course will focus on a variety of materials including natural biopolymers, synthetic polymers, and soft materials with additional treatment of metals and ceramics. Topics include considerations in molecular design of biomaterials, understanding cellular aspects of tissue-biomaterials interactions, and the application of bulk and surface properties in the design of medical devices. This course will discuss practical applications of these materials in drug delivery, tissue engineering, biosensors, and other biomedical technologies. Prerequisites: 06-221 or 24-221 or 27-215

42-426 Biosensors and BioMEMS  
Intermittent: 9 units  
This course emphasizes the principles of biomolecule-based sensing, including molecular recognition, biomolecular binding kinetics and equilibrium; methods of detection and signal transduction, including optical, colorimetric, fluorescence, potentiometric, and gravimetric techniques; statistical principles of high throughput screening; microfluidic and microarray device design principles and fabrication technologies; molecular motors. Prerequisites: 03-231 OR 03-232 Biochemistry. Prerequisite: 03-232

42-431 Introduction to Biomedical Imaging and Image Analysis  
Fall: 12 units  
This course gives an overview of tools and tasks in various biological and biomedical imaging modalities, such as microscopy, magnetic resonance imaging, x-ray computed tomography, ultrasound and others. Students will be exposed to the major underlying principles in modern imaging systems as well as state of the art methods for processing biomedical images such as deconvolution, registration, segmentation, pattern recognition, etc. The discussion of these topics will draw on applications from many fields, including physics, statistics, signal processing, and machine learning. As part of the course, students will be expected to complete an independent project. Students will have the opportunity to visit laboratory to see real biomedical imaging devices in action. Prerequisites: 18-290 Signals and Systems or permission of the instructor, working knowledge of Matlab, and some image processing experience. Cross-listed courses: 18-496  
Prerequisites: 18-290 and 42-202

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 course is an introduction to the engineering, clinical, legal and regulatory aspects of medical device performance and failure. Topics covered include a broad survey of the thousands of successful medical devices in clinical use, as well as historical case studies of devices that were withdrawn from the market. In-depth study of specific medical devices will include: cardiovascular medicine, orthopedics, and general medicine. We will study the principles of operation (with hands-on examples), design evolution, and modes of failure. Additional lectures will provide basic information concerning biomaterials used for implantable medical devices (metals, polymers, ceramics) and their biocompatibility, 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 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. Open only to students with junior standing who have had at least one engineering class or by permission of instructor.

42-474 Special Topics: Introduction to Biophotonics  
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: 42-474 is intended for undergraduates only. Pre-requisite: 33-107 Physics II for Engineering Students or permission of the instructor. Prerequisite: 33-107

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: 9 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.
42-620 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.

42-622 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 individual-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, biochemical 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: 03-232 or 42-321 or 06-422

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 perform 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 03-21 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.

42-630 Introduction to Neuroscience for Engineers
Intermittent: 12 units
The first half of the course will introduce engineers to the neurosciences from the cellular level to the structure and function of the central nervous system (CNS) and include a study of basic neurophysiology; the second half of the course will review neuroengineering methods and technologies that enable study of therapeutic solutions for diseases or damage to the CNS. A goal of this course is to provide a taxonomy of neuroengineering technologies for research or clinical application in the neurosciences.

42-631 Neural Data Analysis
Fall: 9 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. Prerequisites: Undergraduate probability (36-225/227, or its equivalent), some familiarity with linear algebra and Matlab programming.

42-632 Neural Signal Processing
Fall: 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.

42-640 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 biomechanics and simulations at the molecular, cellular, tissue, and organ level scales.

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 motor 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. iec.
Prerequisite: Instructor permission. Prerequisites: None. Corequisites: None. Cross Listed Courses: 24-655 Notes: None. Reservations:

42-646 Molecular Biomechanics
Intermittent: 9 units
This class is designed to present concepts of molecular biology, cellular biology and biophysics at the molecular level together with applications. Emphasis will be placed both on the biology of the system and on the fundamental physics, chemistry and mechanics which describe the molecular level phenomena within context. In addition to studying the structure, mechanics and energetics of biological systems at the nano-scale, we will also study and conceptually design biomimetic molecules and structures. Fundamentals of DNA, globular and structured proteins, lipids and assemblies thereof will be covered.

42-647 Continuum Biomechanics: Solid and Fluid Mechanics of Physiological Systems
Spring: 12 units
This course provides a general survey of the solid and fluid mechanics of physiological systems, within the framework of continuum mechanics. The main objective of the course is to understand mathematical modeling of solid materials such as bone and tissues, and fluid mechanics of blood and other biofluids such as synovial fluid, etc. The course as a whole encourages class participation and discussion in a seminar-type fashion. The course begins with a historical review of the subject followed by a review of vector and tensor analysis, before discussing various measures of deformation and stress formulations. The development and understanding of appropriate constitutive models for particular problems are at the core of this course. Both analytical and to some extent experimental results are presented through readings from recent journals and the relevance of these results to the solution of unsolved problems is highlighted. The intent is to provide the basic ideas of continuum mechanics for engineering and science students with little or no background in biomechanics or mathematical modeling, with particular emphasis on the application of quantitative and system perspectives to fluid and solid mechanics problems. In addition to looking at various examples with physiological applications, the last few weeks of the course are dedicated to discussing individually-crafted research projects for the students.

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).

42-661 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, 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 (42-101 or 27-100 or 24-101 or 19-101 or 06-100 or 12-100 or 18-100)

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

42-664 Bioinstrumentation
Intermittent: 9 units
This course aims to build the foundation of basic principles, applications and design of bioinstrumentation. Topics covered include biosignals recording, transducers for biomedical application, action potentials EMG, EEG, ECG, amplifiers and signal processing, blood flow and pressure measurements, data acquisition and signal conditioning, spectral analysis of data, filtering, and safety aspects of electrical measurements. Ultimately, students will learn: (1) how to apply basic circuit theory to perform measurement of biosignals, (2) be familiar and use common measurement devices, such as multimeter and oscilloscope, (3) be familiar with Op-amps circuits, (4) how to acquire and analyze a signal using time and frequency techniques, and (5) how to filter a signal to remove noise. Pre-requisite: Physics II (E&M)

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. New characterization techniques will include cell culture techniques, microscopic, cytotechnical, 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 >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 engineering 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/CASS. 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.

42-674 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

42-676 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.'

42-678 Medical Device Innovation and Realization  
Spring: 6 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.

42-679 Medical Device Realization  
Spring: 9 units  
This course is a companion to 42-678, Medical Device Innovation, which is a pre-requisite for this course. Medical Device Realization will take the research and early conceptualization work in 42-678and use it to further conceptize and develop a prototype. Prerequisites: 49-732 or 42-678

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/CASS. 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 and Measurement
Fall: 12 units
This course aims to build the understanding of basic concepts and applications of instrumentation used for biomedical research and patient care. The course will follow a fast track, using a flipped format to cover components ranging from simple resistors, capacitors, transistors, sensors, actuators, to operational amplifiers and microcontrollers, using a combination of lectures, guided tutorials, lab exercises, and term projects. Students will gain hands-on skills of how to integrate components into functional instruments, based on physiological measurements such as temperature, humidity, oxygen concentration, blood pressure, and EKG signals. MATLAB programming will be used throughout the course. The course is designed for advanced undergraduate and graduate students with a knowledge in basic physics of electricity and magnetism.

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 immunoengeenering fits into other disciplines of engineering such as mechanical, chemical, and materials science. Because the purpose of immunoengeenering 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 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.

42-686 Biomedical Ultrasound
Intermittent: 9 units
In this course, emerging technologies using sound waves and their biomedical applications will be introduced. The course will cover the fundamental physics of the propagation and the interaction of sound waves with biological tissues, acoustic devices and sensors, and associated core signal processing for imaging, stimulation, and therapy. Their applications in biomedicine in different scales from cell, tissue, organ to whole body, and from structural to functional scale will be discussed. Students should have a background in Physics II and differential equations.
Prerequisites: 21-260 and 33-142

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 Bioimaging
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

42-693 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.
42-713 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.

42-735 Medical Image Analysis
Spring: 12 units
Students will gain theoretical and practical skills in medical image analysis, including skills relevant to general image analysis. The fundamentals of computational medical image analysis will be explored, leading to current research in applying geometry and statistics to segmentation, registration, visualization, and image understanding. Student will develop practical experience through projects using the National Library of Medicine Insight Toolkit (ITK), a popular open-source software library developed by a consortium of institutions including Carnegie Mellon University and the University of Pittsburgh. In addition to image analysis, the course will include interaction with clinicians at UPMC. It is possible that a few class lectures may be videoed for public distribution. Prerequisites: Knowledge of vector calculus, basic probability, and either C++ or python. Required textbook, 'Machine Vision', ISBN: 052116981X; Optional textbook, 'Insight to Images', ISBN: 9781568812175. Prerequisite: 03-121
Course Website: http://www.cs.cmu.edu/~galeotti/methods_course/

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. Pre-requisite: Graduate standing. College level physics covering electromagnetism and optics or permission of the instructor.

42-773 Special Topics: Inventive Problem Solving in Biomedical Engineering
Fall: 12 units
This course is aimed at discovering inventive solutions to some of medicines most difficult problems. It involves a theory of inventive problem solving known as Triz that teaches the student how to invent on demand. The structure of the course will follow a flipped classroom model: with reading assignments and pre-recorded lectures assigned before class and homework performed in-class. This will allow students to learn the material at their own pace, and to translate theory to practice in a group setting with mentorship of the course instructor and teaching assistant, and teamwork of classmates. Throughout the semester, specific problems will be assigned to the entire class on topics emphasizing cost saving (affordable health care act), medicine for under-resourced settings, and global health. A final project will be required of each student on a topic of choice (with instructor approval.) Each project will have an associated client from industry or healthcare who will serve as outside reviewer. The composition of the class will emphasize biomedical engineering students, but will also invite a limited enrollment of students from the School of Design, Tepper, and Heinz. Accordingly, there will be emphasis on multi-disciplinary teamwork, and networking. In summary, the goals of this course are to: develop formal skills in inventive problem solving, gain proficiency in teamwork and networking, and to actually solve real-world problems in medicine. May count as practicum for practicum-option MS. Pre-requisite: Graduate standing for MCS and CIT students. For non-MCS or CIT graduate students, a degree in a science or engineering. For all other students, permission of the instructor.

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.