UNDERGRADUATE
BIOMEDICAL ENGINEERING
CURRICULUM GUIDE
SEPTEMBER 2024

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BME ADVISORS

BME PRIMARY FACULTY

Chair of the Department

Stephen McAleavey, Ph.D. *Associate Professor of Biomedical Engineering and of Electrical and Computer Engineering*

Research Area – Instrumentation, signal processing, ultrasound imaging, motion tracking, elasticity imaging methods, ultrasound echo models

Edward Brown III, Ph.D. *Associate Professor of Biomedical Engineering and of Neuroscience*

Research Area – Multiphoton laser scanning microscopy, novel in vivo imaging and measurement techniques, tumor biology

Mark Buckley, Ph.D. *Associate Professor of Biomedical Engineering and the Center for Musculoskeletal Research*

Research Area – Soft biological tissue biomechanics, surgical biomechanics, viscoelasticity and poroelasticity, novel imaging techniques to characterize soft tissue properties

Laurel Carney, Ph.D. *Marylou Ingram Professor of Biomedical Engineering and of Neuroscience, and of Electrical & Computer Engineering*

Cherice Natasha Hill, Ph.D. *Assistant Professor of Biomedical Engineering*
Research Area – Multi-scale biomechanics of the human temporomandibular and lower extremity joints with a particular focus on diverse populations

Edmund Lalor, Ph.D. *Associate Professor of Biomedical Engineering and of Neuroscience*
Research Area – Human sensory neurophysiology, brain-computer interfacing, computational neuroscience, neural encoding of natural sounds, sensory processing in psychiatric and developmental disorders

Whasil Lee, Ph.D. *Assistant Professor of Biomedical Engineering and of Pharmacology and Physiology*
Research Area – Cell mechanics and mechanotransduction, mechanosenstivie ion channels, therapeutic strategies for musculoskeletal disease and joint pain

Amy Lerner, Ph.D. *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. *Associate Professor of Biomedical Engineering and of Neuroscience*
Research Area – Role of cochlear outer hair cells in hearing and hearing loss, at both the molecular and systems levels

James McGrath, Ph.D. *William R. Kenan, Jr. Professor of Biomedical Engineering*
Research Area – Microphysiological systems, nanomembranes for diagnostics, and microfluidics

Scott Seidman, Ph.D.

Engineering, and Professor in the Center for Visual Science

Lizabeth Romanski, Ph.D. *Associate Professor of Neuroscienc,e and of Bioedical Engineering*

Deborah Rubens, M.D. *Professor of Imaging Sciences, and of Biomedical Engineering*

Jesse B. Schallek, Ph.D. *Associate Professor of Ophthalmology, of Neuroscience, and Associate Professor in Center for the Visual Science*

Marc H. Schieber, Ph.D. *Professor fo Neurology, of Biomedical Engineering, of Neuroscience, of Brain and Cognitive Sciences, and Professor in the Center for Visual Science*

Edward Schwarz, Ph.D. Richard and Margaret Burton Distinguished Professor of Orthopaedics, of Medicine, Allergy/Immunology and Rheumatology, of Pathology & Laboratory Medicine, of Biomedical Engineering, of Microbiology and Immunology, and of Urology

Laura Slane, Ph.D. *Associate Professor of Mechanical Engineering, and of Biomedical Engineering*

Eric M. Small, Ph.D. *Associate Professor of Medicine, Aab Cardiovascular Research Institute, of Biomedical Engineering, and of Pharmacology and Physiology*

Jonathan J. Stone, M.D. *Assistant Professor of Neurosurgery, of Neurology, and of Biomedical Engineering*

Md Nasir Uddin, Ph.D. *Assistant Professor of Neurology, and of Biomedical Engineering*

Chia-Lung Wu, Ph.D. *Assistant Professor of Orthopaedics and of Biomedical Engineering*

David R. Williams, Ph.D. *William G. Allyn Professor of Medical Optics, Professor of Optics, of Brain and Cognitive Sciences, of Ophthalmology, of Biomedical Engineering, and Professor in the Center for Visual Science*

Nichole Wilson, M.D. *Assistant Professor of Surgery, Pediatric Surgery, of Biomedical Engineering, and of Pediatrics*

Axel Wismueller, Ph.D. *Professor of Imaging Science, of Biomedical Engineering, and of Electircal and Computer Engineering*

J.H. David Wu, Ph.D. Emeritus Professor of Chemical Engineering

Chia-Lung Wu, Ph.D. Assistant Professor of Orthopaedics, and of Biomedical Engineering

Zhenqiang Yao, PhD. *Associate Professor of Pathology & Laboratory Medicine, of Pharmacology and Physiology, of Biomedical Engineering, and of Dentistry*

Shu-Chi Yeh, Ph.D. *Assistant Professor of Orthopaedics, of Biomedical Engineering, and of Pharmacology and Physiology*

Xinping Zhang, Ph.D. *Professor of Orthopaedics, Denter for Musculoskeletal Research*

Jianhui Zhong, Ph.D. *Professor of Imaing Sciences, and of 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

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

Upper Level Writing Requirement

Significant writing experience in one's discipline is an important adjunc

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 218 - Intro to Neuroengineering, BME 251 - Biomedical Ultrasound, or BME 253 - Ultrasound Imaging (not offered Fall 2024)

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
ME 123 - Thermodynamics *or* CHE 225 – Thermodynamics (prerequisites required)
Upper Level BME:
e.g. BME 262 - Cell & Tissue Engineering

Medical Optics

BME 270 - Biomedical Microscopy
OPT 241 - Geometrical Optics
OPT 261 - Interference & Diffraction
Upper Level BME:
e.g. 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 bi

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. Ed Brown 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, using the Custom Concentration Petition form.)

Medical Robotics

BME 228 – Physiological Control Systems
ECE 216 – Mechatronics & Embedde Systems
ECE 217 – Robot Motion Planning and Manipulation
ULBME: BME 218 – Introduction to Neuroengineering

Devices in Biological Tissues

<u>Basic Science Electives</u> (BSEs) (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 (B

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

Online Courses

Non-University of Rochester online courses are allowed if taken through a degree granting institution, provided that the offering institution itself accepts the 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

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	

BIOSIGNALS & BIOSYSTEMS

3rd Year

Fall	**Spring**
BME 230 –Signals, Sy	

ADMISSION REQUIREMENTS

Students wishing to major in Biomedical Engineering must file completed a BME Curriculum Planning form ordinarily during the fourth semester of study. This form and an online BME Major Declaration form constitute application to the upper-division BME program. Both must be approved by the BME Undergraduate Chair.

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 form and the online Major Declaration form

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 yel(s)-.MTjs ffor 464(sr in ths ffhisns)(titus ffration mayfwill)TJ20422 0 TD.0006 Tc-.0016 Twputn ths

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

program will have demonstrated strong aptitude for engineering throughout their high school academic and co-curricular activities. Please visit GEAR Admissions at: https://admissions.rochester.edu/academics/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 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/

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)
Eight BME engineering credits and 4 additional engineering credits are required. The BME courses can include 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 cautioned 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 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

BME214/414 Biomedical Printed Circuit Board Design & Prototyping (Not offered Fall 2024)
Introduction to the design of printed circuit boards using computer aided design tools for biomedical engineers. Topics include schematic capture, layout of printed circuit boards (PCBs), PCB fabrication, and assembly of PCBs using modern surface mount technology. Prerequisites: PHYS122, BME210 or equivalent. PERMISSION OF INSTRUCTOR required. Semester Taught: Fall – CREDITS: 4

BME 216/416 Speech on the Brain (not offered Spring 2025)
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 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

healing, immune response, etc.), 3) FDA approval and applications of biomaterials (including drug delivery, tissue

BME 265/465 Introduction to Cell Mechanics and Mechanobiology

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

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 – CREDITS: 4 **(2-credit course for Spring 2025, BME 469)**

BME 492 Neuroenhancement & Rehabilitation Engineering (Not offered Fall 2024)
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