Roy J. Carver Department of Biomedical Engineering

Chair

Kim L. Blackwell

Undergraduate major: biomedical engineering (BSE)

Graduate degrees: MS in biomedical engineering; PhD in biomedical engineering

Faculty: https://engineering.uiowa.edu/bme/people

Website: https://engineering.uiowa.edu/bme

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, computational neuroscience, 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

- 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: the Bioimaging and Cardiovascular Engineering Laboratory; the Biomechanics and Biomaterials 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 Cardiovascular Engineering Laboratory

The Bioimaging and Cardiovascular Engineering Laboratory provides computer and experimental equipment to allow students to become familiar with biomedical imaging hardware and software for biomedical image analysis as well as cardiovascular engineering devices. The laboratory has four lab benches with computers for teamwork, two desktop ultrasound machines, and two desktop magnetic resonance imaging devices, a pulse duplicator apparatus for characterizing blood flow through mechanical and tissue heart valves, and a stent crimper for characterizing vascular stent designs. 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 versus 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, BME:5510 Cardiovascular Engineering, BME:5525 Cardiopulmonary Design and Modeling and senior design projects.

Biomechanics and Biomaterials Laboratory

The Biomechanics and Biomaterials Laboratory allows students 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; a Tekscan I-scan system with associated sensors; two cone-and-plate viscometers; compact stress-strain devices for characterizing cardiovascular tissues; goniometers; human structures biomechanical modeling sets and associated sensors; still, video, and motion-capture digital 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 like BME:4710 Medical Device Design Studio, 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, an automated multimode microplate reader for quantifying cell activity and extracellular matrix (ECM) remodeling, microscopes, a nanodrop spectrophotometer, PCR maching, and various support apparatus used in cell-based studies. This teaching lab is used for the courses BME:2400 Cell and Tissue Engineering Fundamentals and BME:5421 Cell Material Interactions.

Carver Medical Device Design Laboratory

The Carver Medical Device Design Laboratory is used for prototyping and fabrication by biomedical engineering students in design-related courses. It allows students to engage in industry-relevant hands-on projects and develop important skills related to prototyping, fabrication, and design. The lab houses computer workstations with a large LED display, 250W laser cutter, a medical-grade adhesive station, a benchtop computer numerical control (CNC) machine, 3D scanner, a manual drill-mill, a bandsaw, lathe, and micro pulse arc welder. It also has an assortment of hand and power tools, as well as several 3D printers for rapid prototyping and development. The Carver Medical Device Design Laboratory is utilized by students taking BME:3710 Medical Device Design: The Fundamentals, BME:4710 Medical Device Design Studio, & BME:5715 Advanced Medical Device Design Studio. It also used for prototyping and fabrication by students taking BME:4910 Biomedical Engineering Senior Design I and BME:4920 Biomedical Engineering Senior Design II, as well as, BME:5101 Biomaterials and Implant Design, and BME:2200 Systems, Instrumentation, and Data Acquisition.

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 hand tools, electronics, measurement devices, soldering stations, dremels, a 3D printer, 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 provides a collaborative environment for student teams to gain practical experience designing and testing electronic biomedical devices. It is equipped to measure, acquire, and analyze biomedical signals of clinical and physiological interest; to design, build, and test electronic instrumentation; and to conduct modeling experiments in physiology. The equipment includes computer workstations, power supplies, multimeters, function generators, oscilloscopes, breadboards, electrical components, integrated circuits, various transducers, Arduino microprocessors, and National Instruments data acquisition boards. It is used for the courses BME:2200 Systems, Instrumentation, and Data Acquisition and BME:4710 Medical Device Design Studio, biomeasurements and biological systems analysis, and senior design projects.

Research Facilities and Laboratories

The following laboratories are transformational spaces that enable the biomedical engineering faculty and students (graduate and undergraduate research assistants) to interact with one another by bringing together investigators with complementary fields of study. The laboratories have a direct impact on training graduate students and contribute to numerous research projects across campus. They have 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.

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 that supports tissue biomechanics, mechanobiology, and biomaterials research across health and disease. The lab's mission is to advance discovery and translation related to the biological processes that regulate tissue mechanics and to develop biomaterials that better model physiological and pathological environments.

The laboratory houses equipment for both soft-tissue and cellular mechanics, including an Agilent Cytation 5 for cellular contractility imaging, a Discovery HR-30 rheometer for extracellular matrix (ECM) viscoelastic characterization, a Stellaris 5 confocal microscope for high-resolution imaging, and a lyophilizer and cryomill for hydrogel preparation. The CBML supports experiments investigating how changes to the ECM alter fibroblast contractility and tissue mechanics in models of aging and fibrosis, as well as the design and testing of biomaterial scaffolds engineered to mimic or modulate these microenvironmental cues.

Coordinated Laboratory for Computational Genomics (CLCG)

The Coordinated Laboratory for Computational Genomics (CLCG) aims to catalyze the development of new areas of study and expanded research opportunities in informatics areas related to the basic biological sciences and applied medical research. Founded in 2002 as a joint enterprise between the College of Engineering and Carver College of Medicine, the CLCG involves faculty from five colleges, seven affiliated centers, institutes, and cores, and more than 19 departments. It serves as a coordinating home for interdisciplinary research, undergraduate, pre- and post-doctoral training, as well as faculty recruiting and professional development. At the hub of an inherently interdisciplinary field, the goal of the CLCG is to assist in overcoming traditional disciplinary hurdles to collaboration and assist in utilizing state-of-the-art instrumentation and analysis methods needed by 21st-century biomedical and basic science research.

Bioinformatics and Computational Biology Laboratory

The Center for Bioinformatics and Computational Biology 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) seeks to leverage principles from biomechanics, biomaterials, and medical imaging to develop tools for plumbing the human body with a focus on the heart, arteries, and lungs. It houses a 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.

Bioinspired and Bioengineered Microsystems Laboratory

The Bioinspired and Bioengineered Microsystems Lab is interested in exploiting bioinspired and multidisciplinary approaches (cellular, material, and bioengineering) to help understand respiratory diseases and develop effective treatments and accessible diagnostic tests to benefit patients. Structural and proteinaceous materials, such as silk fibroin, are a central research focus, as these materials enable aqueous and ambient processing, facilitate host-implant integration, and exhibit rare immunogenicity, a promising alternative to most synthetic polymers.

The laboratory is equipped with major equipment for material and bioengineering research, including a Leica Stellaris 5 confocal microscopy, a Cellink Inkcredible 3D printer, an Eppendorf 5804R centrifuge, a Laurell spin coater, an OptiMelt Automated Melting Point System, a Class 100 vertical laminar chamber, and a SpectraMax iD3 microplate detection system. The lab also has access to other shared equipment, including a biosafety hood, CO2 incubators, a chemical fume hood, -80°C and -20°C freezers, a fridge, an ice machine, a Thermofisher Barnstead water purification system, and a Tuttnauer 2540E autoclave.

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. Housed within this facility are the 3MT (multi-scale mechanics, mechanobiology, and tissue engineering) lab and Worthington lab.

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 the growth, maintenance, and characterization of mammalian cells, the lab also houses biosafety cabinets, incubators, a transfection system, an automated cell counter, a low-volume spectrophotometer, a 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.

Computational Laboratory

The Collaborative Computational Laboratory is a shared research computing resource, providing space and computational equipment for research in several fields, including computational fluid dynamics, medical image analysis, magnetic resonance imaging, machine learning, computational neuroscience, 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 focuses on molecular biophysics theory and high-performance computational algorithms used for engineering drugs and organic biomaterials. Located in the Bowen Science Building, the lab 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, autism spectrum disorder, and vision loss. Heavy use is made of the University of Iowa Argon compute cluster, including dedicated availability of 22 compute nodes, 76 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 is also used to predict how pharmaceuticals crystalize (i.e., into drug tablets) and to understand their thermodynamic properties (e.g., solubility).

Computational and Experimental Neuroplasticity Laboratory

The Computational and Experimental Neuroplasticity Laboratory (CENlab) is a multidisciplinary research group devoted to investigating the biophysical and biochemical mechanisms of long-term memory storage in neurons and networks. The computational research takes place in the Collaborative Computational Laboratory. The experimental research, located in the Bowen Science Building, utilizes a whole cell patch recording rig, comprised of a vibration isolation table with faraday cage, IR-DIC microscope, temperature controller, LED light source for optogenetics, two micromanipulators, and a low-noise, ultra-fast, digital patch clamp amplifier with integrated A-D connected to a Windows computer for computerized experimental control and data acquisition. In addition, the laboratory contains a fume hood, vibratome, analytical balance, heating stir plate, and a refrigerator for solution and tissue preparation.

Orthopedic Biomechanics Laboratory

The Orthopedic Biomechanics Laboratory is located in the medical center in North Liberty. The purpose of the laboratory is macroscopic-level physical testing of musculoskeletal constructs (e.g., bones, articular joints, orthopedic implants) and 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 (includes a mill, lathe, and a 3D printer), and a specimen storage area. There is designated space for computational modeling as well as offices for faculty, research staff, students, and fellows.

Pulmonary Microfluidic Laboratory

The Pulmonary Microfluidic Laboratory integrates micro-engineering methods with biology to understand airway physiology, treat pulmonary disease, and improve human health.

Regenerative Engineering Laboratory

The Regenerative Engineering Laboratory inhabits over 1,000 square feet of the Pappajohn Biomedical Discovery Building. The lab leverages the principles of regenerative medicine to promote healing and resolution of disease in vivo and to build better models of human tissues in vitro. 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, a 37°C bead bath, and centrifuges. A separate four-color fluorescence microscope is also 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 allow for the capture and analysis of three-dimensional z-stacks.

The chemistry portion 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.

Respiratory Dynamics Laboratory

The Respiratory Dynamics Laboratory, located in Seamans Center, uses multiscale dynamic imaging and biomechanics to learn how lung structures move, stretch, and transport gas during breathing and mechanical ventilation. The facility houses equipment for isolated lung preparation and imaging, including a laminar flow clean bench, a dissecting microscope, an isolated organ perfusion system, purpose-built mechanical ventilators, and a high-resolution x-ray micro-CT scanner. The lab maintains an array of supplies and equipment for electropneumatic control and measurement of respiratory gas flows and pressures. The facility also includes pressurized air and vacuum outlets, a chemical fume hood, biosafety cabinet, ice machine, water purification system, and cold storage at 4ºC, -20ºC, and -80ºC.

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 the 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 the 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, and 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.

These advanced courses are offered infrequently depending on the research focus of currently enrolled graduate students: BME:6415 Advanced Biomechanics and Modeling of Soft Tissues and BME:6230 Principles of Magnetic Resonance Imaging.

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 or HHP:2400 or BME:3260) 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 and Tissue Engineering Fundamentals 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 or HHP:2400 or BME:3260) 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:3260 Quantitative Physiology 3 s.h.
Introduction to core concepts in human physiology, homeostatic regulation, and structure-function relationships across cellular and organ systems; emphasis on analytical and quantitative methods including topics from dynamical systems, systems analysis, feedback, and control; students use mathematical modeling and computational simulation (MATLAB) to explore sensitivity analysis and emergent phenomena in complex physiological systems. Prerequisites: CHEM:1120 and BIOL:1411 and MATH:2560 and ENGR:1300.

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. Prerequisites: BME:2710 or ME:2200. Corequisites: BME:2500. Requirements: junior standing.

BME:3995 Undergraduate Research in Biomedical Engineering arr.
Research performed by a biomedical engineering student under mentorship of a faculty supervisor.

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.

BME:4135 Health Monitoring of Structural and Mechanical Systems 3 s.h.
Structural analysis, vibration analysis, experimental modal analysis, health monitoring, damage detection, measurements, and physical and numerical testing of structural and mechanical systems. Prerequisites: ENGR:2750. Same as CEE:4135, ME:4235.

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: BMB:3110 or BMB:3120. Same as BMB:4310.

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. 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 1 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:5240 Deep Learning in Medical Imaging (DLMI) 3 s.h.
Overview of deep learning architectures related to medical image analysis, including convolutional neural networks, auto-encoders, generative adversarial networks, and transformers; solve challenging medical imaging problems using image diagnosis, detection, segmentation, registration, and synthesis; use Python libraries including PyTorch, MONAI, SimpleITK, NumPy, and Matplotlib. Prerequisites: ENGR:2730. Requirements: practical knowledge of programming. Recommendations: ECE:5480, proficiency in Python, and comfortable with calculus, matrix algebra, and basic probability and statistics.

BME:5245 Introduction to Computed Tomography 3 s.h.
Principles of computed tomography (CT) from a signal processing perspective. Focus will be on image reconstruction and representation, with and without contrast, including identifiable sectional anatomy. Includes practical aspects such as CT system configurations, artifacts, and quality assurance. Also includes programming and literature readings. Prerequisites: BME:2210.

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:5335 Computational Bioinformatics 3 s.h.
Introduction to computational methods used in genomics, genome analysis, biological sequence analysis, sequence database search, expression analysis, and biological network analysis; in-depth coverage of principal genome science challenges and contemporary solutions. Prerequisites: (BIOS:4120 or STAT:2020 or STAT:3510) and (CS:5110 or ENGR:1300).

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.
Examine the current knowledge of cell and material interactions in terms of biomaterial science, the mechanobiology of native tissues and engineered analogs, and immunity. 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. Corequisites: BME:2500.

BME:5431 Biofabrication for Tissue Engineering 3 s.h.
Understanding the principles and approaches of advanced biofabrication for tissue engineering and regenerative medicine. Biofabrication relies on the use of biological materials and cells to create bioengineered tissue to regenerate or repair diseased or injured tissues and organs, such as respiratory bioengineering. Emphasis is on the fundamental mechanisms, processing conditions, and bioinspired strategies of biofabrication, additive approaches, the integration of molecular sciences, and tissue-level micro-physiological systems. Prerequisites: ENGR:2110 and BME:2400 and BME:2500.

BME:5435 Systems Biology for Biomedical Engineering 3 s.h.
Although systems biology is comprised of both experimental and computational aspects, the focus is on computational aspects; introduction to deterministic and stochastic models of biochemical reaction networks, including systems of nonlinear ordinary differential equations; introduction to diffusion; use of several software systems to perform simulations and analyze stability 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:5460 Biomedical Micro Devices and Systems 3 s.h.
Impact on biomedical research and entry into mainstream commercial markets, including biochemical molecule sensing, single-cell transcriptomics, cell sorting, and high-throughput drug screening; lab-on-a-chip, microfluidic, micro-electro-mechanical, micro total analysis systems, and related micro-devices; examination of history, theory, design, fabrication, and functional units of micro-sized devices; discussion of state-of-the-art technologies and real-life biomedical applications; fabrication and operation of lab-on-a-chip devices. Prerequisites: BME:2500.

BME:5510 Cardiovascular Engineering 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:5525 Cardiopulmonary Design and Modeling 3 s.h.
Cardiac and pulmonary systems; physiologic fluid mechanics critical to tissue/organ function, transport, homeostasis, and disease progression; diseases that afflict cardiopulmonary system; focus on role of fluid mechanics in how diseases develop, progress, and are treated; use of computational modeling tools to simulate disease conditions and understand challenges of designing devices and interventions. Prerequisites: ENGR:2510 and BME:2500.

BME:5540 Quantitative Studies of Respiratory and Cardiovascular Systems 3 s.h.
Quantitative physiological aspects of respiratory and cardiovascular systems; classical linear and nonlinear models, including lumped and distributed parameter models to predict air and blood flows in branching tree structures; biomedical instrumentation for respiratory and cardiovascular measurements; computer models to simulate the behavior of the respiratory and cardiovascular systems in frequency and time domains, under conditions of health and disease; functional and quantitative imaging techniques for the respiratory and cardiovascular systems. Prerequisites: BME:2200.

BME:5610 Musculoskeletal Biomechanics 3 s.h.
Fundamentals of mechanical principles applied to analytical and experimental investigations of musculoskeletal systems, emphasizing biomechanical understanding of clinical problems in bones, tendons, ligaments, cartilages, and musculoskeletal joints. Prerequisites: BME:2500 and ENGR:2750.

BME:5620 Introduction to Applied Biomedical Finite Element Modeling 3 s.h.
Introduction to finite element modeling techniques, software, and analysis with particular emphasis on solid biomechanics applications. Topics include various modeling techniques (pre- and post-processing), element types, convergence, anatomic modeling, model verification and validation, and appropriate communication of finite element results. Prerequisites: ENGR:2750 and BME:2500.

BME:5630 Kinetics of Musculoskeletal Systems 3 s.h.
Principles of kinematic and kinetic analyses of multibody systems; multivariable calculus and vectors and matrices required for multibody kinetic analyses; examples of mathematical modeling and human musculoskeletal system. Prerequisites: ENGR:2710.

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:4910.

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 MS Thesis arr.
Experimental and/or analytical investigation of an approved topic for partial fulfillment of the requirements for the MS with thesis in biomedical engineering. Requirements: graduate standing.

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:6230 Principles of Magnetic Resonance Imaging 3 s.h.
Focus on modern computational and model-based MRI methods; after a brief primer on MRI signal formation and basic pulse sequences, topics include image reconstruction as an inverse problem, spatiotemporal modeling, regularization, and constrained reconstruction using physics-based, motion-compensated, and machine-learning models; includes hands-on sequence programming and testing on scanners at UI Healthcare and the Magnetic Resonance Research Facility using open-source Pulseq API. Recommendations: BME:5210 or BME:5200 or ECE:5460; students should be comfortable with Fourier transforms, signals and systems, and basic linear algebra; a background in medical imaging or signal processing will be helpful but is not essential.

BME:6415 Advanced Biomechanics and Modeling of Soft Tissues 3 s.h.
Application of continuum mechanics to the study of soft biological tissues and biomaterials; soft tissue mechanical behaviors such as nonlinear elasticity, viscoelasticity, and anisotropy; use of principles from continuum mechanics for characterizing three dimensional deformation of tissues and development of constitutive models to describe material behavior.

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