BIOENGINEERING
(EG) {BE}

100. Introduction to Bioengineering. (A) Corequisite(s): MATH 104, PHYS 140 or 150. Freshmen Only. Freshmen Only

Survey course introducing students to the breadth of bioengineering. Course consists of introductory lectures, guest speakers/panelists, and a series of small assignments that allow students to explore different facets of bioengineering and the Penn Bioengineering program.

101. Introduction to Bioengineering II. Prerequisite(s): BE 100. Freshmen Only

Introduction to Bioengineering II. Continuation of the freshman introductory bioengineering course. This course introduces students to the design process and emphasizes its role in engineering.

L/R 200. Introduction to Biomechanics. (A) Prerequisite(s): MATH 114, PHYS 140, or PHYS 150. Corequisite(s): MATH 240.

This course investigates the application of statics and strength of materials to soft and hard biologic tissues. The course will cover simple force analyses of the musculoskeletal system and introduces the fundamentals of the mechanics of materials including axial loading, torsion and bending and their application to biomechanics. The lecture and recitation will be complemented with hands-on examples emphasizing connections between theoretical principles and practical applications.

220. Biomaterials. (B) Prerequisite(s): BE 200, CHEM 102.

This course investigates the application of materials science and engineering to biomedical applications, with a focus on polymers, ceramics, and metals. The course will cover concepts related to basic material fabrication and synthesis, structure and property characterization, as well as applications of biomaterials. The lecture and recitation will be complemented with laboratory examples of material assessment and characterization.

SM 225. Technology and Engineering in Medicine. (C) Prerequisite(s): Math 114, Physics 140 and 141 or Physics 150 and 151; sophomore and higher only.

The course is appropriate for engineering and science majors and premeds. This engineering course will provide an examination of technology and its design and its impact on medicine with an emphasis on the intersection of engineering with medicine and health. Modules will focus on specific technological advances as a basis for the discussion. Planned topics change from yea r to year and include, for example, cochlear implants and visual sensory rehabilitative devices. The course includes homework and reading assignments. Every student presents a paper on a relevant biomedical technology.

L/R 301. Bioengineering Signals and Systems. (A) Prerequisite(s): MATH 241, PHYS 141 OR 151, ENGR 105 (can be taken as a corequisite).

Properties of signals and systems; Examples of biological and biomedical signal and systems; Signal operations, continuous and discrete signals; Linear, time invariant systems; Time domain analysis; Systems characterized by linear constant-coefficient differential equations; Fourier analysis with applications to biomedical signals and systems; Introduction to filtering; Sampling and the sampling theorem. Examples vary from year to year, but usually include signals such as the ECG and blood pressure wave, principles of signal coding in the auditory system and cochlear implants, and simple applications in biomedical imaging.

L/R 305. Engineering Principles of Human Physiology. (A) Prerequisite(s): MATH 241.

Quantitative analysis of cellular and systems-level human physiology. Emphasis is on the neural, cardiovascular, musculoskeletal, and pulmonary systems.

BIOENGINEERING
(EG) {BE}

L/R 306. Molecular Physiology and Cellular Engineering from Atoms to Disease. Prerequisite(s): CHEM 102, MATH 241, PHYS 140/141, BIOL 121.

This course explores physical biology of the cell across several length and timescales, while simultaneously emphasizing molecular specificity and clinical implications such as disease outcome or biomedical applications. The course emphasizes how the basic tools and insights of engineering, physics, chemistry, and mathematics combined with "Big Data" can illuminate the study of molecular and cell biology to make predictive biomedical models and subject them to clinical validation. Drawing on key examples and seminal experiments from the current clinical literature, the course demonstrates how quantitative models can help refine our understanding of existing biological data and also be used to make useful clinical predictions. The course blends traditional models in cell biology with the quantitative approach typical in engineering, in order to introduce the student to both the possibilities and boundaries of the emerging field of physical systems biology. While teaching physical model building in cell biology through a practical, case-study approach, the course explores how quantitative modeling based on engineering principles can be used to build a more profound, intuitive understanding of cell biology. Lab modules will be embedded in the lectures and all labs will be in silico (or computational) in nature.

309. Bioengineering Lab I. (A) Prerequisite(s): ENGR 105, PHYS 141/151, MATH 240, BE 200, BE 220.

The first of two laboratory courses that are taken during the junior year. The goal of these laboratories is to provide students with hands-on experience in utilizing fundamental engineering skills to solve complex medical problems. Topics vary from year to year but generally include instrumentation, analog and electronics, fluid transport, pharmacokinetics, and engineering physiology. The course includes a lecture component and laboratory experiments. Students work in teams and submit assignments, a midterm, lab reports, and a final lab practical.

310. Bioengineering Lab II. (B) Prerequisite(s): ENGR 105, PHYS 141/151, BE 220, BIOL 121/123, MATH 240. Corequisite(s): MATH 241, BE 301.

The second of two laboratory courses that are taken during the junior year. The goal of these laboratories is to provide students with hands-on experience in utilizing fundamental engineering skills to solve complex medically relevant problems. Topics vary from year to year but generally include instrumentation, analog and digital electronics, signals and systems, microfluidics, synthetic biology, and rapid prototyping. The course includes a lecture component and laboratory experiments. Students work in teams and submit assignments, lab reports, and a final lab practical.

L/R 324. Chemical Basis of Bioengineering II. (A) Prerequisite(s): PHYS 140, 141 or 150, 151, MATH 240, CHEM 101, 102.

Advanced topics in physical chemistry including solution and colloid chemistry, electrochemistry, surface phenomena, and macromolecules applied to biological systems.

330. (MSE 330) Soft Materials. (C) Prerequisite(s): Juniors and higher, CHEM 102.

This course will serve as an introduction of soft condensed matter to students with background in chemistry, physics and engineering. It covers general aspects of fundamental interactions between soft materials with applications involving polymers, colloids, liquid crystals, amphiphiles, food and biomaterials.

L/R 350. Introduction to Biotransport Processes. (B) Prerequisite(s): MATH 241, PHYS 140 or 150.

Introduction to basic principles of fluid mechanics and of energy and mass transport with emphasis on applications to living systems and biomedical devices.

BIOENGINEERING
(EG) {BE}

400. Preceptorship in Clinical Bioengineering. (B) Junior and Senior BE majors only

Introduction to the integration of biomedical engineering in clinical medicine through lectures and a preceptorship with clinical faculty. This course is for BE majors ONLY, with preference given to BSE students.

440. (BE 540) Biomolecular and Cellular Engineering. (C)

This course will introduce concepts and methods for the quantitative understanding of molecular and cellular phenomena. Topics include molecular recognition, receptor-ligand binding, viral infection, signal transduction, cell adhesion, motility, and cytoskeletal dynamics. The course requires mathematics at the level of differential equations, and some knowledge of Matlab programming. A basic knowledge of cell biology is suggested, although not required.

441. Engineering Microbial Systems. (C) Prerequisite(s): Biol 121.

This course is designed to expose students to the principles underlying engineering microbial systems. The fundamentals of DNA, RNA, and proteins will be reviewed. An emphasis will be placed on recombinant DNA technologies, mutagenesis, cloning, gene knockouts, altered gene expression and analysis, with practical real world examples of their application. Throughout this course we will also focus on case studies and cricial literature evaluation.

455. (MEAM455) Continuum Biomechanics. (A) Prerequisite(s): Math through 241; BE 200 or MEAM 210; BE 350 or MEAM 302.

Continuum mechanics with applications to biological systems. Fundamental engineering conservation laws are introduced and illustrated using biological and non-biological examples. Kinematics of deformation, stress, and conservation of mass, momentum, and energy. Constitutive equations for fluids, solids, and intermediate types of media are described and applied to selected biological examples. Class work is complemented by computational laboratory experiences.

483. (BE 583, MMP 507) Molecular Imaging. (C) Prerequisite(s): MATH 241, BIOL 215 or BE 305.

This course will provide a comprehensive survey of modern medical imaging modalities and the emerging field of molecular imaging. The basic principles of X-ray, ultrasound, nuclear imaging, and magnetic resonance imaging will be reviewed. The course will also cover concepts related to contrast media and targeted molecula r imaging. Topics to be covered include the chemistry and mechanisms of various contrast agents, approaches to identifying molecular markers of disease, ligand screening strategies, and the basic principles of toxicology and pharmacology relevant to imaging agents.

470. Medical Devices. (C) Prerequisite(s): Junior or Senior BE Majors only, ENRG 105, permission of the instructor. Students who have taken ESE 350 or a similar course may not enroll

Lab-based course where students learn the fundamentals of medical device design through hands-on projects using microcontrollers. Students first learn basic design building blocks regularly employed in microcontroller-based medical devices, and then carry out a small design project using those building blocks. Projects are informed by reverse-engineering of competing products, FDA regulations, and marketplace considerations.

BIOENGINEERING
(EG) {BE}

480. Introduction to Biomedical Imaging. (C) Prerequisite(s): BE 301 or ESE 325.

Introduction to the mathematical, physical and engineering design principles underlying modern medical imaging systems including x-ray computed tomography, ultrasonic imaging, and magnetic resonance imaging. Mathematical tools including Fourier analysis and the sampling theorem. The Radon transform and related transforms. Filtered backprojection and other reconstruction algorithms. Bloch equations, free induction decay, spin echoes and gradient echoes. Applications include one-dimensional Fourier magnetic resonance imaging, three-dimensional magnetic resonance imaging and slice excitation.

490. Independent Project in Bioengineering. (C) Prerequisite(s): Sophomore, Junior and Senior BE majors only.

An intensive independent study experience on an engineering or biological science problem related to bioengineering. Requires preparation of a proposal, literature evaluation, and preparation of a paper and presentation. Regular progress reports and meetings with faculty advisor are required.

492. Independent Project in Bioengineering. (C) Prerequisite(s): Sophomore, Junior and Senior BE majors only.

Second semester of an independent project.

495. Senior Design Project. (A) Prerequisite(s): Seniors in BE or Department Permission.

Group design projects in various areas of bioengineering. Projects are chosen by the students with approval of the instructor in the Spring semester of the Junior year and refined during the Fall semester. The course guides the students through choosing and understanding a biomedical problem, defining characteristics of a successful design solution, creatively developing potential approaches to designing solutions to eliminate or mitigate the problem, choosing, iteratively refining, and implementing a particular solution, and evaluating how well the solution fulfills the need. Final oral and written reports are required. Also emphasized are teamwork, project management, time management, regulations/standards, and effective communication.

496. Senior Design Project. (B) Prerequisite(s): Seniors in BE or Department Permission.

Second semester of a two semester design project.

497. Senior Thesis in Biomedical Science. (A) Prerequisite(s): Seniors in BAS or Department Permission.

An intensive independent project experience incorporating both technical and non-technical aspects of the student's chosen career path. Chosen topic should incorporate elements from the student's career path electives, and may involve advisors for both technical and non-technical elements. Topics may range from biomedical research to societal, technological and business aspects of Bioengineering. A proposal, regular progress reports and meetings with a faculty advisor, a written thesis, and a presentation are required.

498. Senior Thesis in Biomedical Science. (B) Prerequisite(s): Seniors in BAS or Department Permission.

Second semester of a year-long project.

BIOENGINEERING
(EG) {BE}

502. From Biomedical Science to the Marketplace. (C) Prerequisite(s): Graduate students or permission of the instructor.

This course explores the transition from discovery of fundamental knowledge to its ultimate application in a clinical device or drug. Emphasis is placed upon factors that influence this transition and upon the integrative requirements across many fields necessary to achieve commercial success. Special emphasis is placed on entrepreneurial strategies, intellectual property, financing and the FDA process of proving safety and efficacy. Current public companies in the medical device and drug industry are studied in detail and critiqued against principles developed in class.

504. Biological Data Science II: Data Mini ng Principles for Epigenomics. (C) Prerequisite(s): Graduate students or permission of the instructor.

This course will teach upper level undergraduates and graduate students how to answer biological questions by harnessing the wealth of genomic and epigenomic data sets generated by high-throughput technologies such as microarrays and deep sequencing.

505. Quantitative Human Physiology. (C) Prerequisite(s): Graduate students or permission of the instructor.

Introduction to human physiology using the quantitative methods of engineering and physical science. Emphasis is on the operation of the major organ systems at both the macroscopic and cellular level.

510. Biomechanics and Biotransport. (C) Prerequisite(s): MATH 241, BE 200, 350.

The course is intended as an introduction to continuum mechanics in both solid and fluid media, with special emphasis on the application to biomedical engineering. Once basic principles are established, the course will cover more advanced concepts in biosolid mechanics that include computational mechanics and bio-constitutive theory. Applications of these advanced concepts to current research problems will be emphasized.

512. Bioengineering III: Biomaterials. (C) Prerequisite(s): General Chemistry, basic biomechanics.

This course provides a comprehensive background in biomaterials. It covers surface properties, mechanical behavior and tissue response of ceramics, polymers and metals used in the body. It also builds on this knowledge to address aspects of tissue engineering, particularly the substrate component of engineering tissue and organs.

514. (IPD 504) Rehab Engineering and Design. (C) Prerequisite(s): Graduate students or permission of the instructor.

Students will learn about problems faced by disabled persons and medical rehabilitation specialists, and how engineering design can be used to solve and ameliorate those problems. The course combines lectures, multiple design projects and exercises, and field trips to clinical rehabilitation facilities. Students will have substantial interactio with clinical faculty, as well as with patients.

BIOENGINEERING
(EG) {BE}

515. Bioengineering Case Studies. (C) Prerequisite(s): Graduate students or permission of the instructor.

This course introduces students to bioengineering research and development as related to meeting clinical needs. The course is broadly organized about the question of "what makes medical technology work". It introduces students to the assessment of medical technology including studies to evaluate safety and effectiveness of new devices. Introduction to regulatory, ethical, legal, and economic issues as they relate to the success of new medical technologies. The course will be taught through examination of case studies, which may vary from year to year. Recent case studies included mammography, heart assist devices and the artificial heart, hyperthermia, safety of radiofrequency energy. The course will include experts (both in person and via teleconferences) and student presentations in addition to lectures by the instructor.

L/R 518. Optical Microscopy. (C) Prerequisite(s): Graduate students or permission of the instructor.

An introduction to the fundamental concepts of optics and microscopy. Geometrical optics: ray tracing, optical elements, imaging systems, optical aberrations. Physical optics: the electromagnetic spectrum, the wave equation, diffraction, interference and interferometers, optical resolution limits, optical coherence, lasers. Microscopy methods: phase contrast, differential interference contrast, fluorescence microscopy, confocal microscopy, multiphoton microscopy, optical coherence tomography, superresolution microscopy.

L/R 521. (NGG 521) Brain-Computer Interfaces. (C) Prerequisite(s): BE 301 (Signals and Systems) or equivalent, computer programming experience, preferably MATLAB (e.g., as used the BE labs, BE 310). Some basic neuroscience background (e.g. BIOL 215, BE 305, INSC core course), or independent study in neuroscience, is required. This requirement may be waived based upon practical experience on a case by case basis by the instructor.

The course is geared to advanced undergraduate and graduate students interested in understanding the basics ofimplantable neuro-devices, their design, practical implementation, approval, and use. Reading will cover the basics of neuro signals, recording, analysis, classification, modulation, and fundamental principals of Brain-Machine Interfaces. The course will be based upon twice weekly lectures and "hands-on" weekly assignments that teach basic signal recording, feature extraction, classification and practical implementation in clinical systems. Assignments will build incrementally toward constructing a complete, functional BMI system. Fundamental concepts in neurosignals, hardware and software will be reinforced by practical examples and in-depth study. Guest lecturers and demonstrations will supplement regular lectures.

530. (PHYS585) Theoretical Neuroscience. (C) Prerequisite(s): Knowledge of multivariable calculus, linear algebra and differential equations is required (except by permission of the instructor). Prior exposure to neuroscience and/or Matlab programming will be helpful.

This course will develop theoretical and computational approaches to structural and functional organization in the brain. The course will cover: (i) the basic biophysics of neural responses, (ii) neural coding and decoding with an emphasis on sensory systems, (iii) approaches to t he study of networks of neurons, (iv) models of adaptation, learning and memory, (v) models of decision making, and (vi) ideas that address why the brain is organized the way that it is. The course will be appropriate for advanced undergraduates and beginning graduate students.

BIOENGINEERING
(EG) {BE}

537. (CIS 537) Biomedical Image Analysis. (C) Prerequisite(s): Math through multivariate calculus (MATH 241), programming experience, as well as some familiarity with linear algebra, basic physics, and statistics.

This course covers the fundamentals of advanced quantitative image analysis that apply to all of the major and emerging modalities in biological/biomaterials imaging and in vivo biomedical imaging. While traditional image processing techniques will be discussed to provide context, the emphasis will be on cutting edge aspects of all areas of image analysis (including registration, segmentation, and high-dimensional statistical analysis). Significant coverage of state-of-the-art biomedical research and clinical applications will be incorporated to reinforce the theoretical basis of the analysis methods.

546. Fundamental Techniques of Imaging I. (C) Prerequisite(s): Graduate students or permission of the instructor.

This course covers the fundamentals of modern techniques in biological and in vivo biomedical imaging. This practical course consists of a series of hands-on lab exercises, covering major imaging modalities, but also extends to non-radiology modalities of interest in biological, pathological or animal imaging (e.g., optical imaging). Topics include x-ray, mammography, MRS, MRI, PET, and ultrasound. The emphasis will be on hands-on aspects of all areas of imaging and imaging analysis. Small groups of students will be led by a faculty member with technical assistance as appropriate.

L/R 540. (BE 440, CBE 540) Biomolecular and Cellular Engineering. (C) Prerequisite(s): Graduate students or permission of the instructor.

This course will introduce concepts and methods for the quantitative understanding of molecular and cellular phenomena. Topics include molecular recognition, receptor-ligand binding, viral infection, signal transduction, cell adhesion, motility, and cytoskeletal dynamics. The course requires mathematics at the level of differential equations, and some knowledge of Matlab programming. A basic knowledge of cell biology is suggested, although not required.

541. (CBE 541) Engineering and Biological Principles in Cancer. (B) Prerequisite(s): Seniors in BE or permission of the instructor.

This course provides an integrative framework and provides a quantitative foundation for understanding molecular and cellular mechanisms in cancer. The topics are divided into three classes: (1) the biological basis of cancer; (2) cancer systems biology; and (3) multiscale cancer modeling. Emphasis is placed on quantitative models and paradigms and on integrating bioengineering principles with cancer biology.

547. Fundamental Techniques of Imaging 2. (C) Prerequisite(s): Graduate students or permission of the instructor.

This course is a continuation of the course Fundamental Techniques of Imaging 1 (BE546). It builds upon the fall course instruction and continues to expose students to the fundamentals of modern techniques in biological and in vivo biomedical imaging. This course consists of a series of hands-on lab exercises, covering major imaging modalities, but also extends to non-radiology modalities of interest in biological, pathological or animal imaging (e.g., optical imaging). Topics include SPECT, Micro-CT, diffuse optical spectroscopy, in vivo fluorescence imaging, and computed tomography. The course will continue to emphasize the hands-on aspects of all areas of imaging and imaging analysis. Small groups of students will be led by a faculty member with technical assistance as appropriate.

BIOENGINEERING
(EG) {BE}

551. BIOMICROFLUIDICS. (C) Prerequisite(s): Experience with an undergraduate level fluid mechanics course is preferred. Examples of relevant SEAS courses include BE 350 (Biotransport), CBE 350 (Fluid Mechanics), and MEAM 302 (Fluid Mechanics).

The focus of this course is on microfluidics for biomedical applications. Topics to be covered in the first half of this course include microscale phenomena, small-scale fabrication techniques, and sensing technologies that are often leveraged in the development of microfluidic systems for the study of biomolecules, cells, tissues, and organs in living biological systems. In the second half of this course, strong emphasis will be placed on the application of microfluidics in cell biology, bioanalytical chemistry, molecular biology, tissue engineering, and drug discovery.

553. Principles, Methods, and Applications of Tissue Engineering. (C) Prerequisite(s): Graduate Standing or instructor's permission.

Tissue engineering demonstrates enormous potential for improving human health. This course explores principles of tissue engineering, drawing upon diverse fields such as developmental biology, cell biology, physiology, transport phenomena, material science, and polymer chemistry. Current and developing methods of tissue engineering, as well as specific applications will be discussed in the context of these principles. A significant component of the course will involve review of current literature within this developing field.

554. (CBE 554) Engineering Biotechnology. (M) Prerequisite(s): Graduate standing or permission of the instructor.

Advanced study of re DNA techniques; bioreactor design for bacteria, mammalian and insect culture; separation methods; chromatography; drug and cell delivery systems; gene therapy; and diagnostics.

L/R 555. (BE 444, CBE 555, MEAM555) Nanoscale Systems Biology. (C) Prerequisite(s): Background in Biology, Chemistry or Engineering with coursework in thermodynamics or permission of the instructor.

From single cell manipulations down to studies of single nanoparticles and single molecules, basic cell- molecular biology and biotechnologies are increasingly 'nano' as well as quantitative. Lectures and laboratories in this course start with nano aspects of optical detection, address the basic thermodynamics of biomolecular interactions, and then cover genomic scale devices. Nanoprobe methods are then complemented by basic theories of self-assembly and polymers as well as application in drug delivery and virus engineering with analyses of limitations imposed by the innate immune system. Skills in analytical and professional presentations, papers and laboratory work will be developed.

L/R 557. (CBE 582) From Cells to Tissue: Engineering Structure and Function. (C) Prerequisite (s): Math through 241; BE350, BE324 as pre- or corequisites; Molecular & cellular biology.

The goal of this course is to introduce students to quantitative concepts in understanding and manipulating the behavior of biological cells. We will try to understand the interplay between molecules in cells and cell function. A particular focus is on receptors - cell surface molecules that mediate cell responses. We will also try to understand processes such as adhesion, motility, cytoskeleton, signal transduction, differentiation, and gene regulation.

562. (CBE 562) Drug Discovery & Development. (C) Prerequisite(s): Graduate standing or permission of the instructor.

This course covers topics such as drug discovery targets, drug development, high throughput screening, solid phase synthesis, instrumentation, Lab-on-a-chip, pharmacokinetics, and drug delivery.

BIOENGINEERING
(EG) {BE}

L/R 558. Principles of Biological Fabrication. (C) Prerequisite(s): Graduate standing or permission of the instructor.

BE 558 introduces methodological approaches that are currently used for the de novo construction of biological molecules - primarily, nucleic acids and proteins - and how to use these molecules to engineer the properties of cells and intact tissue. By the end of the semester, students should (i) possess a molecular-scale understanding of key biological synthesis and assembly processes, (ii) gain an intuition for how to create novel methodologies based on these existing processes, and (iii) appreciate the drivers of technology adoption. Course content will be placed in context of cutting edge applications in bioengineering and human health.

L/R 559. Multiscale Modeling of Biological Systems. (C) Prerequisite(s): Undergraduates who have taken BE 324 or equivalent courses in Quantum Mechanics and/or Statistical Physics need no permission. Others, email instructor for permission.

This course aims to provide theoretical, conceptual, and hands-on modeling experience on three different length and time scales that are crucial to biochemical phenomena in cells and to nanotechnology applications. Special Emphasis will be on cellular signal transduction. 60% lectures, 40% computational laboratory. No programming skills required.

561. Musculoskeletal Biology and Biolengineering. (B) Prerequisite(s): Graduate student standing in Engineering and/or CAMB. Undergraduate students with permission of the instructor.

The goal of this course is to educate students in core principles and expose them to cutting-edge research in musculoskeletal biology and bioengineering through (1) lectures covering the basic engineering principles, biological fundamentals, and clinical practices involved in the function, repair, and regeneration of the musculoskeletal tissues; (2) critical review and presentation by student groups of recent and seminal publications in the field related to the basic science, translation, and clinical practice of musculoskeletal biology and bioengineering, with discussion input by faculty members with relevant expertise. This course will place an emphasis on delivering multidisciplinary knowledge of cell and molecular biology, mechanics, material science, imaging, and clinical medicine as it relates to the field of musculoskeletal bioengineering and science.

566. (ESE 566) Network Neuroscience. (C) Prerequisite(s): Graduate standing or permission of the instructor. Experience with Linear Algebra and MATLAB.

The human brain produces complex functions using a range of system components over varying temporal and spatial scales. These components are couples together by heterogeneous interactions, forming an intricate information-processing network. In this course, we will cover the use of network science in understanding such large-scale and neuronal-level brain circuitry.

L/R 567. (AMCS567, GCB 567) Mathematical Computation Methods for Modeling Biological Systems. (C) Prerequisite(s): BE 324 and BE 350.

This course will cover topics in systems biology at the molecular/cellular scale. The emphasis will be on quantitative aspects of molecular biology, with possible subjects including probabilistic aspects of DNA replication, transcription, translation, as well as gene regulatory networks and signaling. The class will involve analyzing and simulating models of biological behavior using MATLAB.

BIOENGINEERING
(EG) {BE}

570. Biomechatronics. (C) Prerequisite(s): A first course in programming, Senior standing in BE or permission of the instructor.

Mechatronics is the combination of mechanical, electrical and computer engineering principles in the design of electromechanical systems. Biomechatronics is the application of these principles to human biology and includes orthopaedic, hearing, respiratory, vision and cardiovascular applications. In this hands-on, project-based course, these biomechatronic systems will be explored. Students will learn the basic mechanical and electrical elements needed to complete a biomechatronic design challenge including basic circuits, design considerations, material fabrication, microcontrollers and mechanisms (e.g. converting rotational motion into linear motion). Students will carry out a final design project utilizing these building blocks.

575. Injury Biomechanics. (C) Prerequisite(s): ENM 500 or 510, BE 510 or MEAM 519 or equivalent. A background in physiology and anatomy is also recommended.

This course is intended as an introduction to investigating the mechanics of injury, from the organism to the tissue level. The students will be exposed to both formal didactic instruction and selected field work. The course will cover principles in continuum and analytical mechanics, and will use application in injury research to illustrate these concepts. The course will be divided into three major units. The first unit will be an introduction to variational principles of mechanics and calculus of variations, and will apply these concepts to injury problems (e.g., occupant kinematics during a collision, vehicle kinematics, impact to padded surfaces). Special emphasis will be placed on converting a system input into a body response. The second unit of the course will be used to discuss the effect of gross body motion on tissue and organ mechanical response. Material models of biological tissue will be discussed, and examples relating body motion to tissue response will be reviewed. In the final unit of this course, students are required to research and review a problem of their choice and present a report detailing an engineering based solution to the problem.

580. (PHYS582) Medical Radiation Engineering. (C) Prerequisite(s): Junior standing.

This course in medical radiatioin physics investigates electromagnetic and particulate radiation and its interaction with matter. The theory of radiation transport and the basic concept of dosimetry will be presented. The principles of radiation detectors and radiation protection will be discussed.

586. Signal Analysis & Process. (A) Prerequisite(s): BE 301.

This course takes off where BE 301 ends. The course will add new topics and methods as well as depth and rigor accompanied with biomedical applications. In particular, the course will emphasize discrete-time signal processing, relationship betwee continuous-time and discrete-time signals, Fourier transform methods, filtering, signal sampling, and reconstruction and biomedical applications.

581. (BMB 581) Techniques of Magnetic Resonance Imaging. (M) Prerequisite(s): Graduate standing or permission of the instructor.

Detailed survey of the physics and engineering of magnetic resonance imaging as applied to medical diagnosis. Covered are: history of MRI, fundamentals of electromagnetism, spin and magnetic moment, Bloch equations, spin relaxation, image contrast mechanisms, spatial encoding principles, Fourier reconstruction,imaging pulse sequences and pulse design, high-speeding imaging techniques, effects of motion, non-Cartesian sampling strategies, chemical shift encoding, flow encoding, susceptibility boundary effects, diffusion and perfusion imaging.

BIOENGINEERING
(EG) {BE}

583. (BE 483, MMP 507) Molecular Imaging. (C) Prerequisite(s): MATH 241, BIOL 215 or BE 305.

This course will provide a comprehensive survey of modern medical imaging modalities and the emerging field of molecular imaging. The basic principles of X-ray, ultrasound, nuclear imaging, and magnetic resonance imaging will be reviewed. The course will also cover concepts related to contrast media and targeted molecula r imaging. Topics to be covered include the chemistry and mechanisms of various contrast agents, approaches to identifying molecular markers of disease, ligand screening strategies, and the basic principles of toxicology and pharmacology relevant to imaging agents.

584. (MATH584) Mathematics of Medical Imaging and Measurements. (M) Prerequisite(s): Math through 241 as well as some familiarity with linear algebra and basic physics.

In the last 25 years there as has been a revolution in image reconstruction techniques in fields from astrophysics to electron microscopy and most notably in medical imaging. In each of these fields one would like to have a precise picture of a 2 or 3 dimensional object, which cannot be obtained directly. The data that is accessible is typically some collection of weighted averages. The problem of image reconstruction is to build an object out of the averaged data and then estimate how close the reconstruction is to the actual object. In this course we introduce the mathematical techniques used to model measurements and reconstruct images. As a simple representative case we study transmission X-ray tomography (CT). In this contest we cover the basic principles of mathematical analysis, the Fourier transform, interpolation and approximation of functions, sampling theory, digital filtering and noise analysis.

597. Master's Thesis Research. (C)

For students working on an advanced research program leading to the completion of master's thesis.

599. Master's Independent Study. (C)

The purpose of BE 599 is to allow a student to create a customized curriculum to study material beyond or outside the scope of our standard BE course offerings. Independent study is NOT a research or design project, it is a one-on-one or small-group course with a professor. The course should require an effort comparable to that of a regular course, about 10-12 hours per week. A paper or presentation is required

608. (MTR 620) Translational Therapeuti. (B) Prerequisite(s): Engineering students only or permission of the instructor.

612. Materials Affecting Cell and Molecular Function. (M) Prerequisite(s): Graduate standing or permission of the instructor.

This course provides advanced knowledge regarding the effect of the various classes of materials on tissues, cells and molecules, with the emphasis on musculoskeletal tissues. Topics include the effect of particulate matter, controlled release carriers and scaffolds for tissue repair. Emphasis is placed on recent developments in tissue engineering of bone and cartilage. The course discusses the use of materials science techniques in the study of tissue-engineered constructs. Data in the literature related to the subject matter will be extensively discussed and the students will write two articles on selected topics.

BIOENGINEERING
(EG) {BE}

640. (CAMB703) The Extracellular Matrix. (J) Prerequisite(s): BIOM 600. Graduate students only.

This course is geared towards first and second year graduate students in BGS/CAMB and SEAS/BE with an interest in the interface of extracellular matrix (ECM) cell biology and biomechanics. Students will learn about the ECM and adhesion receptors and their impact on the cytoskeleton and signaling, as well as fundamental concepts in biomechanics and engineered materials. We will discuss how these topics can inform the study of cell biology, physiology and disease . An additional objective of the course is to give students experience in leading critical discussions and writing manuscript reviews. Invited outside speakers will complement the strengths of the Penn faculty.

645. Biological Elasticity. (M) Prerequisite(s): BE 510 or equivalent.

Large deformation mechanics of biological materials. Nonlinear elasticity theory, strain energy functions, constitutive laws of hyperelastic and viscoelastic biological materials. Applications to heart, lung, and arteries.

650. Adv Biomed Imag Applic. (A)

L/R 662. (CBE 618, MEAM662) Advanced Molecular Thermodynamics. (C) Prerequisite(s): Graduate Standing or permission of the instructor.

Review of classical thermodynamics. Prediction of thermodynamic functions from molecular properties. Concepts in applied statistical mechanics. Modern theories of liquid mixtures.

SM 699. Bioengineering Seminar. (C)

799. Research Rotation. (C) Prerequisite(s): PhD Students only.

For students who are fulfilling the Bioengineering research rotation requirements

700. Special Topics in Bioengineering. (M)

The research areas discussed will be those of the participating BE faculty who will direct the discussions and present background material. The purpose of the course is to present current research being done in the bioengineering Graduate Group and study relevant literature. The grade will be based on class participation and a final paper or presentation. Course content and staffing varies from year to year.

895. (BIOM895) Methods in Bioengineering Education. (M) PHD students only

This course provides training in the practical aspects of teaching. The students will attend seminars emphasizing basic pedagogical skills. Depending on the course setting for the practicum portion, student will obtain handson experience developing and delivering lectures, leading recitations, developing and supervising instructional laboratories, preparing and grading homework, grading laboratory reports, and preparing and grading examinations. Practicum experiences will be supervised by a faculty mentor. Students will meet during the practicum portion of the course to discuss difficult situations encountered in the classroom/laboratory and to constructively review each other. Final evaluations will be based on mentor, peer, and student feedback.

BIOENGINEERING
(EG) {BE}

899. Independent Study. (C) Graduate Students Only

The purpose of BE 899 is to allow a student to create a customized curriculum to study material beyond or outside the scope of our standard BE course offerings. Rather than a research or design project, BE 899 is a one-on-one or small-group course with a professor. Students must submit a proposal outlining the study area along with the professor's approval. A paper or presentation is required.

990. Masters Thesis. (C)

For Master's students who have completed the course requirements for the Master's degree and are strictly working to complete the Master's Thesis leading to the completion of a Master's degree. Permission Required.

995. Doctoral Dissertation Status. (C) Prerequisite(s): For Ph.D. Candidates only.

Ph.D. Students register for Doctoral Dissertation Status after they have advanced to Ph.D. candidacy by completing the Candidacy Exam which consists of the Dissertation Proposal Defense.. Permission required

999. Thesis/Dissertation Research. (C)

For students working on an advanced research program leading to the completion of master's thesis or Ph.D. dissertation requirements.