Roy J. Carver Department of Biomedical Engineering

Chair

- Joseph M. Reinhardt

Undergraduate major: biomedical engineering (B.S.E.)
Graduate degrees: M.S. in biomedical engineering; Ph.D. in biomedical engineering
Faculty: https://bme.engineering.uiowa.edu/people
Website: https://bme.engineering.uiowa.edu/

The past half century has seen tremendous growth of technological activity in biology and medicine. As engineers increasingly have become involved with projects in the life and health sciences, biomedical engineering has emerged to bridge the gap between these sciences and engineering.

The Roy J. Carver Department of Biomedical Engineering fosters interdisciplinary activities across departments and colleges and maintains strong ties with the Carver College of Medicine and the Colleges of Dentistry, Nursing, and Public Health. The department strives to provide a well-rounded and superior engineering education that attracts outstanding students at both the undergraduate and graduate levels; to conduct high-quality research that enables faculty members and students to keep pace with and initiate new developments; and to serve government, industry, and institutions worldwide by making the department's facilities and faculty expertise accessible.

Department faculty members have teaching and research expertise in areas related to cardiovascular and fluid biomechanics, musculoskeletal biomechanics, biomaterials and tissue engineering, bioinstrumentation, biosystems, biomedical imaging, biological signal analysis, bioinformatics and computational biology, respiratory and pulmonary engineering, and other allied fields. Several faculty members have joint appointments with the Carver College of Medicine, the College of Dentistry, or the College of Public Health. Biomedical engineering undergraduates and graduate students collaborate with faculty members and their colleagues on research problems in the life and health sciences.

Programs

Undergraduate Program of Study

Major

- Major in Biomedical Engineering (Bachelor of Science in Engineering)

Graduate Programs of Study

Majors

- Master of Science in Biomedical Engineering
- Doctor of Philosophy in Biomedical Engineering

Facilities

Undergraduate Teaching Laboratories

Seven dedicated undergraduate teaching laboratories are associated with the required and elective courses in biomedical engineering: the Bioimaging and Bioinformatics Laboratory; the Biomechanics and Biomaterials Laboratory; the Carver Biomechanics and Mechanobiology Laboratory; the Carver Cellular Engineering Laboratory; the Carver Medical Device Design Laboratory; the Senior Design Laboratory; and the Systems, Instrumentation, and Data Acquisition Laboratory.

Bioimaging and Bioinformatics Laboratory

The Bioimaging and Bioinformatics Laboratory provides computer and experimental equipment to allow students to become familiar with biomedical imaging hardware and software for biomedical image analysis. The laboratory has four lab benches with computers for teamwork, two desktop ultrasound machines, and two desktop magnetic resonance imaging devices. In addition, the lab has 12 sets of in-house-built optics laboratory kits that use light sources and semitranslucent objects to simulate basic x-ray physics. Students are introduced to concepts such as image magnification as it relates to source-object distance (SOD)/source-image distance (SID), depth-dependent magnification, ideal point source verses parallel beam source effects, and projection image formation with lack of depth information artifacts. An instructor workstation and computer projector are available for presentations and software demonstrations. The lab is used primarily for the core course BME:2210 Bioimaging and Bioinformatics, the elective course BME:5210 Medical Imaging Physics, and for senior design projects.

Biomechanics and Biomaterials Laboratory

The Biomechanics and Biomaterials Laboratory is equipped to perform experiments relating to the cardiovascular and human musculoskeletal systems as well as the various properties of biomaterials. The laboratory houses a table-top material testing machine; two cone-and-plate viscometers; compact stress-strain devices for characterizing cardiovascular tissues; goniometers; human structures biomechanical modeling sets and associated sensors; digital still, video, and motion-capture cameras for kinematic analysis; a ski binding tester; a drop tower for impact testing; digital calipers; various skeletal/bone models; an assortment of hand tools; and dissecting tools. The lab is used for the course BME:2500 Biomaterials and Biomechanics, elective courses in cardiovascular and musculoskeletal biomechanics, and senior design projects.

Carver Biomechanics and Mechanobiology Laboratory

The Carver Biomechanics and Mechanobiology Laboratory (CBML) is a shared resource in the Roy J. Carver Department of Biomedical Engineering with a mission to enhance teaching, training, and research in the field of biomechanics and mechanobiology. Biomechanics and mechanobiology involve the study of how cells, fluids, tissues, and organs respond to physical forces. The lab contributes to the understanding of cardiovascular disease, cancer metastasis, wound healing, medical device function, and stem cell therapies.

The lab houses a planar biaxial stress-strain test apparatus, a pulse duplicator apparatus for characterizing blood flow through mechanical and tissue heart valves, a micron-resolution particle image velocimetry (micro-PIV) system for quantifying flow and particle dynamics at the microscale, a stent crimper for characterizing vascular stent designs, a multimode plate reader for quantifying cell activity and extracellular matrix (ECM) remodeling, a lyophilizer for quantifying elastin and collagen content in soft tissue samples, a micromanipulator for performing micropipette aspiration studies, and a controlled microscope room for imaging live cells over long durations. The lab is used for courses in cardiovascular biomechanics and cellular engineering, other elective courses, and senior design projects.

Carver Cellular Engineering Laboratory

This laboratory trains students in cell culture and biochemical analysis techniques as a foundation for future work in quantitative cell-based studies. Students learn basic cell culture techniques, protein and nucleic acid analysis, as well as techniques for studying the effects of engineered materials on cellular systems.

Major equipment in the lab includes laminar flow hoods, cell culture incubators, centrifuges, spectrophotometers, an ultracold freezer, protein and nucleic acid electrophoresis equipment, thermal cyclers, microscopes, an automated microplate reader, and various support apparatus used in cell-based studies. This teaching lab is used for the courses, BME:2400 Cell Biology for Engineers and BME:5421 Cell Material Interactions.

Carver Medical Device Design Laboratory

The Carver Medical Device Design Laboratory provides a space for students to gather to collaborate on the design of medical implants, fixtures for testing such implants, and software for modeling, analyzing, and optimizing the function of these devices. Space and equipment are provided for progressing from a back-of-the napkin sketch to a finalized computer-aided design (CAD) model and through multiple iterations of physical prototypes.

A variety of tools and equipment are available such as a micro 24 laser system, a benchtop milling machine, a bandsaw and lathe, a soldering station, an expanded plasma cleaner, a micro pulse arc welder, and five computer workstations. The lab was established to serve students with an interest in medical device design and in required and elective courses in the areas of biomaterials, biomechanics (cardiovascular and musculoskeletal), and the senior design sequence.

Senior Design Laboratory

The Senior Design Laboratory provides a collaborative atmosphere for student groups as they create working prototypes. It has computer workstations, project workspace, and storage space for the development of senior design projects. In addition, a variety of tools and equipment are available in the lab, including electronics measurement devices, soldering tools, Dremel tools, miscellaneous sample medical equipment, and other resources for students. It is used by students taking BME:4910 Biomedical Engineering Senior Design I and BME:4920 Biomedical Engineering Senior Design II.

Systems, Instrumentation, and Data Acquisition Laboratory

The Systems, Instrumentation, and Data Acquisition Laboratory is equipped to measure biomedical variables of clinical and physiological interest, to design and build electronic instrumentation, and to conduct modeling experiments in physiology. The lab is designed to give practice in designing and building electronic circuits to measure, acquire, and analyze signals; and acquire and analyze images. It is used for the elective courses, BME:2200 Systems, Instrumentation, and Data Acquisition and BME:4710 Medical Device Design Studio, for biomeasurements and biological systems analysis, and senior design projects.

Research Facilities and Laboratories

Bioinformatics and Computational Biology Laboratory

The Bioinformatics and Computational Biology Center is wired for high-speed networking (100-megabit and gigabit ethernet, hardwired and wireless). It includes two dedicated Linux clusters, 126 computing systems, 178 CPUs, more than 20 terabytes of RAM, and 250 terabytes of disk space. Computer resources include a dedicated experimental, reconfigurable computer cluster of 18 Linux systems (36 CPUs) connected with a dedicated, switched, copper Gigabit Ethernet intranet and a second dedicated computer server cluster of 16 Linux systems (32 CPUs) connected with a dedicated, switched, fiber-optic Gigabit Ethernet intranet. An additional 78 computers are used as compute servers, web servers, database servers, file servers, workstations, laptops, and for other developmental and experimental needs.

Biomechanics of Soft Tissues Laboratory

The Biomechanics of Soft Tissues Laboratory (BioMOST) houses ViVitro Pulse duplicating left-heart simulating flow loop system, mechanical extension testers, durability testers for accelerated testing of valves, flow loop with programmable pump, resisters and compliance chambers, optical micrometer, a furnace for nitinol shape memory alloy stent fabrication, and the Vascular Simulations Replicator (a portable realistic angio-suite friendly blood flow simulator). The lab also houses high-end image and data processing workstations.

Carver Laboratory for Regenerative Engineering and Translational Science

The Carver Laboratory for Regenerative Engineering and Translational Science is a state-of-the-art multi-investigator wet laboratory devoted to cell and tissue-based research. The laboratory is a transformational space that enables the biomedical engineering faculty and students (graduate and undergraduate research assistants) to interact with one another by bringing together investigators with similar yet varying fields of study, all with an emphasis on cellular and tissue engineering. The laboratory has a direct impact on training graduate students and contributes to numerous research projects across campus. The laboratory has been designed to be responsive to current and future needs; to encourage interaction among engineers, scientists, and physicians from various disciplines; to help recruit and retain qualified faculty and students; and to facilitate partnerships and development.

The laboratory is equipped with major equipment to synthesize and characterize biomaterials, including a chemical fume hood, rotary evaporator, freeze-dryer, rheometer, and several light-based curing systems. To enable growth, maintenance, and characterization of mammalian cells, the lab also houses biosafety cabinets, incubators, a transfection system, automated cell counter, low-volume spectrophotometer, microplate reader, thermal cyclers, quantitative polymerase chain reaction (PCR) instruments, electrophoresis units, and a gel imaging system. The dedicated microscope room includes an atomic force microscope and several fluorescent microscopes, which are equipped with confocal and live cell imaging capabilities.

Collaborative Computational Laboratory

The Collaborative Computational Laboratory is a shared research computing resource. Research focus areas include computational fluid dynamics, medical image analysis, magnetic resonance imaging, machine learning, and artificial intelligence. Desktop computers, compute servers, and access to the campus research data storage and high performance computing cluster are available through the lab.

Computational Biomolecular Engineering Laboratory

The Computational Biomolecular Engineering Laboratory, located in the Bowen Science Building, is a collaboration between the Roy J. Carver Department of Biomedical Engineering and the Department of Biochemistry and Molecular Biology. It includes eight workstations used to simulate biomolecular phenotypes in the context of understanding the genetics of hearing loss, rare renal diseases, and vision loss. Heavy use is made of the University of Iowa Argon compute cluster, including dedicated availability of 30 compute nodes, 50 Nvidia graphics processing units (GPUs), and 100 terabytes of backed-up storage. The lab distributes a high performance physics-based molecular simulation code called Force Field X (FFX) that is being used to produce a family of protein structures for genes associated with hearing loss, available in the Deafness Variation Database. The software also is being used to predict how pharmaceuticals crystalize (i.e., into drug tablets) and to understand their thermodynamic properties (e.g., solubility).

Large Scale Digital Cell Analysis Laboratory

The Large Scale Digital Cell Analysis System (LSDCAS) is an automated microscopy system designed to perform non-perturbing live cell imaging. LSDCAS has been used in studies designed to determine mechanisms of cell death following treatment with anti-cancer therapies. Current studies involve the adaptation of the LSDCAS technology toward the development of automatic single-cell analysis techniques to be used in drug discovery. LSDCAS consists of two computer-controlled inverted Hoffman modulation contrast microscopes outfitted with environmental control chambers, motorized stages, shutters, focusing systems, and high-resolution digital camera systems.

LSDCAS is housed in a dedicated microscopy room that provides the dark environment necessary for systems that operate around the clock automatically recording cell growth and other phenomena. LSDCAS data is stored and analyzed using a data center consisting of an 8 processor Linux server with 16 gigabytes of RAM, a 30 terabyte hardware RAID storage system, and a 30 terabyte robotic tape backup system. Web application software and many other programs provide robust analysis capabilities for the large variety of data produced by the system. The LSDCAS code base contains over one hundred thousand lines of program code developed over the past two decades to provide automatic single cell analysis capabilities of general interest in cell biology. In addition, the lab has equipment and technologies generally used in cell and molecular biology, including protein and nucleic acid gel electrophoresis analysis systems, real-time reverse transcription polymerase chain reaction (RT-PCR) systems, cell culture incubators, a laminar flow cell culture biosafety cabinet, a chemical fume hood, -80°C freezer, other refrigerators and freezers, an ice machine, water purification system, autoclave, and many other tools, reagents, and devices.

Orthopedic Biomechanics Laboratory

The Orthopedic Biomechanics Laboratory occupies 20 rooms on the ground floor of Westlawn. It is configured primarily for macroscopic-level physical testing of musculoskeletal constructs (e.g., bones, articular joints, orthopedic implants) and for corresponding computational modeling. The physical testing area includes a multipurpose wet lab, a multipurpose dry lab, a surgical preparation room, a mechanical testing room, a machine shop, and a specimen storage area. The computational modeling area is arranged around eight separate workstation seats in two adjoining partially partitioned areas. Adjacent to these core operational areas are offices for faculty, research staff, students, and fellows; a secretarial/reception area; a conference room; and a library.

Regenerative Engineering Laboratory

The Regenerative Engineering Laboratory inhabits over 1,000 square feet of the Pappajohn Biomedical Discovery Building. The lab is fully equipped to support research at the interface of materials, engineering, and cell biology. The Biosafety Level 2 (BSL-2) cell culture room in the lab has two Panasonic cell culture incubators, two Thermo Scientific biological safety cabinets, a fluorescent microscope, 37°C bead bath, and centrifuges. A separate four-color fluorescence microscope also is available. The fully automated Leica DMI6000 captures four-color fluorescence images at up to 63x magnification. A built-in z-motor and post-acquisition analysis software allows for the capture and analysis of three-dimensional z-stacks.

The chemistry part of the lab is equipped for biodegradable particle synthesis and analysis. In addition to a fume hood, sink, and laboratory counters, the lab has an analytical grade Mettler Toledo XS64 balance, water bath sonicator, homogenizer, syringe pumps, and a LabConco -86°C Cascade Lyophilizer. To support long term storage of the reagents required for the molecular biology and chemistry portions of the lab, a variety of cold storage options are available including 4°C, -20°C, -80°C, and -130°C.

Spine Biomechanics Research Laboratory

The Spine Biomechanics Research Laboratory is equipped for interdisciplinary research. The lab's MTS Bionix servohydraulic testing equipment (with extended columns) permits application of uniaxial tension or compression together with axial torsion under displacement or load control. The lab also has a fully automated three-dimensional motion measuring system. These devices are used to test mechanical properties of biomechanical joints and tissues, and for biomechanical evaluation of the performance of surgical treatment modalities. Other equipment includes digital cameras, surgical tools, and sensors (i.e., linear variable differential transformers, six-degrees-of-freedom load cell, pressure transducers, digital inclinometers).

A biaxial biomechanical culture system is available for application of controlled compression and/or shear forces onto the intervertebral disc during culture in order to investigate the disc's biological responses to mechanical loads. This culture system is used in conjunction with an incubator in which cells and tissues can be cultured. Basic equipment for histology and immunohistochemical analyses includes a microtome, ovens, a microscope, and glassware for chemical processes.

Courses

Biomedical Engineering Courses

For current and planned course offerings, visit MyUI on the University of Iowa website.

These advanced courses are offered infrequently depending on the research focus of currently enrolled graduate students: BME:6110 Mechanics of Cells and Cellular Systems, BME:6415 Advanced Biomechanics and Modeling of Soft Tissues, and BME:6610 Spine Mechanics.

BME:0000 Biomedical Engineering Internship/Co-op 0 s.h.
Biomedical engineering students participating in the Cooperative Education Program register for this course during work assignment periods; registration provides a record of participation in the program on the student's permanent record. Requirements: admission to Cooperative Education Program.

BME:1010 First-Year Forum 1 s.h.
Presentations by faculty, graduate students, collaborators from the Carver College of Medicine, and Colleges of Dentistry and Law; may include visits to laboratories and industries.

BME:2010 Professional Seminar: Biomedical Engineering 1 s.h.
Professional aspects of biomedical engineering presented through lectures and discussions by guest speakers, field trips, films, panel discussions. Requirements: sophomore or higher standing.

BME:2200 Systems, Instrumentation, and Data Acquisition 4 s.h.
Introduction to engineering art and science of modeling, acquisition, and analysis of data collected from living systems; modeling of physiological and biological systems; concepts of analog circuit design, with emphasis on circuits for collecting data for biomedical applications using operational amplifiers, active filters, conversion, and interface to microcomputers; patient safety; clinical circuits; analysis of data using time domain and Fourier domain techniques and models; time domain sampling, and Nyquist sampling theorem. Prerequisites: ENGR:2120. Corequisites: HHP:3500, and BIOS:4120 or STAT:3510.

BME:2210 Bioimaging and Bioinformatics 4 s.h.
Introduction to bioinformatics and biomedical imaging; computer algorithms, machine learning, databases and SQL, the web and web servers, ethics, computer security, genome technology, public warehouses of biological data; medical imaging hardware and software for acquisition and analysis of medical images, especially those collected from X-ray, CT, MR, and ultrasound systems; medical imaging system physics, including interaction of energy with tissue, concepts of image spatial and temporal resolution; applications of filtering, enhancement, and image processing for analysis of medical images. Prerequisites: ENGR:1300 and BIOL:1411. Corequisites: BIOS:4120 or STAT:3510.

BME:2400 Cell Biology for Engineers 3 s.h.
Introduction to fundamental concepts in quantitative cell biology from an engineering perspective. Prerequisites: BIOL:1411. Corequisites: BIOS:4120 or STAT:3510.

BME:2500 Biomaterials and Biomechanics 4 s.h.
Introduction to mechanics and materials in biological systems; principles of mechanics (stress, strain, motion, fluid flow) presented and used to characterize behavior of biological entities (tendon/ligament, bone and cartilage, blood, blood vessels, heart); principles of material science; role of biomaterials (metals, polymers, ceramics) in medical devices. Prerequisites: ENGR:2110. Corequisites: HHP:3500, and BIOS:4120 or STAT:3510.

BME:2710 Engineering Drawing, Design, and Solid Modeling 3 s.h.
Introduction to methods and principles used by engineers to define and describe geometry and topology of engineered components; use of Parametric Technology's Creo Pro (formerly ProEngineer) 3D computer-aided design software; emphasis on elements of design; basic commands used in parametric design to develop spatial visualization skills and the ability to create and understand 3D solid parametric design for assembly and 3D drawing documentation; creation of 3D assemblies and detailed drawings from art of design to part utilization of solid modeling techniques.

BME:3010 Leadership and Resourcefulness 1 s.h.
Development of leadership skills and resourcefulness for real-world professional work and life. Requirements: completion of BME:1010 and two semesters of BME:2010.

BME:3710 Medical Device Design: The Fundamentals 3 s.h.
Introduction to medical device design process; project-based; development of prototyping and fabrication skills needed for engineering design projects, safety, communication, and teamwork; focus on physical rehabilitation science and assistive technologies; preparation for senior design course sequence. Prerequisites: BME:2500 and BME:2710. Corequisites: BME:4010. Requirements: junior standing.

BME:3998 Individual Investigations: Biomedical Engineering arr.
Individual projects for biomedical engineering undergraduate students, such as laboratory study, engineering design projects, analysis and simulation of an engineering system, computer software development, research.

BME:4010 Biomedical Engineering Design Seminar 1 s.h.
Students develop an awareness of design with emphasis on biomedical applications; principles and tools of user-centered design; basics of intellectual property (IP); skills for use in senior design and beyond. Requirements: junior standing.

BME:4310 Computational Biochemistry 3 s.h.
Introduction to biomolecular modeling and computer simulation techniques; biomolecular structure and molecular driving forces; principles of structural optimization and conformational sampling; applications to biomolecular phenotypes; scripting and molecular visualization in PyMol, setting up and running molecular dynamics simulations using VMD and NAMD, performing refinement of X-ray diffraction data sets using Phenix, and executing Poisson-Boltzmann electrostatic calculations using APBS. Prerequisites: (MATH:1560 or MATH:1860) and CHEM:1120. Recommendations: BIOC:3110 or BIOC:3120. Same as BIOC:4310.

BME:4314 Introduction to Synthetic Biology in the Lab 4 s.h.
Introduction to theory and practice of large-scale design goals of synthetic biology in which various types of DNA instructions, known from decades of research and discovery on specific biological systems, are taken out of context and used to execute various novel tasks designed to solve real-world problems; basic laboratory instruction in standardized construction techniques for stringing together off-the-shelf DNA components that are then introduced into organisms capable of executing the instructional set; controlled experiments to investigate the degree of variability exhibited by engineered genetic constructs. Prerequisites: BIOL:1411. Same as BIOL:4314.

BME:4710 Medical Device Design Studio 3 s.h.
Intermediate medical device design geared towards electro-mechanical design and techniques; builds on foundational knowledge acquired in BME:3710 and BME:2200; focus on advanced prototyping skills including solid modeling, proper electrical component selection, integrating electrical components into hardware design, and testing electro-mechanical device against industry standards. Prerequisites: BME:2200 and BME:2500 and BME:2710 and BME:3710.

BME:4910 Biomedical Engineering Senior Design I 4 s.h.
Individual or group work on a creative design project involving current problems in biomedical engineering; interdisciplinary projects involving biomedical engineering and health sciences faculty members; first semester of a year-long senior capstone design project. Prerequisites: (BIOS:4120 or STAT:3510) and BME:4010. Requirements: senior standing.

BME:4920 Biomedical Engineering Senior Design II 4 s.h.
Second semester of a year-long senior capstone design project begun in BME:4910. Prerequisites: BME:4910.

BME:5010 Seminar in Biomedical Engineering 0 s.h.
Presentation of recent advances in biomedical engineering. Requirements: graduate standing.

BME:5101 Biomaterials and Implant Design 3 s.h.
Introduction to material and mechanical considerations underlying a broad range of medical implants; emphasis on understanding factors involved in orthopedic device design; major classes of biomaterials; considerations that underlie implant design, use, failure; contemporary areas of biomaterials and implant development. Prerequisites: ENGR:2750 and BME:2500.

BME:5200 Biomedical Signal Processing 3 s.h.
Application of signal processing methods (e.g., Fourier, Laplace, z-transforms) to biomedical problems, such as analysis of cardiac signals, circadian rhythm, the breathing cycle; computer simulation lab. Same as IGPI:5212.

BME:5210 Medical Imaging Physics 3 s.h.
Physics and data acquisition techniques of major medical imaging modalities (X-ray, CT, MR, ultrasound, PET, SPECT); physical interactions of energy with living tissue; principles and methods for acquiring imaging data and subsequent image construction; how individual modalities influence image quality; MATLAB programming required. Second in a medical imaging sequence. Prerequisites: BME:2200 and BME:2210. Same as ECE:5470, IGPI:5206.

BME:5251 Advanced Biosystems 3 s.h.
Biological systems unique to systems analysis; operation under nonequilibrium conditions; tools for systems analysis developed from models of systems at equilibrium (i.e., mechanical systems); fundamental difference between biological and mechanical systems that impact systems analysis; expand knowledge of linear systems and begin work with nonlinear systems; various modeling and analysis approaches useful in biomedical and biomedical engineering research. Prerequisites: BME:2200. Same as IGPI:5251.

BME:5320 Bioinformatics Techniques 3 s.h.
Informatics tools and techniques applied to modern problems in biomedicine and basic life sciences; common tools, experience applying tools in contemporary problem settings; genomics and genetics, how to sequence a genome, transcription and expression, SNPs, Perl, BioPerl, Perl modules, Ensembl API, BLAST/BLAT, NCBI, UCSC, Ensembl Genome browsers, linkage, association, disease gene identification. Prerequisites: BIOL:1411 and (ENGR:2730 or CS:2110 or CS:5110). Same as ECE:5210, IGPI:5321.

BME:5330 Computational Genomics 3 s.h.
Introduction to computational methods used in genome analysis and functional genomics; biological sequence analysis, sequence database search, microarray data analysis, biological network analysis; in-depth coverage of principal genome science challenges and recent solutions. Prerequisites: (BIOS:4120 or STAT:3510) and (CS:5110 or ENGR:1300). Recommendations: completion of BME:5320. Same as BIOL:5320, ECE:5220, GENE:5173, IGPI:5330.

BME:5340 Contemporary Topics in Biomedical Engineering 3 s.h.
New and emerging areas of biomedical engineering and related fields; specific content varies.

BME:5421 Cell Material Interactions 3 s.h.
Current thought and techniques in the engineering and assessment of biomaterials. Prerequisites: BME:2400.

BME:5430 Biotransport 3 s.h.
Energy, mass, and momentum transport in living systems; processes essential for understanding how physiological systems function from molecular level through scale of tissues and organs; fluid mechanics and physiological flows, mass transport, biochemical kinetics and reactions, bioheat transfer; conservation laws; various biological applications. Prerequisites: BME:2500.

BME:5435 Systems Biology for Biomedical Engineering 3 s.h.
Although systems biology is comprised of both experimental and computational aspects, focus is on computational aspects; introduction to deterministic models of biochemical reaction networks; development and application of mathematical models of reaction networks using systems of nonlinear ordinary differential equations; numerical techniques employed to study system stability and perform simulations in realistic biological contexts. Prerequisites: BME:2400 and BME:2200.

BME:5441 Numerical and Statistical Methods for Bioengineering 3 s.h.
Mathematics and computation as indispensable tools needed to model and explain complex phenomena relevant to biomedical engineering problems; introduction to concepts from linear algebra, differential equations, probability and statistics, nonlinear model regression, optimization, numerical integration, and other numerical methods, all using Matlab. Prerequisites: MATH:2560 and MATH:2550.

BME:5445 Stem Cells in Regenerative Engineering 3 s.h.
Discovery and history of stem cells, how they are defined and grouped, and various techniques for their isolation, creation, culture, and characterization; focus on current state of stem cells in medical research and treatment of human disease, as well as future outlook of their use; particular emphasis placed on practical knowledge that students may find useful as they pursue careers in cellular and tissue engineering. Prerequisites: BME:2400 or BIOL:2723.

BME:5451 Research Methods in Cellular Engineering 3 s.h.
Statistical approaches and principles of assays routinely used in cell engineering; design of experiments and statistical approaches commonly used to analyze biological data including t-tests and one- and two-way ANOVAs, taking into consideration the constraints of cellular engineering research; students design, execute, and analyze data collected from actual experiments; review of recently published literature and analysis of public data sets to understand how each assay and test contributes to understanding of cellular phenotype. Prerequisites: BIOL:1411 and (STAT:3510 or BIOS:4120).

BME:5510 Cardiovascular Biomechanics 3 s.h.
Mechanics—forces and motion—at the heart of the cardiovascular system; fluid and solid mechanics inherent to the motion of the heart, valves, arteries, and veins, and how they facilitate the flow of blood; how to use mechanics to understand and diagnose the severity of cardiovascular disease states and to design implants and devices. Prerequisites: BME:2500.

BME:5520 Cardiovascular Fluid Mechanics 3 s.h.
Anatomy and physiology of the human circulatory system, pressure-flow relationship in arteries, elastic properties of the arterial wall, steady and pulsatile flow dynamics, flow dynamics of human heart valves, flow dynamics past valve prostheses, fluid mechanical measurements in circulation, relationship between fluid mechanics and diseases in human circulation. Prerequisites: BME:2500 and BME:5510.

BME:5530 Design of Circulatory Implants and Artificial Organs 3 s.h.
Exploration of current innovations and new technologies; examination of various devices currently on the market from a standpoint of design variables and objectives (i.e., stents, heart valves, dialyzers, VADs, artificial organs); biomedical engineers' vital role in design and improvement of these implants. Prerequisites: BME:2500 and BME:5510.

BME:5540 Quantitative Studies of Respiratory and Cardiovascular Systems 3 s.h.
Quantitative physiological aspects of respiratory and cardiovascular systems; classical models of these systems are considered including lumped element models, branching tree structures, and distributed parameter models to predict wave propagation in compliant walled tubes filled with compressible or incompressible fluids; development of extensive computer models to simulate the behavior of these systems in frequency- and time-domains, under various conditions of health and disease. Prerequisites: BME:2200 and HHP:3500.

BME:5550 Cardiovascular Tissue Mechanics 3 s.h.
Solid mechanics principles applied to understand behavior of tissues in the cardiovascular system; mechanical properties of ventricles, valves, and blood vessels, their normal function, how they are affected by disease states; solid mechanics of tissue-prosthesis interactions. Prerequisites: ENGR:2750 and BME:2500 and BME:5510.

BME:5610 Musculoskeletal Biomechanics 3 s.h.
Principles of solid mechanics applied to analytical, experimental investigation of biological systems; emphasis on applications in kinesiology of human musculoskeletal system. Prerequisites: BME:2500 and ENGR:2750.

BME:5620 Introduction to Applied Biomedical Finite Element Modeling 3 s.h.
Introduction to finite element modeling as applied to biomechanics-related applications. Prerequisites: ENGR:2750 and BME:2500.

BME:5630 Kinetics of Musculoskeletal Systems 3 s.h.
Principles of kinematics; kinetics applied to analytical and experimental investigation of musculoskeletal systems; mathematical foundations for kinematic and kinetic analyses; examples of mathematical modeling of human movements. Prerequisites: ENGR:2710.

BME:5640 Ergonomics of Occupational Injuries 3 s.h.
Epidemiology, surveillance systems, ergonomics, biomechanics, physiology, psychology, legal aspects, and cost control. Prerequisites: BME:2500. Corequisites: ENGR:2750.

BME:5715 Advanced Medical Device Design Studio 3 s.h.
Continuation of BME:3710 and BME:4710; biomedical engineering project based; focus on advanced prototyping and manufacturing techniques of mechanical and electromechanical medical devices; implementation of design controls and testing to medical industry standards for quality and safety; development of project management skills and communication within a team; final course in medical device design sequence. Prerequisites: BME:2200 and BME:2500 and BME:2710 and BME:3710 and BME:4710.

BME:5720 Optimization of Structural Systems 3 s.h.
Advanced topics; optimization of structural topology, shape, and material; finite dimensional dynamic response optimization, sensitivity analysis, distributed parameter systems; projects. Same as CEE:5236.

BME:5998 Individual Investigations: Biomedical Engineering arr.
Individual projects for biomedical engineering graduate students, such as laboratory study, engineering design project, analysis and simulation of an engineering system, computer software development, research. Requirements: graduate standing.

BME:5999 Research: Biomedical Engineering M.S. Thesis **arr.**
Experimental and/or analytical investigation of an approved topic for partial fulfillment of the requirements for the M.S. with thesis in biomedical engineering. Requirements: graduate standing.

BME:6110 Mechanics of Cells and Cellular Systems **3 s.h.**
Mechanics of cells; focus on cellular mechanical properties, responses to mechanical stimuli, cellular forces and measurement, and computational tools; cellular environment considered with implication to disease pathologies and medical device design considerations.

BME:6225 Communicating Science **3 s.h.**
Writing and speaking about biomedical engineering and science research; key principles of writing with clarity and cohesion; practice applying these principles on a piece of research writing students are currently working on; review of best practices for presenting research to peers and at conferences; students share their work with peers through writing and presentations.

BME:6415 Advanced Biomechanics and Modeling of Soft Tissues **3 s.h.**
Application of continuum mechanics and modeling to study of biological tissues and biomaterials.

BME:6610 Spine Mechanics **3 s.h.**
Biomechanics applied to mechanics of the human spine; clinical aspects; state-of-the-art in spine research; basic engineering principles for biomechanical analysis. Prerequisites: BME:5610.

BME:6630 Human Response to Vibration **3 s.h.**
Exploration of the human body, a complex mechanism exposed to mechanical shock and vibration from many sources, under many conditions; interactions and applicable exposure standards, effects of whole-body and hand-arm vibration. Requirements: graduate standing in College of Engineering or College of Public Health.

BME:7999 Research: Biomedical Engineering Ph.D. Dissertation **arr.**
Experimental and/or analytical investigation of an approved topic for partial fulfillment of requirements for Ph.D. with thesis in biomedical engineering.