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 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, and other allied fields. Several faculty members have joint appointments in biomedical engineering and in 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

Six dedicated undergraduate teaching laboratories are associated with the required and elective courses in biomedical engineering: Biomaterials Laboratory, Biomeasurements and Biosystems Laboratory, Biomechanics Laboratory, the Carver Biomechanics and Mechanobiology Laboratory, Cell Biology for Engineers Laboratory, and Senior Design Laboratory.

Biomaterials Laboratory

The Biomaterials Laboratory is equipped to test varied properties of biomaterials, including hard and soft tissues and prostheses. The laboratory is used for BME:2500 Biomaterials and Biomechanics and other biomaterials courses,BME:5421 Cell Material Interactions, and senior design projects.

Biomeasurements and Biosystems Laboratory

The Biomeasurements and Biosystems Laboratory is equipped to measure biomedical variables of clinical and physiological interest, design and build electronic instrumentation, and conduct modeling experiments in physiology. It is used for BME:2200 Systems, Instrumentation, and Data Acquisition, BME:2210 Bioimaging and Bioinformatics, elective courses in biomeasurements and biological systems analysis, senior design projects, and demonstrations in BME:2110 Cell Biology for Engineers.

Biomechanics Laboratory

The Biomechanics Laboratory is equipped to perform experiments relating to the cardiovascular and human musculoskeletal systems. The laboratory houses two cone-and-plate viscometers; compact stress-strain devices for characterizing cardiovascular tissues; digital still, video, and motion-capture cameras for kinematic analysis; goniometers; a ski binding tester; a drop tower for impact testing; a dual-mode amplifier system; two 3-D printers; a table-top material testing machine; and dissecting tools. The lab is used for BME:2500 Biomaterials and Biomechanics, elective courses in cardiovascular and musculoskeletal biomechanics, other elective courses, and senior design projects.

Carver Biomechanics and Mechanobiology Laboratory

The Carver Biomechanics and Mechanobiology Laboratory (CBML) is a shared resource in the 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 micro-PIV system for quantifying flow and particle dynamics at the micro-scale, a stent crimper for characterizing vascular stent designs, a multimode plate reader for quantifying cell activity and 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 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.

Cell Biology for Engineers Laboratory

The Cell Biology for Engineers Laboratory trains students in cell culture and biochemical analysis techniques as a foundation for future studies in quantitative cell-based studies. Students learn basic cell culture techniques, protein and nucleic acid analysis, adenovirus-mediated gene transfer techniques, microarray and analysis, and polymerase chain reaction (PCR) analysis of nucleic acids. They also are introduced to bioinformatics techniques used in cell biology.

Major equipment in the lab includes laminar flow hoods, cell culture incubators, centrifuges, an ultracold freezer, protein and nucleic acid electrophoresis equipment, thermal cyclers, microscopes, an automated microplate reader, and varied support apparatuses used in cell-based studies. The lab is used for BME:2110 Cell Biology for Engineers andBME:5421 Cell Material Interactions.

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.

Research Facilities and Laboratories

Bioinformatics and Computational Biology Laboratory

The Bioinformatics and Computational Biology Laboratory is wired for high-speed networking (10- and 100-megabit and gigabit ethernet, hardwired and wireless, and ATM). It includes five dedicated Linux clusters, 126 computing systems, 178 CPUs, more than 100 gigabytes of RAM, and 2.5 terabytes of disk space.

Computer resources include a dedicated computer server cluster of 18 Linux systems (36 CPUs) connected with a dedicated, switched, copper Gigabit Ethernet intranet—18 Dual AMD MP-2400 (2.2 GHz, 2 GB memory, 40 GB disk each); second dedicated computer server cluster of 16 Linux systems (32 CPUs) connected with a dedicated, switched, fiber-optic Gigabit Ethernet intranet—12 Dual Pentium III (500 MHz, 1 GB memory, 9 GB disk each), and four dual Pentium III (500 MHz, 2 GB memory, 9 GB disk each); and third dedicated computer cluster of nine Linux systems (18 CPUs) connected with a dedicated 2.4 GB multistage intranet—eight dual Pentium III (866 MHz, .5 GB memory, 45 GB disk each), and one dual Pentium III (866 MHz, 1 GB memory, 45 GB disk each).

There are two additional clusters: an 8-node cluster of Pentium II class machines and a 12-system heterogeneous cluster of various SUNs, HPs, and SGIs; four dedicated, dual fiber channel, redundant disk storage systems (RAID) with 412 GB usable each. An additional 78 computers are used as compute servers, web servers, database servers, file servers, workstations, laptops, and for other developmental and experimental needs.

Cardiovascular Biomechanics Laboratory

The Cardiovascular Biomechanics Laboratory houses an EMS Whitest uniaxial tension/compression testing system, a pulse-duplicating apparatus with flow loop, a spectrophotometer, silicone prototype fabrication utilities, high-speed/high-resolution cameras, a Sun Solaris workstation, and personal computers. The lab is equipped for soft tissue tensile/compression testing and viscoelastic creep/relaxation testing; simulation of flow through fabricated, anatomically realistic, patient-specific models of vasculature and heart valves; quantification of protein content in soft tissues; fabrication of realistic, compliant prototypes of human organs; and computational modeling of hemodynamics and tissue mechanics of normal and pathological cardiovascular organs.

Jolt/Vibration/Seating Laboratory

The Jolt/Vibration/Seating Laboratory is equipped for investigation of the biomechanics of the spine, particularly problems related to low back pain due to the interaction between people and equipment in jolt (impact) and vibration environments. Shakers are available to simulate impact and vibration environments.

Human responses are measured using equipment including load cells, electromyography, accelerometry, position sensors, and pressure pads. Portable sensors and data recorders are used to evaluate impact and vibration environments in the field and compare them to domestic and international guidelines and standards.

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 towards 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 codebase 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 RT-PCR systems, cell culture incubators, a laminar flow cell culture biosafety cabinet, a chemical fume hood, -80C freezer, other refrigerators and freezers, an ice machine, water purification system, autoclave, and many other tools, reagents, and devices.

Multiscale Modeling, Mechanobiology, and Tissue Engineering Laboratory

The Multiscale Modeling, Mechanobiology, and Tissue Engineering Laboratory is equipped for computational and experimental investigations centered on the role of physical forces in directing cell-material interactions that govern biological phenomena across multiple scales. A 650-square-foot core wet lab has equipment for isolating, culturing, maintaining, and analyzing cells, including a Nu-Aire two-chamber incubator, lab refrigerator and freezer, and a Thermo Scientific 1300 Series class II, type A2 biological safety cabinet. A 120-square-foot microscopy room houses an ADMET BioTense top-mounted perfusion bioreactor that integrates with a Nikon Ti-E inverted microscope, a system equipped to simultaneously record force values and acquire images of cell-to-extracellular matrix interactions in 3-D environments (e.g., a collagen gel) at high magnification over long periods of time and under a suite of mechanical testing protocols. The MTESTQuattro material testing system and accompanying software controls the bioreactor temperature, drives the actuator, and records force. The system can be operated in load or displacement control, supplying monotonic, cyclic, or segmented control profiles. Both the microscope and bioreactor are interfaced with an HP Z210 convertible minitower base model workstation.

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 1000 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 BSL2 cell culture room in the lab has two Panasonic cell culture incubators, two thermo biological safety cabinets, a fluorescent microscope, 37°C bead bath, and centrifuges. A separate 4-color fluorescence microscope also is available. The fully automated Leica DMI6000 captures 4-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 Research Laboratory

The Spine 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 3-D 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., LVDTs, 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

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:2110 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: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) 3-D CAD software; emphasis on elements of design; basic commands used in parametric design to develop spatial visualization skills and the ability to create and understand 3-D solid parametric design for assembly and 3-D drawing documentation; creation of 3-D 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:3200 Systems Biology for Biomedical Engineers **3 s.h.**
Introduction to computational approaches relevant to systems biology; although systems biology is comprised of both experimental and computational aspects, the focus is on the latter, providing an introduction to the use of deterministic models to study biochemical reaction networks; computational models will be constructed using Wolfram Mathematica to provide insights into the complexities of biochemical systems and also serve to acquaint students with the types of modeling approaches used to study these systems. Prerequisites: BME:2110 and BME:2200.

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.**
Information and presentations about possible projects; mentors available for senior design projects. Requirements: junior standing.

BME:4110 Principles of Regenerative Bioengineering **arr.**
Embryonic, fetal, and adult sources, human and nonhuman "stemness" of cells; references to biomaterials (i.e., those designed to direct organization, growth, and differentiation of cells in process of forming functional tissue by providing physical and chemical cues); biomarkers and nano-medicine; promises of bioinformatics in support tissue engineering, gene and protein sequencing, gene expression analysis, protein expression, and interaction analysis. Prerequisites: BIOL:1411. Corequisites: HHP:3500. Recommendations: BME:2110.

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: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. 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 IGPI:5206.

BME:5220 Digital Image Processing   **3 s.h.**
Mathematical foundations and practical techniques for digital manipulation of images; image sampling, compression, enhancement, linear and nonlinear filtering and restoration; Fourier domain analysis; image pre-processing, edge detection, filtering; image segmentation. Prerequisites: ECE:2400 or BME:2200. Same as ECE:5480, IGPI:5480.

BME:5230 Multidimensional Medical Imaging Process   **3 s.h.**
Algorithms developed to process and analyze large volumetric data sets; physics of CT, MRI, ultrasound, 3-D convolution and filtering, geometric transformations, shape features, surface segmentation, regional segmentation, surface tiling, surface reconstruction, volumetric registration. Third in a medical imaging sequence. Prerequisites: ENGR:1300.

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 BME:5320 and (CS:5110 or ENGR:1300). 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:5401 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:5415 Polymer Fundamentals   **1 s.h.**
Basic knowledge of polymers required as a foundation for other UI courses on polymers: basic polymer terminology, polymer groups, polymerization mechanisms, molecular weight determination. Five weeks. Same as CBE:5309.

BME:5421 Cell Material Interactions   **3 s.h.**
Current thought and techniques in the engineering and assessment of biomaterials. Prerequisites: BME:2110.

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:2110 and BME:2200 and BME:5430.

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:2110 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 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.

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.

BME:5540 Quantitative Studies of Respiratory and Cardiovascular Systems
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. Corequisites: 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:5660 Intermediate Mechanics of Deformable Bodies   **3   s.h.**
Application of equilibrium analyses, strain-displacement relations, and constitutive relationships to practical structural systems and elementary plane elasticity problems. Prerequisites: ENGR:2750. Same as CEE:5540, ME:5150.

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, ME:5236.

BME:5910 Fast-Track Biomedical Engineering Design 1-A   **3   s.h.**
Part A of first semester of year-long senior capstone design project; individual or group design project involving biomedical engineering problems. Corequisites: BME:5911. Requirements: senior standing.

BME:5911 Fast-Track Biomedical Engineering Design 1-B   **1   s.h.**
Part B of first semester of year-long senior capstone design project; individual or group project involving biomedical engineering problems. Corequisites: BME:5910. Requirements: senior standing.

BME:5920 Fast-Track Biomedical Engineering Design 2-A   **3   s.h.**
Part A of second semester of year-long senior capstone design project started in BME:5910 and BME:5911. Prerequisites: BME:5910. Corequisites: BME:5921.

BME:5921 Fast-Track Biomedical Engineering Design 2-B   **1   s.h.**
Part B of second semester of year-long senior capstone design project started in BME:5910 and BME:5911. Prerequisites: BME:5910. Corequisites: BME:5920.

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:6515 Advanced Biological Soft Tissue Mechanics   **3   s.h.**
Topics in vascular solid mechanics; study of vascular tissue from theoretical (constitutive modeling), experimental, and computational perspectives.

BME:6520 Advanced Biofluid Mechanics   **3   s.h.**
Hemodynamic theories of atherogenesis, Womersley models, steady and unsteady flows in curavature, bifurcation and branching arterial segments, flow dynamics past prosthetic implants, experimental and computational models, particulate and mass transport simulations in human circulation. Prerequisites: BME:5520.

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.