# BIOMEDICAL ENGINEERING

Biomedical engineering is an exciting, multidisciplinary field that lies at the interface of medicine, biology and engineering. Biomedical engineers use engineering principles to analyze and solve problems in biology and medicine, providing an overall enhancement to healthcare. Biomedical engineers create technology to save lives and improve the quality of life. Much of the equipment in hospitals and clinics across the globe was designed, built and tested by biomedical engineers. At the same time, biomedical engineers employ concepts learned from biology and medicine to generate new (biomimetic) engineering designs in fields such as robotics and artificial intelligence.

**Course code for this program is BMEN.**

## Bachelor's Degree

- Biomedical Engineering - Bachelor of Science (BSBM) (https://catalog.colorado.edu/undergraduate/colleges-schools/engineering-applied-science/programs-study/biomedical-engineering/biomedical-engineering-bachelor-science-bsbm/)

## Minor

- Biomedical Engineering - Minor (https://catalog.colorado.edu/undergraduate/colleges-schools/engineering-applied-science/programs-study/biomedical-engineering/biomedical-engineering-minor/)

## Faculty

While many faculty teach both undergraduate and graduate students, some instruct students at the undergraduate level only. For more information, contact the faculty member's home department.

Ahmed, Alaa A. (https://experts.colorado.edu/display/fisid_144736/)
Assistant Professor; PhD, University of Michigan

Alistar, Mirela (https://experts.colorado.edu/display/fisid_164177/)
Assistant Professor; PhD, Technical University of Denmark

Allen, Mary Ann (https://experts.colorado.edu/display/fisid_149077/)
Research Associate Professor; PhD, University of Colorado Boulder

Borden, Mark A. (https://experts.colorado.edu/display/fisid_148514/)
Associate Professor; PhD, University of California, Davis

Bottenus, Nick (https://experts.colorado.edu/individual/fisid_165371/)
Assistant Professor; PhD, Duke University

Bruns, Carson J. (https://experts.colorado.edu/display/fisid_159851/)
Assistant Professor; PhD, Northwestern University

Calve, Sarah (https://experts.colorado.edu/individual/fisid_165779/)
Associate Professor; PhD, University of Michigan

Cha, Jennifer N. (https://experts.colorado.edu/display/fisid_151746/)
Professor; PhD, University of California, Santa Barbara

Clark, Torin K. (https://experts.colorado.edu/display/fisid_155959/)
Assistant Professor; PhD, Massachusetts Institute of Technology

Davis, Robert H. (https://experts.colorado.edu/individual/fisid_113653/)
Associate Faculty Director; PhD, Stanford University

Del Rio Flores, Antonio
Assistant Professor; PhD, University of California, Berkeley

Ding, Xiaoyun (https://experts.colorado.edu/display/fisid_158563/)
Assistant Professor; PhD, Pennsylvania State University

Dowell, Robin D. (https://experts.colorado.edu/display/fisid_147779/)
Professor; DSc, Washington University

Enoka, Roger M. (https://experts.colorado.edu/display/fisid_110122/)
Professor; PhD, University of Washington

Ferguson, Virginia L. (https://experts.colorado.edu/display/fisid_110131/)
Associate Professor; PhD, University of Colorado Boulder

Fox, Jerome Michael (https://experts.colorado.edu/display/fisid_156682/)
Assistant Professor; PhD, University of California, Berkeley

Gopinath, Juliet T. (https://experts.colorado.edu/display/fisid_147075/)
Associate Professor; PhD, Massachusetts Institute of Technology

Grabowski, Alena Marie (https://experts.colorado.edu/display/fisid_149727/)
Associate Professor; PhD, University of Colorado Boulder

Hayman, Allison P. (https://experts.colorado.edu/display/fisid_156275/)
Assistant Professor; PhD, Massachusetts Institute of Technology

Hind, Laurel (https://experts.colorado.edu/individual/fisid_165642/)
Assistant Professor; PhD, University of Pennsylvania

Huang, Shu-Wei (https://experts.colorado.edu/display/fisid_159847/)
Assistant Professor; PhD, MIT, Cambridge

Jayaram, Kaushik (https://experts.colorado.edu/display/fisid_165370/)
Assistant Professor; PhD, University of California-Berkeley

Layer, Ryan M. (https://experts.colorado.edu/display/fisid_163567/)
Assistant Professor; PhD, University of Virginia

Lynch, Maureen Ellen (https://experts.colorado.edu/display/fisid_163404/)
Assistant Professor; PhD, Cornell University

McLaughin, Jessica (https://experts.colorado.edu/individual/fisid_167401/)
Teaching Assistant Professor; PhD, Northeastern University

McLeod, Robert R. (https://experts.colorado.edu/display/fisid_107547/)
Professor; PhD, University of Colorado Boulder

Mukherjee, Debanjan (https://experts.colorado.edu/individual/fisid_164181/)
Assistant Professor; PhD, University of California, Berkeley

Murray, Todd W. (https://experts.colorado.edu/display/fisid_146549/)
Professor; PhD, Johns Hopkins University

Myers, Chris (https://experts.colorado.edu/display/fisid_167168/)
Professor; PhD, Stanford University

Neu, Corey P. (https://experts.colorado.edu/display/fisid_156210/)
Associate Professor; PhD, University of California, Davis

Park, Won (https://experts.colorado.edu/display/fisid_122676/)
Associate Professor, Associate Chair; PhD, Georgia Institute of Technology

Piestun, Rafael (https://experts.colorado.edu/display/fisid_118538/)
Professor; PhD, Israel Instit of Tech (Israel)

Regueiro, Richard A. (https://experts.colorado.edu/display/fisid_134705/)
Associate Professor; PhD, Stanford University

Rentschler, Mark E. (https://experts.colorado.edu/display/fisid_146091/)
Associate Professor; PhD, University of Nebraska-Lincoln

Sankaranarayanan, Sriram (https://experts.colorado.edu/display/fisid_147413/)
Associate Professor; PhD, Stanford University

Shields, C. Wyatt IV (https://experts.colorado.edu/individual/fisid_165173/)
Assistant Professor; PhD, Duke University

Spencer, Sabrina Leigh (https://experts.colorado.edu/display/fisid_154911/)
Associate Professor; PhD, Massachusetts Institute of Technology

Sprenger, Kayla (https://experts.colorado.edu/individual/fisid_165650/)
Assistant Professor; PhD, University of Washington

Tan, Wei (https://experts.colorado.edu/display/fisid_141464/)
Associate Professor; PhD, University of Illinois at Chicago

Welker, Cara (https://experts.colorado.edu/display/fisid_168549/)
Assistant Professor; Ph.D., Stanford University

Xu, Nicole (https://experts.colorado.edu/display/fisid_172095/)
Assistant Professor; PhD, Stanford University

Yeh, Tom (https://experts.colorado.edu/display/fisid_151584/)
Associate Professor; PhD, Massachusetts Institute of Technology

Zhang, Yide
Assistant Professor; PhD, University of Notre Dame

# Courses

**BMEN 1000 (1) Exploring Biomedical Engineering**
Introduces the biomedical engineering profession, curriculum, career pathways, ethics and responsibilities, and research opportunities. Academic and industry speakers are invited to address various biomedical engineering topics.
**Requisites:** Restricted to Biomedical Engineering (BMEN) and Open Option Engineering (XXEN) majors only.

**BMEN 1025 (4) Computer-Aided Design & Fabrication**
Introduces engineering drawing techniques through modern computer aided design (CAD) software, and fabrication of some of these designs. The course will begin with an introduction of spatial visualization skills, then an in-depth introduction to Solidworks, an industry standard CAD software tool, along with introduction to fabrication processes including laser cutting, and 3D printing. Additional topics include geometric design and tolerancing techniques and design for manufacturing.
**Requisites:** Restricted to Biomedical Engineering (BMEN) majors only.

**BMEN 1035 (1) Introduction to Fabrication for Biomedical Engineering**
The purpose of this course is to provide biomedical and other engineering students with an introduction to fabrication processes and rapid prototyping techniques including laser cutting, 3D printing, and 3D scanning. Additional topics include geometric design and tolerancing (GD&T) techniques and design for manufacturing (DFM) methods. Provides additional fabrication experience for students in CEAS who have already taken CAD courses and do not want to duplicate material by taking BMEN 1025.
**Equivalent - Duplicate Degree Credit Not Granted:** the fabrication component of BMEN 1025
**Requisites:** Requires prerequisite course of GEEN 1017 (minimum grade C-).

**BMEN 2000 (3) Introduction to Biomedical Engineering**
Reviews concepts from molecular and cellular biology. Establishes important aspects of human physiology and engineering principles to develop a basic understanding of the biomedical engineering field. Introduces topics such as biomechanics, bioinstrumentation, bioimaging and biotechnology.
**Requisites:** Requires prerequisite or co-requisite Biology course MCDB 1150 or BIEN 2810 or EBIO 1210 (min grade C-). Requires prerequisite Chemistry course CHEN 1201 or CHEN 1211 or CHEM 1113 or MCEN 1024 (min grade C-). Restricted to BMEN minors.

**BMEN 2010 (3) Biomaterials**
Introduces the science and engineering of biomaterials, with an emphasis on biomechanical aspects. Addresses the design, fabrication, testing, applications and performance of synthetic and natural materials that are used in a wide variety of biomedical prosthetics, implants and devices. In addition to attending lectures, students will conduct a laboratory experiment and a case study.
**Requisites:** Requires prerequisite course of CHEN 1201 or CHEN 1211 or CHEM 1113 (minimum grade C-). Restricted to Biomedical Engineering (BMEN) majors only.
**Recommended:** for students in fourth semester of Biomedical Engineering curriculum or higher.

**BMEN 2100 (3) Biomedical Engineering Principles and Methods**
This course is an introduction to the fundamental principles and mathematical methods of biomedical engineering. Core conservation equations are applied to mass, energy, charge, and momentum transfer in biomedical systems. Additional topics may cover a breadth of exposure in diagnostics and analytical techniques, statistical analysis of biomedical data, bioinformatics, bioinstrumentation.
**Requisites:** Required prereqs (APPM 1350 or Math 1300 or APPM 1345) and (CHEN 1201 or CHEN 1211 or CHEM 1113) and (PHYS 1110 or PHYS 1115) and (MCDB 1150 or BIEN 2810 or EBIO 1210) (all min grade C-). Restricted to BMEN majors, minors IUT On Track applicants.

**BMEN 3010 (3) Biotransport**
An introduction to the modeling of complex biological systems using principles of transport phenomena and biochemical kinetics. Includes the conservation of mass and momentum; rheology of Newtonian and non-Newtonian fluids; steady and transient diffusion in reacting systems; dimensional analysis; homogeneous versus heterogeneous reaction systems; and physiological transport systems, including receptor-mediated endocytosis and oxygen and drug transport.
**Requisites:** Requires prereq courses BMEN 2100 or BMEN 2000; CHEN 1310 or ASEN 1320 or CSCI 1300 or ECEN 1310; PHYS 1100 or PHYS 1115; and coreq of APPM 2360 or MATH 3430 (min grade C-). Restricted to Biomedical Engineering (BMEN) majors.
**Recommended:** for students in fifth semester of Biomedical Engineering curriculum or higher.

**BMEN 3030 (3) Bioinstrumentation**
This course will provide an overview of instrumentation systems used in clinical medicine and biomedical research. Systems for measuring biologic signals will be discussed including biopotentials, stress and strain, pressure, temperature, and optical properties to interpret data from living systems. There will be applications to engineering design, including a semester-long design project that incorporates the interactions between living and non-living systems. There will also be discussion of ethical and regulatory issues related to bioinstrumentation.
**Requisites:** Requires prerequisite courses of BMEN 2000 or BMEN 2100 and ECEN 2260 and ECEN 2270 (all minimum grade C-). Restricted to Biomedical Engineering (BMEN) major students.
**Recommended:** for students in sixth semester of Biomedical Engineering curriculum or higher.

**BMEN 4010 (3) Biomedical Engineering Capstone Design I**
Offers the first in a two-course sequence of capstone design. Project supervisors and teams are paired through a pitch process, wherein teams pitch their design ideas to meet an existing need on a project. Project is in an area of biomedical engineering, such as biomedical instrumentation, biosensors, tissue engineering, biological signal processing, biological modeling and simulation, clinical imaging or informational systems, etc. Projects will be conducted by teams of typically three to five students, and projects must include significant design experience. The first semester focuses on research of background, planning, crafting of needs statement, and initial work on senior design project . Formal proposal must be approved by technical advisor.
**Requisites:** Prereq of (BMEN 1025 or MCEN 1025) and BMEN 2010 and BMEN 3010. Pre or coreq of ENES 1010 or ENES 3100 or ENLP 3100 or PHYS 3050 or WRTG 3030 or WRTG 3035 (all min. grade C-). Restricted to BMEN majors w 87-180 credits.

**BMEN 4020 (3) Biomedical Engineering Capstone Design II**
Continues BMEN 4010. Teams continue to develop, construct, and evaluate prototypes with consideration of real-world fiscal, regulatory, and safety conditions. Progress is monitored through a series of oral presentations and peer review of teamwork and team dynamics. Requires students to complete a working prototype or simulation as appropriate, and a final written report with oral presentation at the semester Design Expo. Written final report must be approved by the faculty.
**Requisites:** Requires prerequisite course of BMEN 4010 (minimum grade C-). Restricted to Biomedical Engineering (BMEN) majors.

**BMEN 4110 (3) Regenerative Biology and Tissue Repair**
Presents the regenerative biology behind tissue systems, along with the regenerative medicine of that tissue with an emphasis on engineering principles, using the assigned reading as a guideline. Follows lectures with class discussions of current papers on the regenerative biology of the same tissue system. In the final 1 ¿ 2 classes assigned to this topic, individual graduate students give 20 min presentations on a relevant regenerative medicine/engineering-focused paper.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4110, BMEN 5110, and MCEN 5110
**Requisites:** Restricted to Biomedical Engineering majors with 57+ credits only.

**BMEN 4111 (3) Introduction to Microfluidics**
Microfluidics deals with the behavior of fluids in small scale. It is a highly multidisciplinary field at the intersection of engineering, physics, chemistry, biology, medicine, nanotechnology, and biotechnology. This course covers the fundamentals and fabrication of microfluidic devices and their applications, particularly in lab-on-a-chip. Includes lectures, literature discussion, team presentations, and possibly one lab on microfluidic devices. Enhances your understanding of microfluidic technologies and their broad applications.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 5111 and MCEN 4111 and BMEN 5111
**Requisites:** Requires prerequisite course of MCEN 3021 or CHEN 3200 or CVEN 3313 (all minimum grade C-). Restricted to Biomedical Engineering majors only.

**BMEN 4113 (3) Mechanics of Cancer**
Cancer is considered to be an organ or an ecosystem, in which a critical component of the tumor microenvironment is mechanical forces. This course will cover the role of mechanics in cancer and cancer-related processes, with a focus on solid mechanics and fluid mechanics. In this course, you will apply engineering principles to come away with an appreciation of how mechanics influence cancer and its etiology as well as the development of future treatments.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4113 and MCEN 5113 and BMEN 5113
**Requisites:** Requires prerequisite course of MCEN 3021 or CHEN 3200 or CVEN 3313 or MCEN 2063 or CVEN 3161 (all minimum grade C-). Restricted to Biomedical Engineering majors with 57+ credits only.

**BMEN 4117 (3) Anatomy and Physiology for Biomedical Engineering**
The main objective of this multidisciplinary course is to explore human physiological function from the viewpoint of an engineer. It provides an introduction to human anatomy and physiology with a focus on learning anatomical structures, biological signaling, physiological and pathological conditions, as well as fundamental biomedical engineering concepts that apply quantitative analyses (mass transfer, fluid dynamics, mechanics, modeling) and engineering concepts (e.g., device design to restore defective physiological functions) to understand physiology and pathology.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4117 or MCEN 5117 BMEN 5117
**Requisites:** Requires prerequisite of BMEN 2000 or BMEN 2100 (minimum grade C-). Restricted to Biomedical Engineering (BMEN) and Mechanical Engineering (MCEN) majors.
**Recommended:** Prerequisites BMEN 2010 or BMEN 3010 (all minimum grade C-).

**BMEN 4127 (3) Biomedical Ultrasound**
Covers the design of ultrasound systems for medical imaging and therapy, including the physics of wave propagation, transducers, pulse-echo imaging, flow, tissue characterization, and microbubble contrast, with an emphasis on current topics in biomedical ultrasound. Includes lectures on theory, practice and special topics; a laboratory on wave propagation; oral presentations on current literature; signal processing exercises; and a team project. Some experience with MATLAB is strongly encouraged for exercises throughout the course.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4127 and BMEN 5127 and MCEN 5127
**Requisites:** Requires prerequisite course of ECEN 3300 or ECEN 3301 or MCEN 4043. Restricted to Biomedical Engineering majors with 87+ credits only.

**BMEN 4157 (3) Modeling of Human Movement**
Human movement analysis is used in physical rehabilitation, sport training, human-robot interaction, animation, and more. Course provides a systematic overview of human movement on multiple levels of analysis, with an emphasis on the phenomenology amenable to computational modeling. Covers muscle physiology, movement-related brain areas, musculoskeletal mechanics, forward and inverse dynamics, optimal control and Bayesian inference, learning and adaptation. Inspires students to see and appreciate the complexities of movement control in all aspects of daily life.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4157 and MCEN 5157 and BMEN 5157
**Requisites:** Requires prerequisite of (MCEN2043 or GEEN 3024 or ASEN 1022) and (APPM2360 or MATH2130 or MATH3130) all minimum grade C-. Restricted to students with 57-180 credits (Jrs/Srs) Biomedical Engineering (BMEN) majors only.

**BMEN 4171 (3) Biofluids on the Micro Scale**
Introduces fundamental physical concepts and basic mechanisms of biological fluids in microscale. Elaborates on the application of fluid mechanics principles to major biological systems, including human organ systems and animal locomotion in microscale. Covers physiologically relevant fluid flow phenomena on the cellular level and the underlying physical mechanisms from an engineering perspective. Related state-of-art technologies such as organ-on-a-chip and micro/nano fabrication will be emphasized. Will enhance your understanding of organ-on-a-chip technologies and their broad applications.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4171 and MCEN 5171 and BMEN 5171
**Requisites:** Requires prerequisite course of MCEN 3021 or CHEN 3200 or CVEN 3313 (all minimum grade C-). Restricted to Biomedical Engineering majors only.

**BMEN 4195 (3) Bioinspired Robotics**
Bioinspired design views the process of how we learn from nature as an innovation strategy translating principles of function, performance, and aesthetics, from biology to human technology. The creative design process is driven by interdisciplinary exchange among engineering, biology, medicine, art, architecture and business. Diverse teams of students will collaborate on, create, and present original bioinspired design projects in the ITLL.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 5195, BMEN 5195 and MCEN 4195
**Requisites:** Requires prerequisite courses of MCEN 3017 and MCEN 3025 (minimum grade C-). Restricted to students with 57+ credits, BMEN majors only.

**BMEN 4231 (3) Computational Fluid Dynamics**
This course is an in-depth introduction to the basic principles and applications of computational fluid dynamics (CFD). Students learn about fundamental CFD concepts such as discretization, meshing, error and accuracy; and focus on computational solutions of flow and transport problems using the finite element method. Students conduct multiple hands-on simulation-based activities and exercises on canonical and realistic engineering flow/transport problems. Final project for the course culminates in a mini-conference/symposium where students present their work.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4231 and MCEN 5231 and BMEN 5231
**Requisites:** Requires prerequisite courses of MCEN 3021 or CHEN 3200 or CVEN 3313 and MCEN 3030 or APPM 4650 or CSCI 3656 (all minimum grade C-). Restricted to Biomedical Engineering majors only.

**BMEN 4292 (3) Materials and Devices in Medicine**
The main objective of this multidisciplinary course is to provide students with a broad survey of biomaterials and their use in medical devices for restoring or replacing the functions of injured, diseased, or aged human tissues and organs. The topics to be covered include: evolution in the medical device industry, a broad introduction to the materials used in medicine and their chemical, physical, and biological properties, discovery of medical problems, potential impacts of treatment innovations, existing devices and design considerations for several major physiological systems (cardiovascular, neuromuscular, skeletal, pulmonary, renal, dermal), materials interaction with the human body, basic mechanisms of wound healing, biocompatibility issues, testing methods and techniques in accordance with standards and relevant regulations, biofunctionalities required for specific applications, as well as state-of-the-art approaches for the development of new regenerative materials targeting cellular mechanisms. Sam
**Requisites:** Requires prerequisite courses of MCEN 2024 and MCEN 4117 or MCEN 5117 (all minimum grade C-). Restricted to students with 87-180 credits (Senior, Fifth Year Senior) BMEN majors only.

**BMEN 4519 (1-3) Special Topics in Biomedical Engineering**
Credit hours and subject matter to be selected from topics of current interest.
**Repeatable:** Repeatable for up to 15.00 total credit hours. Allows multiple enrollment in term.
**Requisites:** Restricted to students with 57-180 credits. Biomedical Engineering (BMEN) majors only.

**BMEN 4840 (1-3) Independent Study**
Provides opportunities for independent study at the undergraduate level. Subject and/or project agreed upon by the student and instructor to fit the needs of the student.
**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.
**Requisites:** Restricted to Biomedical Engineering (BMEN) majors only.

**BMEN 5110 (3) Regenerative Biology and Tissue Repair**
Presents the regenerative biology behind tissue systems, along with the regenerative medicine of that tissue with an emphasis on engineering principles, using the assigned reading as a guideline. Follows lectures with class discussions of current papers on the regenerative biology of the same tissue system. In the final 1 ¿ 2 classes assigned to this topic, individual graduate students give 20 min presentations on a relevant regenerative medicine/engineering-focused paper.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 5110, BMEN 4110, and MCEN 4110
**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Biomedical Engineering undergraduate majors only.

**BMEN 5111 (3) Introduction to Microfluidics**
Microfluidics deals with the behavior of fluids in small scale. It is a highly multidisciplinary field at the intersection of engineering, physics, chemistry, biology, medicine, nanotechnology, and biotechnology. This course covers the fundamentals and fabrication of microfluidic devices and their applications, particularly in lab-on-a-chip. Includes lectures, literature discussion, team presentations, and possibly one lab on microfluidic devices. Enhances your understanding of microfluidic technologies and their broad applications.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 5111 and MCEN 4111 and BMEN 4111
**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Biomedical Engineering undergraduate majors only.

**BMEN 5113 (3) Mechanics of Cancer**
Cancer is considered to be an organ or an ecosystem, in which a critical component of the tumor microenvironment is mechanical forces. This course will cover the role of mechanics in cancer and cancer-related processes, with a focus on solid mechanics and fluid mechanics. In this course, you will apply engineering principles to come away with an appreciation of how mechanics influences cancer and its etiology as well as the development of future treatments.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 5113 and BMEN 4113 and MCEN 4113
**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Biomedical Engineering undergraduate majors only.

**BMEN 5117 (3) Anatomy and Physiology for Biomedical Engineering**
The main objective of this multidisciplinary course is to explore human physiological function from the viewpoint of an engineer. It provides an introduction to human anatomy and physiology with a focus on learning anatomical structures, biological signaling, physiological and pathological conditions, as well as fundamental biomedical engineering concepts that apply quantitative analyses (mass transfer, fluid dynamics, mechanics, modeling) and engineering concepts (e.g., device design to restore defective physiological functions) to understand physiology and pathology. Graduate students will be required to present a primary literature review and lead discussion during a class period, as well as take the lead on the final project: a mock NIH grant proposal.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4117 or MCEN 5117 BMEN 4117
**Requisites:** Restricted to graduate Biomedical Engineering students only.

**BMEN 5127 (3) Biomedical Ultrasound**
Covers the design of ultrasound systems for medical imaging and therapy, including the physics of wave propagation, transducers, pulse-echo imaging, flow, tissue characterization, and microbubble contrast, with an emphasis on current topics in biomedical ultrasound. Includes lectures on theory, practice and special topics; a laboratory on wave propagation; oral presentations on current literature; signal processing exercises; and a team project. Some experience with MATLAB is strongly encouraged for exercises throughout the course.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 5127 and MCEN 4127 and BMEN 4127
**Requisites:** Restricted to graduate students only.
**Grading Basis:** Letter Grade

**BMEN 5133 (3) Intro to Tissue Biomechanics**
Focuses on developing an understanding of the fundamental mechanical principles that govern the response of hard and soft biological tissue to mechanical loading. Specifically, covers mechanical behavior of biological materials/tissues, classical biomechanics problems in various tissues, the relationship between molecular, cellular and physiological processes and tissue biomechanics and critical analysis of related journal articles.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4133 and MCEN 5133
**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Biomedical Engineering undergraduate majors only.

**BMEN 5157 (3) Modeling of Human Movement**
Human movement analysis is used in physical rehabilitation, sport training, human-robot interaction, animation, and more. Course provides a systematic overview of human movement on multiple levels of analysis, with an emphasis on the phenomenology amenable to computational modeling. Covers muscle physiology, movement-related brain areas, musculoskeletal mechanics, forward and inverse dynamics, optimal control and Bayesian inference, learning and adaptation. Inspires students to see and appreciate the complexities of movement control in all aspects of daily life.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 5157 and MCEN 4157 and BMEN 4157
**Requisites:** Restricted to graduate students in the College of Engineering and Applied Science or undergraduate Biomedical Engineering (BMEN) majors with 57+ credits (Junior or Senior).

**BMEN 5171 (3) Biofluids on the Micro Scale**
Introduces fundamental physical concepts and basic mechanisms of biological fluids in microscale. Elaborates on the application of fluid mechanics principles to major biological systems, including human organ systems and animal locomotion in microscale. Covers physiologically relevant fluid flow phenomena on the cellular level and the underlying physical mechanisms from an engineering perspective. Related state-of-art technologies such as organ-on-a-chip and micro/nano fabrication will be emphasized. Will enhance your understanding of organ-on-a-chip technologies and their broad applications.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 5171 and MCEN 4171 and BMEN 4171
**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Biomedical Engineering undergraduate majors only.

**BMEN 5195 (3) Bioinspired Robotics**
Bioinspired design views the process of how we learn from nature as an innovation strategy translating principles of function, performance, and aesthetics, from biology to human technology. The creative design process is driven by interdisciplinary exchange among engineering, biology, medicine, art, architecture and business. Diverse teams of students will collaborate on, create, and present original bioinspired design projects in the ITLL.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4195, BMEN 4195, and MCEN 5195
**Requisites:** Restricted to graduate students in the College of Engineering and Applied Science or undergraduate Biomedical Engineering (BMEN) majors with 57+ credits (Junior or Senior).

**BMEN 5231 (3) Computational Fluid Dynamics**
This course is an in-depth introduction to the basic principles and applications of computational fluid dynamics (CFD). Students learn about fundamental CFD concepts such as discretization, meshing, error and accuracy; and focus on computational solutions of flow and transport problems using the finite element method. Students conduct multiple hands-on simulation-based activities and exercises on canonical and realistic engineering flow/transport problems. Final project for the course culminates in a mini-conference/symposium where students present their work.
**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 5231 and MCEN 4231 and BMEN 4231
**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Biomedical Engineering undergraduate majors only.

**BMEN 5292 (3) Materials and Devices in Medicine**
The main objective of this multidisciplinary course is to provide students with a broad survey of biomaterials and their use in medical devices for restoring or replacing the functions of injured, diseased, or aged human tissues and organs. The topics to be covered include: evolution in the medical device industry, a broad introduction to the materials used in medicine and their chemical, physical, and biological properties, discovery of medical problems, potential impacts of treatment innovations, existing devices and design considerations for several major physiological systems (cardiovascular, neuromuscular, skeletal, pulmonary, renal, dermal), materials interaction with the human body, basic mechanisms of wound healing, biocompatibility issues, testing methods and techniques in accordance with standards and relevant regulations, biofunctionalities required for specific applications, as well as state-of-the-art approaches for the development of new regenerative materials targeting cellular mechanisms. Sam
**Requisites:** Requires prerequisite course of MCEN 4117 or MCEN 5117 (minimum grade C-). Restricted to any College of Engineering and Applied Science graduate students or to BMEN undergraduate majors only.

**BMEN 5840 (1-6) Independent Study**
Provides opportunities for independent study at the graduate level. Subject and/or project agreed upon by the student and instructor to fit the needs of the student.
**Repeatable:** Repeatable for up to 30.00 total credit hours.
**Requisites:** Restricted to graduate Biomedical Engineering students only.

**BMEN 5939 (1-6) Biomedical Engineering Internship**
Grants credit to international graduate students for conducting research via professional research opportunities in the biomedical engineering field. Students are responsible for securing their own internships.
**Repeatable:** Repeatable for up to 6.00 total credit hours.
**Requisites:** Restricted to graduate students only.

**BMEN 6519 (1-3) Special Topics in Biomedical Engineering**
Credit hours and subject matter to be arranged.
**Repeatable:** Repeatable for up to 12.00 total credit hours. Allows multiple enrollment in term.

**BMEN 6949 (1) Master's Candidate for Degree**
Credit hours and subject matter to be arranged.

**BMEN 6950 (1-6) Master's Thesis**
Work with a faculty advisor on a masters thesis.
**Repeatable:** Repeatable for up to 6.00 total credit hours.
**Requisites:** Restricted to graduate Biomedical Engineering students only.

**BMEN 7840 (1-6) Independent Study**
Provides opportunities for independent study at the graduate (PhD) level. Subject and/or project agreed upon by the student and instructor to fit the needs of the student.
**Repeatable:** Repeatable for up to 10.00 total credit hours. Allows multiple enrollment in term.
**Requisites:** Restricted to Biomedical Engineering BMEN-PhD students only.

**BMEN 8990 (1-10) Doctoral Dissertation**
Work with a faculty advisor on a doctoral dissertation.
**Repeatable:** Repeatable for up to 60.00 total credit hours.
**Requisites:** Restricted to Biomedical Engineering (BMEN) Ph.D. graduate students only.