UNDERGRADUATE BIOMEDICAL ENGINEERING CURRICULUM GUIDE SEPTEMBER 2020

Taimi Marple
Undergraduate Coordinator
206 Goergen Hall
(585) 273-4754
taimi.marple@rochester.edu

BME ADVISORS

2021

Awad, Hani	MC 1-8531	3-5268	hani.awad@rochester.edu
Brown, Edward	MC 5-6224A	3-5918	edward_brown@urmc.rochester.edu
Gdowski, Greg	Goergen 310	5-2580	greg.gdowski@rochester.edu
McAleavey, Stephen	Goergen 309	5-7768	stephen.mcaleavey@rochester.edu

2022

Benoit, Danielle	Goergen 308	3-2698	danielleswbenoit@rochester.edu
Dalecki, Diane	Goergen 210a	5-7378	diane.dalecki@rochester.edu
Giacomelli, Mike	MC 5-8527B		mike.giacomelli@rochester.edu
Maddox, Ross	MC G-9607	5-1835	ross.maddox@rochester.edu
Seidman, Scott	Goergen 216	3-2122	scott.seidman@rochester.edu

2023

Lee, Whasil	MC 4-8553	6-4631	whasil_lee@urmc.rochester.edu
Luebke, Anne	MC 6-8547	3-1635	anne_luebke@urmc.rochester.edu
McGrath, Jim	Goergen 306	3-5489	jmcgrath@bme.rochester.edu
Nam, Jong-Hoon	Hopeman 212	3-4555	Jong-hoon.nam@rochester.edu
Vats, Kanika	Goergen 311	6-4628	kanika_vats@urmc.rochester.edu

2024

Buckley, Mark	Goergen 317	6-4195	mark.buckley@rochester.edu
Carney, Laurel	MC 5-6418	6-3948	laurel.carney@rochester.edu
Choe, Regine	MC 5-7233A	3-4374	regine.choe@rochester.edu
Lalor, Edmund	MC G-9609	5-3077	elalor@ur.rochester.edu
Lerner, Amy	Goergen 307	5-7847	amy.lerner@rochester.edu

BME PRIMARY FACULTY

Chair of the Department

Diane Dalecki, Ph.D. (Rochester) *Distinguished Professor of Biomedical Engineering and of Electrical and Computer Engineering, and Director of The Rochester Center for Biomedical Ultrasound*
Research Area - Biomedical ultrasound, acoustics, lithotripsy, biological effects of ultrasound

Hani Awad, Ph.D. (Cincinnati) *Professor of Biomedical Engineering and of Orthopaedics and the Center for Musculoskeletal Research*
Research Area - Biomechanics of connective tissues, functional biomaterials of connective tissue, physicochemical regulation of engineered tissues, tissue engineering bioreactors, differentiation of stem cells, skeletal phenotyping of genetically altered mice

Danielle Benoit, Ph.D. (Colorado) *Professor of Biomedical Engineering and of Chemical Engineering, and the Center for Musculoskeletal Research*
Research Area -Tissue engineering, polymers, scaffolds, stem cells, musculoskeletal tissues, biomaterials, drug delivery, siRNA

Edward Brown III, Ph.D. (Cornell) *Associate Professor of Biomedical Engineering*
Research Area - Multi-photon microscopy for studies of vasculogenesis and tumor diagnostics

Mark Buckley, Ph.D. (Cornell) *Assistant Professor of Biomedical Engineering and the Center for Musculoskeletal Research*
Research Area – Soft biological tissue mechanics, viscoelasticity, tendon healing

Laurel Carney, Ph.D. (Wisconsin) *Marylou Ingram Professor of Biomedical Engineering and of Neuroscience, and of Electrical & Computer Engineering*
Research Area – Auditory Neuroscience; neurophysiological, behavioral, and computational studies of hearing; signal processing for hearing aids

Regine Choe, Ph.D. (U Penn) *Associate Professor of Biomedical Engineering*
Research Area – Development and improvement of diffuse optical methods based on near-infrared light illumination for detection and therapy monitoring of disease, including breast cancer.

Greg Gdowski, Ph.D. (Boston) *Associate Professor of Biomedical Engineering and Executive Director of the Center for Medical Technology & Innovation*
Research Area – The process of commercialization of medical technologies from identifying unmet clinical needs to the design, fabrication, marketing, regulatory and intellectual property aspects of medical devices

Michael Giacomelli, Ph.D. (Duke) *Assistant Professor of Biomedical Engineering*
Research Area – Surgical imaging, two photon microscopy, digital pathology

Edmund Lalor, Ph.D. (University College Dublin) *Associate Professor of Biomedical Engineering and of Neuroscience*
Research Area - Sensory systems neuroscience, computational neuroscience, attention, neural processing of speech, multisensory integration, brain-computer interfacing.

Whasil Lee, Ph.D. (Duke) *Assistant Professor of Biomedical Engineering and of Pharmacology and Physiology*
Research Area – Cell mechanics, chondrocyte mechanotransduction, therapeutics for knee arthritis

Amy Lerner, Ph.D. (Michigan) *Associate Professor of Biomedical Engineering and of Mechanical Engineering and Academic Director of the Center for Medical Technology & Innovation*
Research Area - Orthopaedic biomechanics, cartilage mechanics, medical image-based finite element modeling, knee biomechanics, cornea mechanics

Anne E. Luebke, Ph.D. (Johns Hopkins) *Associate Professor of Biomedical Engineering and of Neuroscience*
Research Area - Gene transfer to the cochlea, stem cell transfection, molecular biology of auditory efferent system receptors

Ross Maddox, Ph.D. (Boston) *Assistant Professor of Biomedical Engineering and of Neuroscience*
Research Area - Auditory neuroscience; Audio-visual integration; Selective attention; Development of electroencephalography paradigms for research and diagnosis.

Stephen McAleavey, Ph.D. (Rochester) *Associate Professor of Biomedical Engineering and of Electrical and Computer Engineering*
Research Area – Biomedical ultrasound, medical imaging, image-guided therapy, applications of time-delay estimation

James McGrath, Ph.D. (MIT) *Professor of Biomedical Engineering*
Research Area - Cell mechanics and motility, endothelial monolayer function, actin-based motility of pathogens

Jong-Hoon Nam, Ph.D. (Virginia Tech) *Associate Professor of Mechanical Engineering and of Biomedical Engineering*
Research Area – Function of inner ear sensory systems, focusing on the mechanical interaction between the inner ear sensory cells and their surrounding structures, combining computational and experimental methods.

Scott Seidman, Ph.D. (Case Western) *Professor of Biomedical Engineering and of Neuroscience*
Research Area – Embedded systems for healthcare, medical device innovation, assistive devices, neuroengineering

Kanika Vats, Ph.D. (Penn State) *Assistant Professor of Biomedical Engineering*
Research Interests – Biomedical nanotechnology, biomimetic membranes, cell-material interactions

Richard E. Waugh, Ph.D. (Duke) *Professor of Biomedical Engineering, of Pharmacology & Physiology, of Biochemistry and Biophysics, and of Mechanical Engineering*
Research Area - Mechanical and thermodynamic properties of biological membranes; cellular mechanics and function of cytoskeletal proteins

BME SECONDARY FACULTY

Joan Adamo, Ph.D. (Cornell) *Adjunct Assistant Professor, Associate Director, Regulatory Support Services, University of Rochester Clinical Translational Science Institute*

Ajay Anand, Ph.D. (Washington) *Deputy Director, Goergen Institute of Data Science, Assistant Professor of Data Science and of Biomedical Engineering*

Tim Baran, Ph.D. (Rochester) *Research Assistant Professor of Imaging Sciences and of Biomedical Engineering*

Andrew Berger, Ph.D. (MIT) *Associate Professor of Optics and of Biomedical Engineering*

Patricia R. Batchelor Chess, M.D. (Columbia) *Professor of Pediatrics and of Biomedical Engineering*

Robert Clark, Ph.D. (Virginia Tech) *Professor of Mechanical Engineering and of Biomedical Engineering;*

University of Rochester Provost & Sr. Vice President for Research

Joe V. Chakkalakal, Ph.D. (Ottowa) *Associate Professor of Pharmacology and Physiology and of Biomedical Engineering*

Benjamin Crane, M.D., Ph.D. (UCLA) *Associate Professor of Otolaryngology, Neuroscience and of Biomedical Engineering*

David Dean, Ph.D. (UC Berkeley) *Professor of Pediatrics, Neonatology and of Biomedical Engineering*

Gregory DeAngelis, Ph.D. (California, Berkeley) *Professor of Brain and Cognitive Sciences, of Biomedical Engineering, of Neuroscience and in the Center for Visual Science*

Lisa A. DeLouise, Ph.D. (Pennsylvania State) *Associate Professor of Dermatology and of Biomedical Engineering*

Ian Dickerson, Ph.D. (Purdue) *Associate Professor of Neuroscience and of Pharmacology and Physiology*

Vikram Dogra, Ph.D. (University of Madras, India) *Professor of Imaging Sciences and of Biomedical* Engineering

Marvin Doyley, Ph.D. (University of London) *Associate Professor of Electrical and Computer Engineering and of Biomedical Engineering*

Thomas Foster, Ph.D. (Rochester) *Professor of Imaging Sciences, and of Biomedical Engineering*

Angela Glading, Ph.D. (Pittsburgh) *Associate Professor of Pharmacology & Physiology and of Biomedical Engineering*

Sheryl Gracewski, Ph.D. (California) *Professor of Mechanical Engineering and of Biomedical Engineering*

Kenneth S. Henry (Purdue) *Assistant Professor of Otolaryngology and of Neuroscience and of Biomedical Engineering*

Denise Hocking, Ph.D. (Albany) *Professor of Pharmacology & Physiology and of Biomedical Engineering*

Thomas Howard, Ph.D. (Carnegie Mellon) *Assistant Professor of Electrical and Computer Engineering and of Biomedical Engineering*

Jennifer J. Hunter, Ph.D. (Waterloo) *Associate Professor of Ophthalmology and of Biomedical Engineering, Center for Visual Science*

Alayna E. Loiselle (Rochester) *Assistant Professor of Biomedical Engineering*

William Merigan, Ph.D. (Maryland) *Professor of Ophthalmology and Biomedical Engineering and Center for Visual Science*

Benjamin Miller, Ph.D. (Stanford) *Professor of Dermatology, of Biochemistry and Biophysics, and of Biomedical Engineering*

Duncan T. Moore, Ph.D. (Rochester) *Vice Provost, Entrepreneurship*, *Professor of Optics and of Biomedical Engineering and Rudolph and Hilda Kingslake Professor of Optical Engineering Science*

Maiken Nedergaard, M.D. (University of Copenhagen) *Professor of Neurosurgery, Center for Translational Medicine, and of Biomedical Engineering*

Ruola Ning, Ph.D. (Utah) *Professor of Imaging Sciences, of Electrical and Computer Engineering and of Biomedical Engineering*

Gary Paige, M.D., Ph.D. (Chicago) *Kilian J. and Caroline F. SCHEMitt Professor of Neuroscience, of Ophthalmology, and of Biomedical Engineering*

Kevin J. Parker, Ph.D. (MIT) *Professor of Electrical and Computer Engineering, of Imaging Sciences and of Biomedical Engineering, Dean Emeritus, Hajim School of Engineering and Applied Sciences*

Tatiana Pasternak, Ph.D., (University of Copenhagen) *Professor of Neuroscience, of Brain & Cognitive Sciences, and of Center for Visual Science*

Renato Perucchio, D. Engr. (Pisa, Italy) *Professor of Mechanical Engineering and of Biomedical Engineering, and Associate Professor of Pediatrics*

J. Edward Puzas, Ph.D. (Rochester) *Donald and Mary Clark Professor of Orthopaedics and of Biomedical*

Engineering

Janick Rolland, Ph.D. (Arizona) *Professor of Optics and of Biomedical Engineering*

Deborah Rubens, M.D. (Rochester) *Professor of Imaging Sciences; Associate Chair of Imaging Sciences*

Michael C. Schell, Ph.D. (Wisconsin, Madison) *Professor of Radiation Oncology and of Biomedical Engineering*

Marc Schieber, M.D. (Washington U Medical Center) *Professor of Neurology, and of Neuroscience, and of Center for Visual Science*

Edward M. Schwarz, Ph.D. (Albert Einstein College of Medicine) *Professor of Orthopaedics, of Microbiology and Immunology, of Urology, of Medicine, of Pathology and Laboratory Medicine, and of Biomedical Engineering*

Eric M. Small, Ph.D. (Univ Texas-Austin) *Associate Professor of Biomedical Engineering and of Medicine and of Pharmacology and Physiology*

Laura Slane, Ph.D. (Wisconsin) *Assistant Professor of Mechanical Engineering and of Biomedical Engineering*

Jonathan J. Stone, DM (Buffalo) *Assistant Professor of Neurosurgery and of Neurology and of Biomedical Engineering*

David R. Williams, Ph.D. (California, San Diego) *William G. Allyn Professor of Optics, Director of the Center for Visual Sciences, Professor of Optics, of Ophthalmology, of Biomedical Engineering, and of Brain & Cognitive Sciences*

Axel Wismüeller, M.D., Ph.D., (Technical University, Munich, Germany), *Professor of Imaging Sciences and of Biomedical Engineering*

J. H. David Wu, Ph.D. (MIT) *Professor of Chemical Engineering, of Microbiology and Immunology and of Biomedical Engineering*

Geunyoung Yoon, Ph.D. (Osaka) *Professor of Ophthalmology, of Biomedical Engineering, and in the Center for Visual Science*

James M. Zavislan, Ph.D. (Rochester) *Associate Professor of Optics, of Dermatology, of Ophthalmology, and of Biomedical Engineering*

Xinping Zhang, Ph.D. (Rochester) *Associate Professor of Orthopaedics, Center for Musculoskeletal Research and of Biomedical Engineering*

Jianhui Zhong, Ph.D. (Brown) *Professor of Imaging Sciences, of Biomedical Engineering and of Physics*

ADJUNCT FACULTY

Jason Condon, M.S. (Pennsylvania) *Adjunct Assistant Professor*, *Senior Project Manager, CMC at Vaccinex, Inc.*

Kevin Davis, Ph.D. (Boston) *Adjunct Associate Professor, Lecturer, Brain & Cognitive Sciences*

Thomas Gaborski, Ph.D. (Rochester) *Adjunct Associate Professor, Associate Professor, Rochester Institute of Technology*

Nipa Mody, Ph.D. (Rochester) *Adjunct Assistant Professor, Senior Engineer at Ortho Clinical Diagnostics*

Owen Papuga, Ph.D. (Rochester) *Adjunct Assistant Professor, Associate Professor New York Chiropractic College*

Jiandi Wan, Ph.D. (Boston) *Assistant Professor of Microsystems Engineering at Rochester Institute of Technology, Adjunct Assistant Professor, Ctr for Translational Neuromedicine& Biomedical Engineering*

INTRODUCTION

Biomedical Engineering (BME) involves the application of engineering science and technology to solve problems in biology and medicine. This broad area offers many career opportunities, ranging in scope from advanced research to engineering practice in industrial or clinical settings. The Department of Biomedical Engineering, in conjunction with strong academic programs in the basic sciences and other engineering disciplines at the University of Rochester, offers outstanding training in this rapidly growing field.

B.S. IN BIOMEDICAL ENGINEERING

The Bachelor of Science degree program in biomedical engineering at the University of Rochester has been accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org since 2001. Our curriculum emphasizes fundamental engineering and design principles taught in the context of current problems in medicine and biology. A series of nine core courses required of all BME students provides a solid foundation in engineering principles relevant to biomedical engineering practice. To ensure in-depth training in engineering, students are required to complete a sequence of four engineering courses in a focus area of biomedical engineering. These areas of concentration are: Biomechanics, Biosignals & Biosystems, Cell & Tissue Engineering, and Medical Optics. The program is capped with a biomedical engineering senior design course required of all students. This program requires a total of 131 credit hours, including a minimum of 50 credit hours devoted to mathematics and natural sciences and a minimum of 51 credit hours devoted to engineering.

The Undergraduate Program

The interdisciplinary nature of biomedical engineering requires expertise in both the biological and engineering sciences. The University of Rochester offers several avenues of academic study in biomedical engineering, each of which can be structured to satisfy pre-medical, pre-dental, physical therapy or nursing requirements. The University of Rochester offers B.S., M.S. and Ph.D. programs in biomedical engineering. The Minor in biomedical engineering (24 credits) provides opportunities for students majoring in other disciplines to obtain substantive exposure to the field of biomedical engineering. Minor requirements are listed below, and on the BME website: http://www.hajim.rochester.edu/bme/undergraduate/minor.html

DEPARTMENTAL MISSION AND PROGRAM EDUCATIONAL OBJECTIVES

Mission

Discover, create, and educate to engineer ever better solutions in biomedical research and health care.

Undergraduate Program Educational Objectives

The overall educational objective of our program is to develop effective practitioners in biomedical engineering and associated fields. We expect that our graduates will contribute to the advancement of their chosen field, while remaining mindful of the ethical and social implications of their work. They will confidently apply knowledge in the basic sciences, mathematics, engineering analysis, and design to address problems in medicine and biology. In keeping with the continuously evolving nature of the field of biomedical engineering, we expect that our alumni will effectively communicate, engage in lifelong learning, and that many of them, inspired by research experiences as undergraduates, will continue their education in advanced degree programs.

BME CURRICULUM AND REQUIREMENTS

Basic Science & Math Courses (38 credit hours)

Nine courses in natural sciences and mathematics divided as follows:

Four Math courses - MATH 161, 162, 164, 165
(MATH 141, 142, & 143 are equivalent to MATH 161 & 162)
Two Chemistry courses - CHEM 131 and CHEM 132 (5 credits each)*
Two Physics courses - PHYS 121 or PHYS 121P, PHYS 122 or PHYS 122P
(PHYS113 may be a required substitute for PHYS121 for those students in the MATH 141-3 series)
One Biology course - BIOL 110**

* Students with a strong chemistry background (AP >4) may choose to take the CHEM 17x series, Freshman Organic Chemistry. This sequence is not a direct replacement for 131 and 132, however, since it does not cover all chemistry material necessary for the major. Therefore, students may take any of the following combinations:

CHEM131 (or AP>=4) and CHEM132
CHEM171 and CHEM132
CHEM171, CHEM172 and CHEM132
CHEM171, CHEM172 and CHEM211 (Inorganic Chemistry: preferred for Pre-med) or CHEM252

** Most BME students take BIOL 110 during the *sophomore* year. However, students with AP credit for BIOL *and* room in their schedules freshman year (due to additional AP credit in Chemistry or Math) may choose to take BIOL 112 during their freshman year. Students with AP credit for Biology will receive 4 credits of elective biology, but are still required to take BIOL 110 or 112. The BIOL110L fall course offering has a required lab component which is held every other week. The BIOL110 spring offering does not have a required lab. Students may use either course to fulfill the BME requirement.

Core BME Courses (35 credit hours)

The curriculum features a series of core BME courses that aims to provide students with a breadth of knowledge and skills in the field of biomedical engineering. The following courses form the BME Core. (See course descriptions provided at the end of the Curriculum Guide.)

BME 101/EAS101 - Introduction to Biomedical Engineering (with lab)
BME 201 - Fundamentals of Biomechanics
BME 201P - MATLAB for Biomedical Engineering (1 credit)
BME 210 - Biosystems and Circuits (with lab)
BME 221 - Biomedical Computation & Statistics (with 099 lab)
BME 230 - Biomedical Signals, Systems & Imaging (with lab)
BME 245 – Biomaterials (with 099 lab)
BME 260 - Quantitative Physiology (with lab)
BME 295 - BME Design Seminar (2 credits)
BME 296 - BME Senior Design

Primary Writing Requirement (4 credit hours)

The Primary Writing Requirement must be satisfied with a grade of C or better before admission to the program. (WRTG 105 - Reason and Writing) See the website: http://www.rochester.edu/College/CCAS/AdviserHandbook/PrimWrReq.html.

Upper Level Writing Requirement

Significant writing experience in one's discipline is an important adjunct to the technical material one learns. As of 7/01, the courses that fulfill the University's Upper Level Writing Requirement by placing significant weight on the effectiveness of written communication are: BME 221, BME 230, BME 260, BME 296, and any Upper Level BME course (concentration capstone courses).

Cluster and Humanities & Social Sciences (H/SS) (16 credit hours)

All BME majors must complete a total of **four** courses in humanities and/or social sciences. Three of these courses must constitute an approved Cluster in either Humanities or Social Sciences and must be passed with a 2.0 average or better. See the Cluster Search Engine on the UR website to review courses and descriptions: https://secure1.rochester.edu/registrar/CSE/index.php

The fourth course can be chosen from any recognized Humanities or Social Science field. This course can not be designated S/F (Satisfactory/Fail). Credit provided for serving as a Teaching Assistant or Workshop Leader can not be used for the H/SS requirement. Transfer or AP credit for this fourth course may be used.

**A second major or minor in a Humanities or Social Science (H/SS) area will also satisfy the cluster and additional H/SS course requirement.

No computer courses offered in humanities or social science fields may be used as an H/SS distribution course.

Communicating Your Professional Identity (2 credit hours)

All students must complete WRTG 273, an interactive course designed to teach "real life communication skills and strategies that help students present their best professional selves". Students will explore and articulate their internship, career and graduate school goals for distinct audiences and purposes as they develop a professional communication portfolio of materials such as resumes, cover letters, statements of purpose, electronic communications, technical project abstracts, online profiles (i.e., LinkedIn), and oral presentations. Most students will complete this course in the spring of the sophomore year or the fall of the junior year.

Free Electives (12 credit hours)

Any courses taken at the University of Rochester, independent study courses, AP courses, study abroad or transfer courses may be used for elective credits. Students may consider additional courses in the humanities, social sciences, natural sciences or engineering and many use these courses to pursue a minor. A full list of BME courses is provided at the end of this document for options to consider within the department. Seniors may choose to take courses at the graduate level, but any courses taken to fulfill this requirement may not also be used toward a graduate degree.

BME Concentration Courses (16 credit hours)

Students choose to concentrate in one of four BME specialty areas. Four engineering courses are required to form a sequence in one of the following areas: Biosignals & Biosystems, Biomechanics, Cell & Tissue Engineering, or Medical Optics. Each concentration includes an upper level BME course in the specialty area. Courses for each concentration and example course schedules are given below.

Biosignals & Biosystems

ECE 230 - Electromagnetic Waves
ECE 221 - Electronic Devices & Circuits **or** BME 228 Physiological Control Systems
ECE 246 - Digital Signal Processing
Upper Level BME:
e.g. BME 251 - Biomedical Ultrasound, BME 253 - Ultrasound Imaging, or BME 218 - Intro to Neuroengineering

Biomechanics

ME 226 - Introduction to Solid Mechanics
ME 225 - Introduction to Fluid Dynamics
ME 123 - Thermodynamics
Upper Level BME:
e.g. BME 283 - Biosolid Mechanics or BME 212 - Viscoelasticity in Biological Tissues

Cell & Tissue Engineering

CHE 243 - Fluid Dynamics
CHE 244 - Heat & Mass Transfer
CHE 225 - Thermodynamics
Upper Level BME:
e.g. BME 262 - Cell & Tissue Engineering, or BME 266 – Bioprocess Engineering, or BME 265 - Intro to Cell Mechanics & Mechanobiology

Medical Optics

BME 270 - Biomedical Microscopy
OPT 241 - Geometrical Optics
OPT 261 - Interference & Diffraction
Upper Level BME:
e.g. OPT 276 -Biomedical Optics, BME 272 – Advanced Biomedical Microscopy or BME 255 - Translational Biomedical Optics

Custom Concentrations:

Most students will complete one of the four concentrations listed above. However, if you have a specialized interest in biomedical engineering, you ***may*** use a custom concentration petition form to the BME Undergraduate Committee to propose a custom concentration tailored to that interest. Such concentrations should be developed in advance of taking the courses, in consultation with your faculty advisor, and must satisfy the following requirements:

- ❑ Must include one course already designated by BME to be an "Upper Level BME course (ULBME)"
- ❑ Must satisfy any pre-requisites identified by that upper level BME Course
- ❑ Must include at least three 4-credit engineering courses from an ABET accredited program in the Hajim School of Engineering & Applied Sciences (i.e., not EAS or CS or AME courses)
- ❑ Courses must create a cohesive theme and show some depth in that area. (For example, typically concentrations have pre-requisites of other engineering courses.) Petitions should include a proposed title and a short paragraph explaining the theme of the concentration.

- ❑ Courses are typically at the 200-level, and may not be considered equivalent to any courses in the BME core.
- ❑ Independent study courses may not be used.
- ❑ Approval must be obtained by the advisor and the BME UG Curriculum Committee

Sophomore students interested in the custom concentration option may make an appointment with Prof. Amy Lerner to discuss in more detail. The following examples demonstrate the flexibility provided by these custom concentrations.

Examples of Custom Concentrations:

(note: These would *still* require approval by the BME UG Curriculum Committee.)

Bioprocess Engineering

CHE 244 - Heat and Mass Transfer
CHE 243 - Fluid Mechanics
CHE 259 - Transport Phenomena in Biological Systems
ULBME: BME 266 – Bioprocess Engineering

Optomechanical Medical Devices

ME 226 - Solid Mechanics
ME 280 - Materials Science
BME 270 - Biomedical Optics
ULBME: BME 283 – Biosolid Mechanics

Upper Level BME Courses - ULBMEs (capstone courses for each concentration). These courses are specially designated for each concentration as they meet specific criteria and are faculty approved.

Biosignals & Biosystems
BME 218 (Fall)
BME 251 (Spring)
BME 253 (Fall)

Biomechanics
BME 283 (Fall)
BME 212 (Spring)

Cell & Tissue Engineering
BME 266 (Fall)
BME 262 (Spring)
BME 266 (Fall)

Medical Optics
BME 255 (Fall)
BME 272 (Spring)
BME 276 (Spring)

Basic Science Electives (8 credit hours)

All students must complete at least two additional courses (at least 8 credit hours) in the basic sciences in addition to the required introductory biology (BIOL 110), chemistry (CHEM 131 & CHEM 132), and physics (PHYS 121/141 & PHYS 122/142) courses. Any natural science course with a number of 110 or higher (biology, microbiology, environmental science, neuroscience, chemistry, physics, or selected courses from brain & cognitive sciences) may be used to fulfill this requirement. Students are encouraged to choose their basic science electives to complement their BME concentration area and career plans. Independent study courses cannot be used to satisfy this requirement.

***Examples* of approved BSEs are:**

ASTR142 Elementary Astrophysics
ASTR231 Gravitation & General Relativity
BCSC110 Neural Foundations of Behavior
BCSC221 Auditory Perception
BCSC223/OPT248 Vision and the Eye
BIOL111 Principles of Biology II
BIOL113 Perspectives in Biology II
BIOL190 Genetics & the Human Genome
BIOL198 Principles of Genetics
BIOL 217 Principles of Human Anatomy
BIOL202 Molecular Biology
BIOL204 Mammalian Physiology
BIOL205 Evolution
BIOL206 Eukaryotic Genomes
BIOL250 Introduction to Biochemistry
BIOL210 Molecular Cell Biology
BME211 Cellular & Molecular Biology
BME258 Human Anatomy
BME415 Neuroscience of Neuroprosthetics
CHEM203 Organic Chemistry
CHEM204 Organic Chemistry II
CHEM262 Biological Chemistry
EESC204W Earth Minerals
EESC206 Petrology
EESC209 Intro to Geochemistry
EESC213 Hydrology and Water Resources
NSCI201 Basic Neurobiology
NSCI243 Neurochemical Foundations of Behavior
NSCI245 Sensory & Motor Neuroscience
NSCI249 Developmental Neurobiology
MBI220 Intro to Microbiology
PHYS123 Modern Physics

These courses will NOT be accepted as a Basic Science Electives:

BIO112 Perspectives in Biology I with Lab
BIOL214 Biostatistics
BIOL253 Computational Biology
CHEM137 Chemistry Principles for Engineers
PHYS252, PHYS257/457 Biomedical Ultrasound
BCSC courses not listed above
Any independent study course

Independent Study Process – Some Guidelines for BME

(Note that you may not use an independent study course for a Basic Science Elective.)

This document aims to provide some guidelines for how to complete an application for Independent Study in the BME Department. Before completing this form, students should have been in contact with the Professor under whose supervision they plan to carry out their independent study. From these discussions, it should be clear to the student what the expectations are for successfully completing the independent study. In particular, it should be clear how big a time commitment is expected and whether that time commitment will require significant blocks of time to be dedicated to the work; it would be expected, for example, that significant blocks of time would be required of students who wish to engage in laboratory research. Also, before embarking on independent study, it should be clear to students what kind of deliverables they are expected to produce at the end of the independent study.

Subject Area: Please select BME if, and only if, the work is to be carried out under the supervision of a PI associated with BME. Even if you are a BME major, research carried out in the labs of PIs that are not associated with BME should *not* be submitted with BME as the subject area. If in doubt, please confirm with your proposed supervisor.

Course #:

- Please select 391 if the goal is to carry out reading or design outside of the PI's research lab.
- Please select 395 if the goal is to carry out research work within the PI's research lab.

Credit:

The BME department would expect about 4 hours of work per week for each credit

- 4 credits – this should be of the order of 16 hours of effort per week for the semester.
- 2 credits – this should be of the order of 8 hours of effort per week for the semester.

Course Title: This is what will appear on your transcript, so please give an information title regarding the planned work, e.g., "Modeling knee cartilage". Only 28 characters are available.

Course Description: Please give 1 sentence description for each of the following: the background, the goal, the approach/skills learned. Only 240 characters. For example,

- Builds on a brain-computer interface design recently introduced by the PI.
- Aims to develop audio/visual stimuli that elicit robust brain responses.
- Stimuli will be developed and will be tested in EEG experiments with human subjects.

Course Evaluation: Please list all of the following methods that will be used to evaluate this work. **NB:** At least one of the deliverables must be some form of final written report.

- Written report(s) – there must be some form of written report. This could be:
    - A technical report with some background, methods/results/findings, and a conclusion.
    - An abstract, short paper or mini-grant proposal
- Regular meetings
- Journal records
- Progress reports
- Oral and/or poster presentations

SAMPLE SCHEDULES FOR FIRST & SECOND YEAR FOR ALL BME STUDENTS

1st Year

Fall	**Spring**
MATH 161*-Calculus IA	MATH 162*-Calculus IIA
CHEM 131-Chem. Concepts I (lab)	CHEM132 -Chem. Concepts II (lab)
EAS/BME 101-Intro. To BME (lab) *(Core)*	PHYS121 or 121P-Mechanics (lab); ***OR*** PHYS 113 if required
Primary Writing ***OR*** H/SS	H/SS ***OR*** Primary Writing

2nd Year

Fall	**Spring**
MATH 165- Linear Algebra with Differential Equations	MATH 164-Multidimensional Calculus
PHYS 122 or 122P-Electricity & Magnetism (lab)	***1st concentration course or Basic Science Elective
BIOL 110-Principles of Biology I	BME 210-Biosystems & Circuits (lab) *(Core)*
BME 201-Fund. Of Biomechanics *(Core)*	H/SS
BME 201P – MATLAB for BME – 1 cr.	**WRTG 273-Communicating Professional Identity – 2 cr.

NOTES: *An alternative to the MATH 161 and 162 sequence is the MATH 141, 142 and 143 sequence. Careful attention must be paid to the effects of this longer sequence, including the possible need to take a course in the summer following the first year. MATH170 series can be used to fulfill the Math requirements

** WRTG 273 may be also taken in the fall of the junior year.

*** **The following courses are required as concentration courses in the Spring of Sophomore year:**
Cell & Tissue - CHE243; Biomechanics - ME226; Medical Optics – BME270

Humanities, Social Sciences (H/SS), and Elective courses can be taken in any semester.

THIRD & FOURTH YEARS

CELL & TISSUE ENGINEERING

3rd Year

Fall	**Spring**
BME 230 – Signals, Systems & Imaging *(Core)*	BME 245 – Biomaterials *(Core)*
CHE 244 – Heat & Mass Transfer	H/SS
Basic Science Elective	BME 221 - Biomedical Computation & Statistics *(Core*)
Elective	Elective *or* Basic Science Elective

4th Year

Fall	**Spring**
BME 260 - Quantitative Physiology *(Core)*	BME 296 - Senior Design *(Core)*
BME 295 - Design Seminar (2 cr.) *(Core)*	Upper Level BME (BME262 C&T Engineering) or Elective
CHE 225-Thermodynamics	Elective or
Upper Level BME (BME 265 Intro to Cell Mechanics or BME 266 Bioprocess Eng) or Elective	BIOL 210 - Molecular Cell Biology (if not taken in fall)
BME 211 – Found of Cell & Molecular Biology	H/SS
OR BIOL 202 – Molecular Biology	
(OR BIOL210 Cell Biology in Spring semester)	

BIOSIGNALS & BIOSYSTEMS

3rd Year

Fall	**Spring**
BME 230 –Signals, Systems, & Imaging *(Core)*	BME 245 – Biomaterials *(Core)*
ECE230 – Electromagnetic Waves	BME 221- Biomedical Computation & Statistics *(Core)*
Basic Science Elective	Basic Science Elective
ECE 221-Electronic Devices & Circuits ***OR*** BME 228- Physiological Control Systems	H/SS

4th Year

Fall	**Spring**
BME 260 - Quantitative Physiology *(Core)*	BME 296 - Senior Design *(Core)*
BME 295 - Design Seminar (2 cr.) *(Core)*	H/SS
ECE246 - Digital Signal Processing	Elective
Upper Level BME (BME 218 or BME 253) ***OR*** Elective	Elective ***OR*** Upper Level BME (BME 251)

BIOMECHANICS

3rd Year

Fall	**Spring**
BME 230 - Signals, Systems, & Imaging *(Core)*	BME 221 - Biomedical Computation & Statistics *(Core)*
H/SS	BME 245 – Biomaterials *(Core)*
Basic Science Elective	ME 123 - Thermodynamics
Elective	Basic Science Elective or Elective

4th Year

Fall	**Spring**
BME 260 - Quantitative Physiology*(Core)*	BME 296 - Senior Design *(Core)*
BME 295 - Design Seminar (2 cr.) *(Core)*	Elective ***OR*** Upper Level BME (BME 212)
ME 225 – Introduction to Fluid Dynamics	H/SS
Upper Level BME (BME 283) ***OR*** Elective	Basic Science Elective **OR** Elective

MEDICAL OPTICS

3rd Year

Fall	**Spring**
OPT 241 - Geometrical Optics	BME 221 - Biomedical Computation & Statistics *(Core)*
BME 230–Signals, Systems, & Imaging *(Core)*	BME 245 – Biomaterials *(Core)*
Basic Science Elective	OPT 261 – Interference & Diffraction
Elective	H/SS

4th Year

Fall	**Spring**
BME 260 - Quantitative Physiology *(Core)*	BME 296 - Senior Design *(Core)*
BME 295 - Design Seminar (2 cr.) *(Core)*	Elective ***OR*** Upper Level BME (BME 472 or OPT 276)
Upper Level BME (BME 255-not offered F19) ***OR*** Elective	Elective
H/SS	Basic Science Elective ***OR*** Elective

ADMISSION REQUIREMENTS

Students wishing to major in Biomedical Engineering must file completed BME Curriculum Planning forms ordinarily during the fourth semester of study. This form, along with an online Declaration of Major Approval form, and a Career Planning form constitutes application to the upper-division BME program.

To be considered for admission to the Biomedical Engineering major a student must have taken courses in the first two years to enable a program of study that satisfies the requirements of the program and that can be completed in the two remaining years.

The minimum requirements for admission to the BME program are

- satisfactory completion of BME 101 (by the end of the sophomore year) (transfer students will substitute another 200-level or above BME elective course)
- two engineering courses (usually BME 201/201P, BME 210)
- a minimum ADMIT GPA of 2.0 in these four courses (BME101, BME201, BME201P & BME 210)
- satisfactory completion of the basic science and math requirements (including records for all AP credit or transfer credits)
- a minimum overall cumulative GPA of 2.0
- satisfactory completion of the University primary writing requirement (WRTG105)
- completion of BME Curriculum and Career Planning Forms, and the online Major Declaration form

The submitted Career Planning form, though never binding, is very useful in helping students focus their interests within the field of biomedical engineering. Before preparing and submitting a career plan, each student should study available online and written materials and then discuss the alternatives fully with his or her faculty advisor or with other faculty. The university requirement that a student should be free of academic probation also applies. The Curriculum Planning Form, approved and signed by the student's faculty advisor, must also be completed for a BME Major Declaration. An online Declaration of Major form must be filled out and will be reviewed by the BME Undergraduate Committee Chair. When approved, the online form is automatically submitted to the School of Engineering and Applied Sciences (SEAS) Dean's Office.

Under special circumstances, such as transfer from another institution or a change of intended major in the early years of study, students may not complete all the requirements for admission by the end of the sophomore year. Students in this situation may fill out the BME Major Declaration paperwork and will be considered when they have completed all necessary coursework for admission to the major. The application must present a realistic plan, approved by the student's adviser, for completion of all BME program admission requirements.

Only the Administrative Committee of the College of Arts, Sciences and Engineering can make exceptions from the general degree requirements published in the Official Bulletin of the University. Petition form for UR Administrative Committee consideration may be found at: https://secure1.rochester.edu/ccas/petition-form.php

GRADUATION REQUIREMENTS

For graduation, biomedical engineering majors must satisfactorily complete all course requirements consisting of a total of 131 credits with an overall cumulative grade point average of 2.00.

TRANSFER CREDITS

Prior approval is required if a student wishes to take a course at another institution to satisfy a BME degree requirement. A Course Approval form is available in the BME Undergraduate Office - Goergen 206 or in Lattimore 312. Students are strongly advised to seek the advice of their advisor and to obtain approval for course equivalency **before** registering for a course at another institution. Credits but not grades transfer to the University. A grade of C or better is required for the course to be transferred.

INTERNSHIPS AND INDUSTRY PRACTICUM

BME majors are strongly encouraged to participate in internships with local or nationally based engineering firms or research institutions. Only in a few cases can internship experiences be used for academic credit. Students who wish to obtain such credit for an internship must obtain prior approval from the BME Undergraduate Committee. The Industry Practicum program is a way to gain valuable work experience. A student in this program takes one semester, and the summer preceding or following that semester to work for a company. Per University policy, this must be done in the Spring semester of Junior year. Academic credit is not granted, but the work experience and references obtained are valuable in later job searching. Typically, graduation is delayed by one semester, but some students with Advanced Placement credit or summer classes can graduate on time. Students should contact Taimi Marple to work out a customized plan for their Industry Practicum. It is best to start planning Sophomore year. Additional information, including example programs, is available from the Hajim Dean's Office or the Gwen M. Greene Career and Internship Center in Dewey Hall, 4th floor, www.rochester.edu/careercenter/

EDUCATION ABROAD

The Hajim School of Engineering and Applied Sciences highly recommends engineering students study abroad and aims to have ~25% of all UR engineering students participate. Study Abroad experiences are achievable through early planning. Our students have traveled to China, Ireland, New Zealand, Australia, England, Spain, South Africa and *many* other countries. If you are considering spending a semester, or a summer in another country, please check out the UR Education Abroad website to explore the opportunities available to you. You will find numerous resources to help you plan your studies overseas at: http://www.rochester.edu/College/abroad/programs/index.html
Visit the Center for Education Abroad (located in Dewey 2-161) as you plan. The Center is there to help you, to share your excitement, and to assist you in making it all work. Additional information at: https://www.rochester.edu/College/abroad/ Please see Undergraduate Coordinator Taimi Marple for early guidance. Biomedical Engineering faculty dedicated to Study Abroad are Professors Anne Luebke (anne_luebke@urmc.rochester.edu) and Scott Seidman (scott_seidman@urmc.rochester.edu). Students are encouraged to share their plans and interests with Professors Luebke or Seidman before departure.

PRE-MEDICAL PROGRAM

BME students interested in a pre-med, pre-dental program or other health professions, such as nursing, physical therapy or veterinary medicine are urged to obtain related materials from the Health Professions Advisors in the Gwen M. Greene Career and Internship Center in Dewey Hall, 4th floor. It is essential that such students begin program planning early and involve both their BME Advisor and a Health Professions Advisor. Additional information at: http://www.rochester.edu/college/health/.
All of the courses usually required for admission to medical school are readily accommodated within the B.S. in BME curricular requirements. These include two semesters of general physics, two semesters of general chemistry, two semesters of organic chemistry with labs, two semesters of biology with labs, two semesters of math, one semester of biochemistry, and some exposure to psychology. Note that the requirements and expectations for the MCAT exam may change over time and vary between programs. Therefore, it is important to consult the Health Professions Advisors periodically and check individual program requirements.

GEAR (Graduate Engineering at Rochester) PROGRAM

Prospective students may apply for the GEAR program only when they first apply to the University of Rochester. The GEAR program provides selected students with an assurance of admission into one of nine engineering master's programs at the University of Rochester's Edmund A. Hajim School of Engineering and Applied Sciences: biomedical engineering, chemical engineering, computer science, electrical and computer engineering, materials science, mechanical engineering, optics, alternative energy, technical entrepreneurship and management (TEAM). GEAR students receive a tuition award of up to 50 percent in their fifth year of study in the form of a teaching assistantship. To remain eligible, GEAR students are required to maintain a 3.3 GPA through the first seven semesters (3.5 for optics). Applicants for this program will have demonstrated strong aptitude for engineering throughout their high school academic and co-curricular activities. Please visit GEAR Admissions at: http://enrollment.rochester.edu/professional/gear/

FIVE-YEAR BS/MS PROGRAM (+1 Program)

BME majors contemplating graduate work may apply to complete their MS degree here in the University of Rochester department of Biomedical Engineering. This provides the opportunity for a smooth transition between undergraduate and graduate study. Program enrollment is competitive and students may apply for admission during their senior year. Our program offers the chance for more advanced study and the completion of a course-work master's degree (Plan B) in **one year**. Undergraduate students may be able to take graduate courses during their junior or senior year, but may not count any course for both their undergraduate and graduate degrees, and limits exist for how many credits may be taken early. Generally, up to 10 graduate credits can be taken as an undergraduate student. Students interested in a research based master's degree may also apply during their senior year, but a thesis master's degree (Plan A) is expected to take one and a half to two years. Partial tuition scholarships are available for either MS program. All full-time MS students are expected to serve as teaching assistants for one semester.
http://www.bme.rochester.edu/graduate/ms.html

Students should consult the UR *Graduate Studies Official Bulletin* for the MS degree requirements and they could meet with a faculty member or the Graduate Coordinator (Goergen 207) to develop an integrated BS/MS program of study. *UR Graduate Studies Official Bulletin is available at: www.rochester.edu/GradBulletin*

MEDICAL TECHNOLOGY & INNOVATION

Another option for graduate study is the Center for Medical Technology & Innovation (CMTI-MS) with coursework leading to an MS degree in Biomedical Engineering. This 12-month program intends to develop improvements in patient care and outcomes while promoting a unique education in both clinical care and biomedical engineering design. It includes a period of clinical immersion (July – August) followed by a one-year, in-depth design experience. http://cmti.rochester.edu/

TAKE FIVE SCHOLAR PROGRAM

The Take Five Scholar Program provides University of Rochester students with opportunities to explore additional disciplines and courses that might not otherwise be available to them within the four year degree path. Accepted students will be granted one or two tuition-free semesters to take courses in addition to those needed to complete their degree. Students may apply from the time they have been formally accepted

into their major through the first semester of their senior year. Transfer students must have completed one full semester at the University before applying.
Additional information at: https: www.rochester.edu/college/ccas/handbook/take-five.html

TEAM

The Master of Science in **T**echnical **E**ntrepreneurship **A**nd **M**anagement, or TEAM degree program at the University of Rochester offers students the opportunity to immerse themselves in a technical cluster of their choice while receiving a strong foundation in entrepreneurial management. Through a fast-paced curriculum at the University's Edmund A. Hajim School of Engineering and Applied Sciences and the William E. Simon Graduate School of Business, students can complete the program in as little as one academic year. TEAM graduates are equipped with detailed technical knowledge in their field as well as business-savvy. They have the tools to innovate, lead, and strategically manage in an industry that increasingly rewards interdisciplinary expertise. The overall placement rate for TEAM graduates is 90% within six months of graduation. Applications are due by February 1st.

For additional information: www.rochester.edu/team/

THE e5 PROGRAM (formerly known as KEY)

The University of Rochester defines entrepreneurship as "transforming an idea into an enterprise that generates value," implying that the enterprise outlives the creator and that it positively affects others. Qualified students may propose to devote as much as an entire academic year to internships, special projects, business plan development, research into various facets of entrepreneurship, or analysis of how culture and public policy influence entrepreneurial activity. Students may apply from the time that they have been accepted into a major through the second semester of their senior year. Application is open to all undergraduates in the College and the Eastman School of Music with the following exceptions:

* Transfer students may not apply during their first semester at the University
* Take Five Scholars may not apply for the e5 Program

Applications are available at each of several information sessions held each semester and at the Center for Advising Services counter outside Lattimore 312.
Additional information at: https://www.rochester.edu/college/ccas/handbook/KEY.html

Applications are due no later than November 1st in the fall semester or the first Thursday after Spring Break in the spring semester. Students should submit their e5 Program materials to Lattimore 312. Letters of recommendation are due the same day as the application and should be sent directly to Lattimore 312.

A list of courses that has been developed with entrepreneurship in mind can be found at www.rochester.edu/aincenter/courses/
Students should also consult the faculty with whom they want to study, and/or the appropriate departmental administrators to be sure that the courses they want to take will be offered, and that they are adequately prepared for the courses they intend to take. Each applicant needs to arrange for two full-time faculty members to send letters of recommendation to the e5 Review Board on his or her behalf.

MINOR IN BIOMEDICAL ENGINEERING

The biomedical engineering minor provides substantive exposure to the biological and engineering sciences and gives students a basic perspective on the complex structure and function of living systems and their analysis by physical and engineering principles. The minor is available to students in all majors, but engineering and biology students find it easier to complete these requirements. Students may not use more than two of the courses required for the BME minor to also satisfy requirements in their major. When filing the online Minor Declaration form, if there are any overlap courses (max two), those will be reported on the form. The online form is at: https://secure1.rochester.edu/registrar/applications/major-minor-declaration.php All students that propose a minor in BME must fulfill the basic math requirements (MATH161, MATH162, MATH165 or MATH141, MATH142, MATH143 or these in combination with Math AP credit). Contact Taimi Marple. BME Undergraduate Coordinator, Goergen 206, for information on how to submit an online Minor Declaration approval.

Biological Science Courses (8 credit hours)
Students must complete two life science courses (i.e., Biology, Microbiology, Neuroscience). Students can use one of the following: BIOL110, BIO112 or AP Biology, plus one other life science to meet the two life science course requirement, including BME 211Cellular & Molecular Biology Foundations and BME 258 Human Anatomy.

Biomedical Engineering Introductory Course (4 credit hours)
BME101 (4.0 credits) is a freshman or sophomore course utilizing the spectrum of examples of BME applications to introduce the scope of the discipline and its range of significance. Faculty advisors have the flexibility of substituting four credits of another BME-related course.

Engineering Courses (12 credit hours)
Choose three engineering courses, ***two of which must be BME courses***, including any 400-level BME courses or cross-listed courses. BME 211 Cellular & Molecular Biology Foundations and BME 258 Human Anatomy can NOT be used for this requirement, as they are life science courses.
Note: Students are warned to confirm that all prerequisites for the courses below are fulfilled

Examples

- BME 201 Fundamentals of Biomechanics
- BME 201P MATLAB for Bioengineers (1 credit)
- BME 210 Biosystems and Circuits
- BME 212 Viscoelasticity in Biological Tissues
- BME 218 Introduction to Neuroengineering
- BME 221 Biomedical Computation
- BME 228 Physiological Control Systems
- BME 230 Biomedical Signals and Measurements
- BME 245 Biomaterials
- BME 251 Biomedical Ultrasound
- BME 253 Ultrasound Imaging
- BME 255 Translational Biomedical Optics
- BME 259 Transport Phenomena in Biological Systems
- BME 260 Quantitative Physiology
- BME 262 Cell and Tissue Engineering
- BME 266 Bioprocess Engineering
- BME 267 Models and Simulations of Biomedical Systems
- BME 270 Biomedical Microscopy
- BME 283 Biosolid Mechanics
- BME 391 Independent Study

BIOMEDICAL ENGINEERING COURSES AND PRE-REQUISITES

BME 101/EAS 101 Introduction to Biomedical Engineering (CORE)
This course provides an introductory overview of the multi-disciplinary field of biomedical engineering. Application of elementary engineering principles to the analysis of physiological systems. Topics include biomechanics, cell and tissue engineering, biosignals and bioinstrumentation, medical imaging, neuroengineering and medical optics. Includes instruction on the use of computers in engineering. This course is open to all freshmen (or sophomores with permission of instructor) interested in an introduction to the field of biomedical engineering. (Cross-listed as EAS 101) Semester Taught: Fall - CREDITS: 4

BME 150 Interfacing with Microcontrollers
This course will instruct on how to interface sensors and actuators with micro controllers to make measurements and control objects in the real world. No knowledge of programming or micro controllers is required. Course will be online, generally asynchronous with one synchronous organizational meeting (available as a live video conference) and will contain many laboratory exercises. Access to a PC or Mac computer, a reliable internet connection, the means to record a video (cell phone is fine) Are necessary. The purchase of a microcontroller kit and some electronic tools and parts (approx $55 total), in lieu of a textbook, are required. No pre-requisites. Semester Taught: Spring and Summer – CREDITS: 2

BME 201 Fundamentals of Biomechanics (CORE)
BME 201 teaches elementary mechanical equilibrium and motion with extended applications to biology. Lectures present a traditional analysis of idealized particles and rigid bodies. Topics include force and moment balances, frames, trusses and pulleys, systems with friction, mass centers, area moments, and the linear and rotational kinetics and kinematics of rigid bodies. Weekly exercises apply fundamental principles to non-biological problems in two and three dimensions. Weekly problems extend the application to biological problems ranging from human motion to the mechanics of cells. In an end-of-term project, students analyze human motion using the MATLAB programming language. This is a required course for BME majors typically taken in the sophomore year. Prerequisites: MATH 161 and 162, BME 101, PHYS 121. Semester Taught: Fall - CREDITS 4

BME 201P MATLAB for Biomedical Engineering (CORE)
Fundamentals of computer programming in MATLAB. Emphasis on programming basics, such as syntax, loop structures, logic, input/output, and graphics. Limited to BME majors; non-BME majors with permission of instructor. Semester Taught: Fall - CREDITS: 1

BME 206/406 Technical Computing in BME
An introduction to the use of Matlab and associated tolls for solving practical problems arising in biomedical engineering and related fields. Topics include: review of Matlab fundamentals; design and implementation of FIR and IIR digital filters; spectral and time-frequency analysis of signals; image processing and enhancement; statistical calculations; optimization and curve fitting; numerical solution of ordinary differential equations; symbolic math operations; applied linear algebra. Final Project. Semester Taught: Spring - CREDITS: 4

BME 210 Biosystems & Circuits (CORE)
Introduction to electrical circuit theory. Examples will include bioelectric systems and signals and models of biological systems. Prerequisites: PHYS 122, MATH 162, BME 201P**,** MATH 165 may be a corequisite. Semester Taught: Spring - CREDITS: 4

BME 211/411 Cellular & Molecular Biology Foundations
Molecular biology, biochemistry, and genetics that are required to understand the biomedical and broader biological issues that affect our lives. Note: You must register for a recitation when registering for the main section. Prerequisites: BIOL 110. Semester Taught: Fall – CREDITS: 4

BME 212/412 Viscoelasticity in Biological Tissues (ULBME for Biomechanics Concentration)
Viscoelastic materials have the capacity to both store and dissipate energy. As a result, properly describing their mechanical behavior lies outside the scope of both solid mechanics and fluid mechanics. This course will develop

constitutive relations and strategies for solving boundary value problems in linear viscoelastic materials. In addition, the closely-related biphasic theory for fluid-filled porous solids will be introduced. An emphasis will be placed on applications to cartilage, tendon, ligament, muscle, blood vessels, and other biological tissues. Advanced topics including non-linear viscoelasticity, composite viscoelasticity and physical mechanisms of viscoelasticity will be surveyed. Prerequisites: ME225 or CHE243, and ME226 or BME201. Semester Taught: Spring – CREDITS: 4

BME 216/416 Speech on the Brain
The focus of this course is on neural representations of speech sounds; introduction to basics of speech phonetics and responses from the auditory nerve through the brainstem, midbrain, and cortex; techniques for analyzing speech and neural responses. Students from BME, LIN, NSC and other programs will work in interdisciplinary teams on a final project. Prerequisites: BME 230 or LIN 210/410 or NSC 201 or BCSC240 or BCSC 260 or BCSC221; or permission of instructor. Semester Taught: Spring – CREDITS: 4

BME 218/418 Introduction to Neuroengineering (ULBME for Biosignals & Biosystems Concentration)
This course introduces many aspects of neuroengineering research, with an emphasis on biologically plausible models of neurons, circuits, and systems. The course begins with a brief review of passive membrane properties and Hodgkin-Huxley channel dynamics, and extends to advanced topics including neural circuits, control systems, and biologically plausible neural models of behavior. There is an emphasis on theory, modeling, and simulation of single neurons, neural networks, and systems. Prerequisites: Co-requisite - BME 260, strong computing skills recommended or permission of instructor. Semester Taught: Fall – CREDITS: 4

BME 220/420 Biomedical Nanotechnology
This course is designed to provide students with detailed knowledge of principles and applications of nanotechnology in the biomedical field. Topics of study include synthesis & assembly of nanoscale structures, lithography, nanobiomaterials and nano-biomechanics along with the applications of nanotechnology in biomedical engineering. Recent innovative research in the field will be highlighted in lectures by discussing and critically analyzing recently published journal articles. Ultimately, students will have an appreciation of the enormous potential of biomedical nanotechnology, its current and potential applications.
Prerequisites: MSC 202, CHEM 131,132, BME 245 Semester taught: Fall – CREDITS: 2

BME 221 Biomedical Computation & Statistics (CORE)
Numerical and statistical methods of scientific computing and their applications to modeling of biomedical systems and interpretation of experimental data, using the MATLAB programming language. Prerequisites: BME 201 and 201P, or permission of instructor. Semester Taught: Spring – CREDITS: 4

BME 228/448 Physiological Control Systems (Concentration course for Biosignals & Biosystems Concentration)
This course focuses on the application of control theory to physiological systems. Lectures present modern control theory in the context of physiological systems that utilize feedback mechanisms. Prerequisites: juniors with MATH164, MATH 165 and BME 230 or ECE 241 (can be concurrent). Semester Taught: Fall – CREDITS: 4

BME 229/429 Applied Nanoscience and Nano-engineering
This course will educate students how engineering at the nanoscale is different from macro-level, how/why it offers novel properties which can be harnessed and applied to multiple research fields. Course content will include topics such as, nanoparticles, nanotubes, nanowires- their synthesis, applications, and properties; nanofabrication: both top-down and bottom-up approaches, nano-electronics, nanophotonics, and nano-pumps. Additionally, the workings of many spectroscopic and microscopic techniques specifically developed to analyze and manipulate nanomaterials will be discussed in detail. Prerequisites: CHEM 131,132; BIOL 110, PHYS 121,122 Semester taught: Fall – CREDITS: 2

BME 230 Biomedical Signals, Systems, and Imaging (CORE)
Introduction to continuous and discrete time signals and linear time invariant systems, with applications to BME including imaging. Topics include convolution. Laplace and Z transforms, stability of systems, the Fourier series and transform, noise and filtering, and fundamental concepts in image processing and enhancement. Prerequisites: BME 210 or equivalent and MATH 165.
Semester Taught: Fall - CREDITS: 4

BME 245 Biomaterials (CORE)
This course provides a background in biomaterials. It covers basic material properties, specifics on ceramics, polymers and metals used in the body, biological responses to implanted materials, and special topics related to biomaterials including tissue engineering, drug delivery, and sensors. At the end of the course, students are expected to articulate design criteria for engineered biomaterials with respect to chemistry, mechanics, lifetime, tissue integration, and FDA approval and be able to recommend optimum designs for different applications. The class is divided into three general sections: 1) Basic material structures of common biomaterials: Metals, Ceramics, and Polymers and how these structures are tested, 2) Cell and Tissue Interactions with Biomaterials (inflammation, wound healing, immune response, etc.), 3) FDA approval and applications of biomaterials (including drug delivery, tissue engineering, sensors). Prerequisites: CHEM132, PHYS122, MATH162, BME 201 and BIOL110 or permission of instructor.
Semester Taught: Spring – CREDITS: 4

BME 251/451 Biomedical Ultrasound (ULBME for Biosignals & Biosystems Concentration)
The physical basis for the use of high-frequency sound in medicine (diagnosis, therapy, and surgery) and biology. Topics include acoustic properties of tissues, sound propagation (both linear and nonlinear) in tissues, interactions of ultrasound with gas bodies (acoustic cavitation and contrast agents), thermal and non-thermal biological effects of ultrasound, ultrasonography, dosimetry, hyperthermia and lithotripsy. Prerequisites: MATH 164, MATH 165, PHYS 122 or permission of instructor.
Semester Taught: Spring – CREDITS: 4

BME253/453 Ultrasound Imaging
This course investigates the imaging techniques applied in state-of-the-art ultrasound imaging and their theoretical bases. Topics include linear acoustic systems, spatial impulse responses, the k-space formulation, methods of acoustic field calculation, dynamic focusing and apodization, scattering, the statistics of acoustic speckle, speckle correlation, compounding techniques, phase aberration correction, velocity estimation, flow imaging, and elastography. A strong emphasis is placed on readings of original sources and student assignments and projects based on realistic acoustic simulations. Prerequisites: BME 230 or ECE 241. Semester Taught: Fall – CREDITS: 4

BME 255/455 Translational Biomedical Optics (ULBME for Medical Optics Concentration)
This course will focus on the macroscopic biomedical optics techniques (e.g., diffuse optical spectroscopy and tomography, photoacoustic tomography) with high potential for clinical translation. Students will learn the aspects of instrumentation design, analytic and numerical approaches for optical data analysis, and validation of new technology in the clinical setting. Pre-requisites: BME221, BME270, OPT241, OPT261. Semester Taught: Fall – CREDITS: 4
(not taught Fall 2019)

BME 258 Human Anatomy
Human Anatomy is the detailed study of the human organism at the cellular, tissue and organ systems levels. The relationship between structure and function is covered with emphasis on structural relationships. The course includes both lectures and laboratory sessions, and provides a basis for further professional and clinical experience. Prerequisites: Any introductory Biology course. (BME students cannot take both BME 258 and BIOL 217 to fulfill major requirements). Semester Taught: Spring - CREDITS: 4

BME 259 Transport Phenomena in Biological Systems
This course will provide an overview of transport phenomena in biological systems that are critical to the function of all living organisms. The fundamental laws and equations of transport phenomena will be applied to topics including cellular, cardiovascular, respiratory, liver and kidney transport, blood flow and rheology, and circulation in tissues and arteries. Homework assignments, in-class quizzes, final exam and a technical paper or presentation. Prerequisites: PHYS 121, MATH 164, MATH 165 (can be taken concurrently) required; CHE243 *preferred but not required.*
Semester Taught: Fall – CREDITS: 4

BME 260 Quantitative Physiology (CORE)
A quantitative, model-oriented approach to physiological systems is presented. Topics include: muscle and nerve tissue, the cardiovascular system, the respiratory system, the renal system, and a variety of neural systems. Prerequisite: ECE 113 or BME 210 or permission of instructor.
Semester Taught: Fall – CREDITS: 4

BME 262/462 Cell & Tissue Engineering (ULBME for Cell & Tissue Engineering Concentration)
This course teaches the principles of modern cell and tissue engineering with a focus on understanding the fundamental interactions between cells and their environment and an emphasis on the concepts relevant to the practice of cell and tissue engineering. The course covers the following modules: Elements of Embryonic Development and Tissue Healing in Tissue Engineering; Cell and Molecular Biology Technologies (cell sourcing, cell culture, growth, differentiation, gene transcription and translation); Stem Cells; the ECM (types of tissues and extracellular matrix constituents); Biomaterials (natural polymers, degradable synthetic polymers, degradable bioceramics, scaffold design and fabrication); Biocompatibility and Basic Immunology; Controlled Drug Release Strategies; Cell Signaling; Strategies to Improve Cell Nutrition, Diffusion & Mass Transport in Engineered Tissues; Bioreactor Technologies; Gene Therapy; and Tissue Mechanics and Mechanobiology. Prerequisites: BME 260, CHE 225 *or* ME 123, CHE 243 *or* ME 225, CHE 244, BIOL 210 (or BIOL 202 or BME 211), BIOL 250, CHEM 203 or permission of instructor. In a term project, graduate students must identify a technological need and present orally and in writing a proposal to meet the need. Semester Taught: Spring - CREDITS: 4

BME 265/465 Introduction to Cell Mechanics and Mechanobiology (ULBME for Cell & Tissue Engineering Concentration)
This course will introduce students to the mechanical properties of cells and tissues and the mechanotransduction processes of clinical and technological importance. Topics covered include the role of mechanotransducing biomolecules, models of cell mechanics, and the methods to measure mechanical properties of cells. This course will also introduce students to effects of internal / external mechanical stimuli on cellular processes which may lead to various human diseases. Students will learn basic terminology and concepts of mechanics at the molecular and cellular level with an emphasis on quantitative analysis, modeling, and applications to clinical medicine. Students will gain knowledge to critically evaluate current literature and analyze models of cell mechanics and mechanotransduction. In addition, laboratory modules will provide hands-on experience to measure cellular mechanical properties and mechanotransduction signaling using FRET-based force sensors and Calcium dye. Prerequisites: BME 260 or BME 211 or permission of instructor. Semester Taught: Fall – CREDITS: 4

BME 266/466 Bioprocess Engineering (ULBME for Cell & Tissue Engineering Concentration)
This course will explore the bioprocesses involved in producing a biopharmaceutical product (therapeutic proteins, cell therapy products, and vaccines). The course will take a stepwise journey through a typical production process from the perspective of a Bioprocess Engineer, starting with cell culture and moving downstream through purification and final fill. Engineering concepts involved in bioreactor design and control, cell removal/recovery operations, and protein purification will be examined. The course will also provide an introduction to the analytical methods used to test biopharmaceutical products for critical quality attributes The role of the regulatory agencies, like the US Food and Drug Administration, and the regulations that govern the industry will be introduced throughout the course in the context of the bioprocess to which they relate. Graduate students will need to complete a semester-end project in order to receive graduate credit for the course. Prerequisites: BIOL 110, CHEM 132, CHE243 *or* ME225, CHE244.
Semester Taught: Fall – CREDITS: 4

BME 270 Biomedical Microscopy (course for Medical Optics concentration)
This course covers the principles and practice of light microscopy as applied to biological and medical questions. Topics include basic light microscopy, epifluorescence, confocal and multiphoton laser-scanning microscopy, and selected methods such as CARS, FRET, FRAP, FCS, etc. Prerequisites: PHYS122 or permission of the instructor.
Semester Taught: Spring – CREDITS: 4

BME274/474 Biomedical Sensors, Circuits & Interfacing
Course will cover circuits and sensors used to measure physiological systems at an advanced level. Both signal conditioning and sensor characteristics will be addressed. Topics will include measurement of strain, pressure, flow, temperature, biopotentials, and physical circuit construction. The co requisite Laboratory will focus on the practical

implementation of electronic devices for biomedical measurements. Prerequisites: BME210, ECE113 or equivalent, or permission of instructor. Semester Taught: Spring – CREDITS: 4

OPT276 Biomedical Optics (course for Medical Optics Concentration)
Biomedical spectroscopy (asorption, fluorescence, Raman, elastic scattering); propagation of photons in highly scattering media (such as tissue); techniques for high-resolution imaging in biological media: confocal imaging, multiphoton imaging and optical coherence tomography. Semester Taught: Spring – CREDITS: 4

BME 283/483 Biosolid Mechanics (ULBME for Biomechanics Concentration)
Application of engineering mechanics to biological tissues including bone, soft tissue, cell membranes, and muscle. Realistic modeling of biological structures, including musculoskeletal joints and tissues. Investigations of the responses of biological tissues to mechanical factors. Experimental methods and material models. Prerequisites: ME 226, BME 201, and 201P *or* ME 120. Semester Taught: Fall – CREDITS: 4

BME 295 BME Design Seminar (CORE)
Guided sessions for project development will be held, using brainstorming and other techniques, and then students will develop proposals and specifications for their projects. Presentations will be given describing all the proposed projects and students will be given an opportunity to turn in resumes to apply to work on projects of their choice. Students who wrote the proposals will select teams for the applicants, and final project execution will be carried out in the spring semester. Prerequisites: math, science, and engineering courses appropriate for fourth-year students in BME. Semester Taught: Fall - CREDITS: 2

BME 296 BME Senior Design Project (CORE)
Senior capstone design course in the Biomedical Engineering Program. Students work in teams to design, build, and test a medical device or instrument for a faculty, community or industrial sponsor. Accompanying lectures and discussions introduce issues related to ethics, economics, project management, regulation, safety, and reliability. Prerequisites: math, science, and engineering courses appropriate for fourth-year students in BME, BME 295, BME 260, or permission of instructor. Semester Taught: Spring – CREDITS: 4

BME 404 Computational Methods Applied to Biology Systems
Computational methods to solve analytically intractable mathematical problems in biological research. Using MATLAB as a programming language; Numerical methods for linear algebra, ODE and PDE; Case studies such as biodynamics of human locomotion, ion channel kinetics, ionic diffusion in cells and finite element analysis of cells/tissues. Prerequisites: Fundamental linear algebra, ordinary differential equations, some experience of MATLAB. Semester Taught: Fall – CREDITS: 4

BME 415 Neuroscience of Neuroprosthetics
This class examines the structure, function, and vulnerability of several major neural systems and how neuroprosthetics may ameliorate damage to them. Undergraduates allowed with permission of instructor. Semester Taught: Spring – CREDITS: 4

BME 425 Human Neurophysiological Measurement
This course introduces students to studies of human brain function using non-invasive methods, including electroencephalography, magnetoencephalography, functional magnetic resonance imaging, electrocorticography. It will focus on experimental paradigms and data analysis in the time and frequency domains. Neural encoding and decoding models and applications to brain-computer interfaces will also be discussed. Course will be a mixed format, with lectures on Tuesdays and labs on (most) Thursdays. Lab exercises will be based around analyzing real data from human subjects. Semester Taught: Spring – CREDITS: 4

BME 431 FDA & Intellectural Property: Introduction to FDA Processes and Intellectual Property (IP) Considerations for Medical Products
This course will offer students exposure to the intellectual property (IP) and regulatory pathways for new medical innovations. Students will learn the terminology, processes and challenges involved in FDA regulations and the protection of intellectual property for medical innovations. An emphasis will be placed on the ways knowledge of prior art and regulatory barriers can optimize concept selection, and early phase project planning to best identify

projects suitable for commercialization. Instruction will include lectures, case studies, guest speakers and integrated assignments that will ask students to explore examples of IP and regulatory challenges, successes and failures. Lectures on regulatory and IP topics will alternate in order to allow students to understand the difficulty presented by balancing these two challenges in the innovation process. Assignments may be tailored to individual students research, design or work concentration areas. Semester Taught: Fall – CREDITS: 2

BME 432 FDA & IP Commercialization
This interactive course focuses on Intellectual Property (IP) and FDA regulatory pathways for medical innovations. Emphasis will be placed on how knowledge of IP protection and evaluation, and regulatory barriers can optimize design, testing and commercialization strategies. Building on BME431 material, students will learn about the processes and barriers to bringing medical products through clinical trials. Instruction will include lectures, case studies, guest speakers and integrated assignments that will ask students to explore examples of IP and regulatory challenges, successes and failures. Lectures on regulatory and IP topics will alternate so students can appreciate the difficulty presented by balancing these two challenges in the innovation process. Some assignments may be tailored to individual student's research, design or work concentration areas. A project conducted in partnership with the FDA will provide students an opportunity to submit a mock pre-Submission to the FDA for review and feedback. Prerequisite: BME 431. Semester Taught: Spring – CREDITS: 2

BME 442 Microbiomechanics
From single molecule motors transporting materials within cells to contracting muscle fibers, molecular engines come in a range of sizes and produce some of the most fascinating phenomena in biology. This course teaches the modern theories behind molecular engines, presuming only an elementary background in cell biology and mechanics. Prerequisites: permission of instructor. Semester Taught: Spring – CREDITS: 4

BME/ECE 452 Medical Imaging - Theory & Implementation
Physics and implementation of X-ray, ultrasonic, and MR imaging systems. Special attention is given to the Fourier transform relations and reconstruction algorithms of X-ray and ultrasonic-computed tomography, and MRI. Prerequisites: ECE 242 Cross-listed: ECE 452.
Semester Taught: Fall – CREDITS: 4

BME 468 Introduction to Structure & Analysis of Biomolecules
This course will introduce students to the principles of protein & DNA structure and function; fundamental principles of protein folding domains, DNA structures, the spatial and conceptual relationships of biomolecules, role of amino acids mutation, and mutation induced abnormal functions, which may be linked directly to human diseases. The course will be taught using multiple instructional methods, including lectures, labs using the open source program Visual Molecular Dynamics (VMD), and oral presentations with an associated critical discussion.
Prerequisite: BIOL 110 or permission of instructor. Semester Taught: Spring – CREDIT: 4

BME 472 Introduction to Optical Microscopy in Biology and Medicine (ULBME for Medical Optics)
This course introduces the fundamentals of optical microscopy for students with some or limited exposure to biomedical microscopy. Topics will include contemporary applications in biology and medicine with a focus on understanding imaging technologies such as confocal microscopy, two photon imaging, optical coherence tomography, digital microscopy and clinical histopathology. Semester Taught: Spring – CREDITS: 4

BME 492 Neuroenhancement & Rehabilitation Engineering
Introduction to topics and devices in the field of neuroengineering. The course will cover approaches to understanding, repairing , replacing, enhancing, and exploiting the properties of neural systems and will include a focus on scientific research directed at the interface between living neural systems and non-living components. Prerequisites: BME 210, BME 201P, BME 230, BME 218. Open to undergraduates with permission of instructor.
Semester Taught: Fall – CREDITS: 4