



## Biomedical Engineering Graduate Concentrations

**Bioelectrics and Neural Engineering:** Bioelectricity is the study of electrical fields and potentials within the body. In the bioelectrical concentration students learn how to examine and control these fields towards developing medical devices and restorative therapies. The core classes within this concentration focus on 1) examining nerve and cardiac bioelectrical fields from a computational standpoint and 2) understanding techniques to model neurons and to stimulate and record from individual and large populations of neurons. Electives within this concentration include courses on medical imaging, systems-level neuroscience, and introductions to microelectronics and signal processing. Students graduating from BME with a bioelectrical concentration will be able to work as engineers in the rapidly expanding fields of neural engineering, medical diagnostics, and medical systems industries, or pursue advanced degrees in medicine, basic medical sciences, or bioelectrical engineering.

*Advisor: Prof. Tim Bruns*

**Biomaterials and Regenerative Medicine:** Biomaterials is the study of interactions between living and non-living materials. Students trained in biomaterials must have a thorough understanding of the materials they work with and properties of the biological system they seek to replace or regenerate. Biomaterials are also an integral component in tissue engineering and regenerative medicine. Biomaterials research areas include: design of orthopaedic, dental, cardiovascular and neuro-sensory prostheses, artificial organs, blood-surface interactions, cellular and tissue engineering, drug delivery, biosensors, microencapsulation technology, and implant retrieval analysis. Students graduating from BME with a concentration in biomaterials will be capable of working in the medical device, tissue engineering or pharmaceutical industries, academic or government laboratories, or pursuing further education in Ph.D. or professional programs. *Advisor: Prof. David Kohn*

**Biomechanics and Biotransport:** Biomechanics is a hybrid discipline requiring a thorough understanding of classic engineering mechanics, physiology and cell biology, and the interface between the two. Biomechanics also has important applications in cutting-edge fields like tissue engineering and mechanotransduction. In tissue engineering, one tries to regenerate new tissues to replace defects in existing tissue. This requires knowledge of tissue-mechanical function. Mechanotransduction is the study of how cells sense and react to mechanical stimulus, a field with applications in such diverse areas as hearing (haircell movement in fluids) and orthopaedics (bone and tendon response to physical stress). Graduates in this concentration will be prepared for a wide range of industries concerned with mechanical effects on the human body including surgical device industries, automotive safety, and biotech industries concerned with mechanically functional tissue. Students will also have excellent preparation to attend medical school or pursue a Ph.D. *Advisor: Prof. David Kohn*

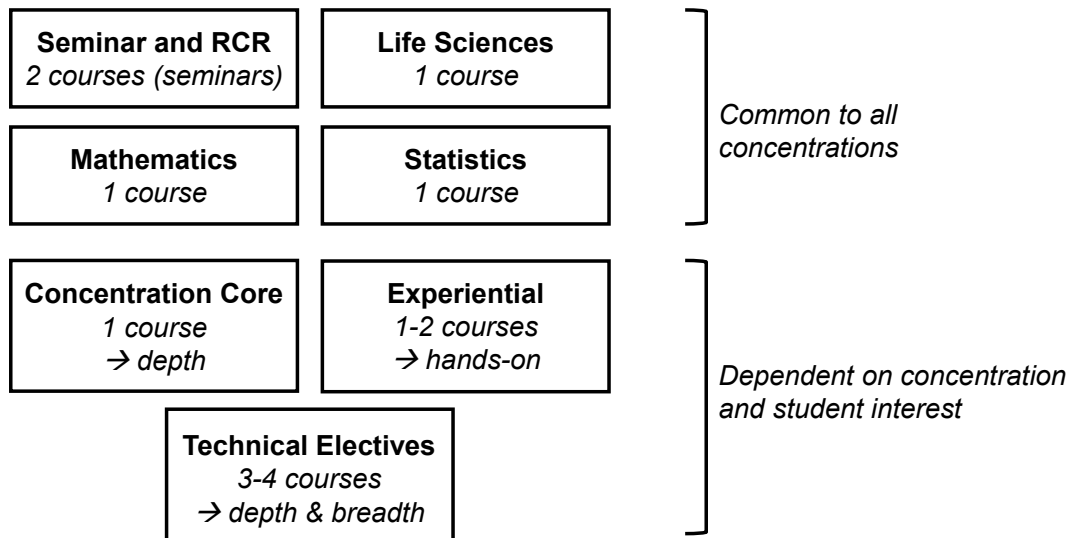
**Biomedical Imaging and Ultrasonics:** Since the invention of x-ray computerized tomography more than 25 years ago, imaging has become the primary noninvasive diagnostic tool available to the clinician. Although many principles are common to all imaging modalities, biomedical imaging scientists and engineers must understand the basic physics and operating principles of all primary modalities including magnetic resonance imaging (MRI), radiography and nuclear medicine, optics, and ultrasound. Major biomedical imaging companies require such multi-modality expertise to design new devices and procedures. In addition, clinical problems increasingly require the techniques of cell and molecular biology to design both new contrast agents and imaging methods for a wider range of applications. The biomedical imaging curriculum recognizes trends and requires students to have a solid background in signal processing and imaging science, and simultaneously be literate in both the basic life sciences and the basic operating principles of several imaging modalities. Graduates of this program will be well prepared to work in the medical imaging industry, to attend medical school, or to study for a Ph.D. in BME. *Advisor: Prof. Xueding Wang*

**Biotechnology and Systems Biology:** Advances in cellular and molecular biology have changed and expanded the ways therapeutic devices and drugs are designed. Modern biotechnology depends on scientists and engineers who study the fundamental properties of cell, molecular, and tissue biology, and apply these to engineer materials and technology to interact with living systems. Goals include production of improved biomaterials for medical

implants and prosthetics, tissues engineered for specific functionality, and new therapeutic drugs. The biotechnology curriculum emphasizes critical areas of chemistry, molecular biology, and cell biology, but also exposes students to a broad range of engineering approaches necessary for this interdisciplinary field. Graduates of this program will be well prepared for jobs in the pharmaceutical or medical device industries, to attend professional schools, or to study for a Ph.D. *Advisor: Prof. Deepak Nagrath*

**Medical Product Development:** The design and development of medical devices and systems is unique in the way they are regulated and structured. Biomedical engineers can play key roles at all stages of medical product development, from needs finding and concept generation to design, prototyping, testing, fabrication, and commercialization. The goal of this concentration is to provide students with the practical knowledge and skills needed to bring new and improved devices to the clinic, in the context of the current healthcare environment. The core course is a two-semester design-build-test experience in which student teams work to solve real clinical problems in collaboration with practicing physicians. This experience is augmented with elective courses in regulatory affairs, quality systems, intellectual property, innovation, and other topics relevant to the development and commercialization of medical products. Graduates of this program will be well prepared for jobs in product development in a variety of medically-oriented industries, including biotechnology, pharmaceuticals, and medical devices. *Advisor: Prof. Jan Stegemann*

#### SCHEMATIC OF COMPONENTS OF THE MASTERS COURSE CURRICULUM:



**Fig. 1:** General components of Masters curriculum in Biomedical Engineering.

#### CONCENTRATION CORE:

##### **Bioelectrics and Neural Engineering (at least one course):**

BIOMEDE 417	Electrical Biophysics (4) (I)
BIOMEDE 517	Neural Engineering (3) (II)

*NOTE:* Students who have previously taken an undergraduate bioelectricity course are advised to take BIOMEDE 517 instead of BIOMEDE 417.



**Biomaterials and Regenerative Medicine:**

BIOMEDE 410 Design and Applications of Biomaterials (3) (I)

**Biomedical Imaging and Ultrasonics:**

BIOMEDE 516 Medical Imaging Systems (3) (I)

**Biomechanics and Biotransport (at least one course):**

BIOMEDE 456 Tissue Mechanics (3) (I)

BIOMEDE 476 Biofluid Mechanics (4) (II)

**Biotechnology and Systems Biology (at least one course):**

BIOMEDE 504 Cellular Biotechnology (3) (II)

BIOMEDE 584 Advances in Tissue Engineering (3) (II, even years)

BIOPHYS 440 Biophysics of Diseases (3) (I)

CHE 517 Biochemical Engineering (3) (I)

**Medical Product Development (both courses are required):**

*NOTE:* These courses satisfy both the Concentration Core and the Experiential Component in the Medical Product Development concentration.

BIOMEDE 599.002 Graduate Innovative Design in Biomedical Engineering Pt. 1 (3) (I)

BIOMEDE 599.004 Graduate Innovative Design in Biomedical Engineering Pt. 2 (4) (II)

**EXPERIENTIAL COMPONENT (at least one course):**

BIOMEDE 458 <sup>1</sup> Biomedical Instrumentation and Design (4) (I,II)

BIOLCHEM 516 Introductory Biochemistry Laboratory (3) (I,II)

BIOMEDE 510 Medical Imaging Laboratory (3) (II)

IOE 432 Industrial Engineering Instrumentation Methods (3) (I)

MCDB 429 Laboratory in Cell and Molecular Biology (3) (II)

BIOMEDE 590 <sup>2</sup> Directed Research (2-6) (I,II,III,IIIa,IIIb)

BIOMEDE 599.002/004 <sup>3</sup> Graduate Innovative Design in Biomedical Engineering (3/4, I/II)

*NOTES:* <sup>1</sup> Required for students without prior, approved bioinstrumentation course. Students with prior bioinstrumentation course can take an additional bioinstrumentation course from this list. Students in the Biomedical Imaging and Ultrasonics concentration may take BIOMEDE 510 in place of BIOMEDE 458. SUGS students who took BIOMEDE 458 as undergraduates and counted it toward their BS degree must take an additional course to satisfy the experiential component of the MS degree.

<sup>2</sup> Students can count up to 6 letter-graded credits of BIOMEDE 590 toward the MS degree. Students who count 4 or more credits, either in a single or multiple terms, are required to complete a MS Thesis and defense. PhD students can also count the MS Thesis and defense as the BME Qualifying Examination.

<sup>3</sup> Priority given to students in Medical Product Development concentration. This is a full-year course; both Fall and Winter sessions must be taken.



**SEMINAR AND RESPONSIBLE CONDUCT OF RESEARCH (both courses are required):**

BIOMEDE 500	Biomedical Engineering Seminar (1) (I,II)
BIOMEDE 550	Ethics and Enterprise (1) (I)

*NOTES:* Recommended to be taken in first term or year of study.  
BIOMEDE 550 satisfies UM Responsible Conduct of Research and Scholarship (RCRS) requirement.

**MATHEMATICS (choose one course):**

*Courses recommended for BME students:*

MATH 450	Advanced Mathematics for Engineers I (4) (I,II)
MATH 454	Boundary Value Problems for Partial Differential Equations (3) (I,II,IIIa)
MATH 463	Mathematical Modeling in Biology (3) (I)

*Course recommended for BME students following the Biomedical Imaging and Ultrasonics concentration:*

EECS 551	Matrix Methods for Signal Processing (4) (I,II)
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*Other courses with specialized content:*

MATH 462	Mathematical Models (3) (II)
MATH 471	Introduction to Numerical Methods (3) (I,II,IIIb)
MATH 540	Mathematics of Biological Networks (3) (I)
MATH 550	Introduction to Adaptive Systems (3) (I)
MATH 555	Introduction to Functions of a Complex Variable with Applications (3) (I,II)
MATH 556	Applied Functional Analysis (3) (I)
MATH 557	Applied Asymptotic Analysis (3) (II)
MATH 558	Applied Nonlinear Dynamics (3) (I)
MATH 559	Topics in Applied Mathematics (3) (varies)
MATH 561	Linear Programming I (3) (I,II)
MATH 562	Continuous Optimization Methods (3) (II)
MATH 563	Advanced Mathematical Methods for the Biological Sciences (3) (II)
MATH 564	Topics in Mathematical Biology (3) (II)
MATH 571	Numerical Linear Algebra (3) (I,II)
MATH 572	Numerical Methods for Differential Equations (3) (II)
MATH 651	Topics in Applied Mathematics I (3) (II)
MATH 656	Introduction to Partial and Differential Equations (3) (I)
MATH 657	Nonlinear Partial Differential Equations (3) (II)
MATH 756	Advanced Topics in Partial Differential Equations (3) (II)
MECHENG 501	Mathematical Methods in Mechanical Engineering (3) (I)
MECHENG 564	Linear Systems Theory (4) (I,II)

**STATISTICS (choose one course):**

*Course recommended for BME students:*

BIOMEDE 503	Statistical Methods for Biomedical Engineering (3) (II)
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*Other courses with specialized content:*

BIOSTAT 602	Biostatistical Inference (4) (II)
BIOSTAT 650	Applied Statistics I: Linear Regression (4) (I)



BIOSTAT 651	Applied Statistics II: Extensions for Linear Regression (3) (II)
EECS 501	Probability and Random Processes (4) (I,II)
IOE 461	Quality Engineering Principles and Analysis (3) (I)
STATS 470	Introduction to the Design of Experiments (4) (I)
STATS 500	Statistical Learning I: Regression (3) (I)
STATS 525	Probability Theory (3) (I)

*NOTE:* BME graduate students can only take EECS 501 in the winter term.

**LIFE SCIENCES (choose one course):**

*Courses recommended for BME students:*

BIOMEDE 519	Quantitative Physiology (4) (I)
BIOMEDE 599.011	Engineering Approaches to Cancer Biology (3) (II)
BIOLCHEM 515	Introductory Biochemistry (3) (I,II)
CDB 530	Cell Biology (3) (I)
CDB 550	Histology (4) (II)

*Other courses with specialized content:*

ANATOMY 403	Human Anatomy: Structure and Function (5) (I,II)
ANATOMY 541	Mammalian Reproductive Physiology (4) (II)
BIOLCHEM 451	Advanced Biochemistry: Macromolecular Structure and Function (4) (I)
BIOPHYS 520	Methods of Biophysical Chemistry (3) (I)
CANCBIO 553	Molecular Biology of Cancer (3) (I)
CANCBIO 554	Cancer Pathogenesis and Treatment (3) (II)
CDB 581	Development Genetics (3) (I)
CDB 583	Organogenesis: Stem Cells to Regenerative Biology (3) (II)
KINESLGY 522	Clinical Neurophysiology and Neuroimaging (3) (varies)
KINESLGY 545	Metabolic Responses to Exercise (3) (II)
MCDB 422	Brain Development, Plasticity, and Circuits (3) (II)
MCDB 423	Introduction to Research in Cellular and Molecular Neurobiology (3) (I,II)
MCDB 427	Molecular Biology (4) (I,II)
MCDB 428	Cell Biology (4) (I,II)
MCDB 435	Intracellular Trafficking (3) (II)
MICRBIOL 440	Human Immunology (3) (II)
NEUROSCI 570	Human Neuroanatomy I (3) (I)
NEUROSCI 601	Principles of Neuroscience I (3) (I)
NEUROSCI 602	Principles of Neuroscience II (3) (II)
PATH 581	Tissue, Cellular and Molecular Disease (3) (II)
PHYSIOL 592	Integrated Neuroscience (2-4) (II)

**TECHNICAL ELECTIVES:**

*Students must take sufficient technical elective credits to reach at least the 30 credits overall required for the MS degree. No more than 2 credits of seminar courses may be applied to the MS degree.*

*NOTE:* Students in any concentration may take one technical elective from the Medical Product Development list of technical electives (see Page 8).



### **Bioelectrics and Neural Engineering**

BIOMEDE 510	Medical Imaging Laboratory (3) (II)
BIOMEDE 516	Medical Imaging Systems (3) (I)
BIOMEDE 517	<sup>1</sup> Neural Engineering (3) (II)
BIOMEDE 599.010	Current Topics in Neuromodulation (3) (II)
EECS 414	Introduction to MEMS (4) (I)
EECS 425	Integrated Microsystems Laboratory (4) (II)
EECS 427	<sup>2</sup> VLSI Design I (4) (I,II)
EECS 445	<sup>2</sup> Intro Machine Learning (4) (I,II)
EECS 522	<sup>2</sup> Analog Integrated Circuits (4) (II)
EECS 545	<sup>2,3</sup> Machine Learning (3) (I,II)
EECS 564	<sup>2,3</sup> Estimation, Filtering, and Detection (3) (II)
NEUROSCI 613	Circuits and Computational Neuroscience (1) (I)
NEUROSCI 614	Sensory and Systems Neuroscience (1) (II)
NEUROSCI 615	Cognitive and Behavioral Neuroscience (1) (II)

- NOTES:*   <sup>1</sup> Can be taken as an elective if BIOMEDE 417 is taken as the concentration core.  
              <sup>2</sup> EECS courses are challenging without an appropriate background. Students are recommended to verify prerequisites and contact course instructors prior to registration.  
              <sup>3</sup> Must take EECS 501 prerequisite, which also covers the STATISTICS component.

### **Biomaterials and Regenerative Medicine**

BIOMEDE 418	Quantitative Cell Biology (3) (I,II)
BIOMEDE 456	Tissue Mechanics (3) (I)
BIOMEDE 476	Biofluid Mechanics (4) (II)
BIOMEDE 479	Biotransport (4) (II)
BIOMEDE 563	Biomolecular Engineering of Interfaces (3) (II)
BIOMEDE 584	Advances in Tissue Engineering (3) (II, even years)
BIOMEDE 599.011	Engineering Approaches to Cancer Biology (3) (II)
MATSCIE 412	Polymeric Materials (3) (I)
MATSCIE 420	Mechanical Behavior of Materials (3) (I)
MATSCIE 440	Ceramic Materials (3) (II)
MATSCIE 465	Structural and Chemical Characterization of Materials (3) (I,II)
MATSCIE 512	Physical Polymers (3) (II)
MATSCIE 514	Composite Materials (3) (II)
MATSCIE 515	Mechanical Behavior of Solid Polymeric Materials (3) (II)
MATSCIE 517	Advanced Functional Polymers: Molecular Design and Applications (3) (I)
MATSCIE 560	Structure of Materials (3) (I)
MATSCIE 562	Electron Microscopy I (4) (II)
MATSCIE 577	Failure Analysis of Materials (3) (I,II)

### **Biomedical Imaging and Ultrasonics**

BIOMEDE 510	Medical Imaging Laboratory (3) (II) (Strongly recommended)
BIOMEDE 417	Electrical Biophysics (4) (I)
BIOMEDE 418	Quantitative Cell Biology (4) (I,II)
EECS 556	Image Processing (3) (II)



### **Biomechanics and Biotransport**

Technical electives with fluid mechanics content:

BIOMEDE 479	Biotransport (4) (II)
AEROSP 521	Experimental Methods in Fluid Mechanics (3) (I)
CHE 527	Fluid Flow (3) (1)
CHE 542	Intermediate Transport Phenomena (3) (II)
MECHENG 520	Advanced Fluid Mechanics I (3) (I)
MECHENG 523	Computational Fluid Dynamics I (3) (I)
MECHENG 524	Advanced Engineering Acoustics (3) (I)
MECHENG 530	Advanced Heat Transfer (3) (I)
MECHENG 617	Mechanics of Polymers II (3) (II)

Technical electives with biomechanics content:

BIOMEDE 534	Occupational Biomechanics (3) (II)
MECHENG 599.002	Cellular Engineering (3) (II)

Technical Electives with Connective Tissue Content:

BIOMEDE 410	Design and Applications of Biomaterials (3) (I)
MECHENG 505	Finite Element Methods in Mechanical Engineering & Applied Mechanics (3) (I)
MECHENG 511	Solid Continua (3) (I)
MECHENG 512	Theory of Elasticity (3) (II)
MECHENG 517	Mechanics of Polymers I (3) (II)

Technical Electives with Dynamics/Control Content:

EECS 562	Nonlinear Systems & Control (3) (II)
MECHENG 440	Intermediate Dynamics & Vibrations (4) (II)
MECHENG 540	Intermediate Dynamics (4) (I)
MECHENG 543	Analytical & Computational Dynamics I (3) (II)
MECHENG 560	Modeling Dynamic Systems (3) (I)
MECHENG 561	Design of Digital Control Systems (3) (II)

### **Biotechnology and Systems Biology**

BIOMEDE 410	Design and Applications of Biomaterials (3) (I)
BIOMEDE 456	Tissue Mechanics (3) (I)
BIOMEDE 476	Biofluid Mechanics (4) (II)
BIOMEDE 479	Biotransport (4) (II)
BIOMEDE 504	Cellular Biotechnology (3) (II)
BIOMEDE 599.011	Engineering Approaches to Cancer Biology (3) (II)
BIOINF 527	Introduction to Bioinformatics and Computational Biology (4) (I)
BIOLCHEM 550	Macromolecular Structure and Function (3) (I)
CANCBIO 553	Molecular Biology of Cancer (3) (I)
CDB 550	Histology (4) (II)
CHE 519	Pharmaceutical Engineering (3) (II)
CHE 528	Reactor Engineering (3) (II)
CHE 538	Statistical and Irreversible Thermodynamics (3) (I)
CHE 542	Intermediate Transport Phenomena (3) (II)
CHE 696	Selected Topics (3) (I,II)



EECS 414	Introduction to MEMS (4) (I)
MCDB 611	Neurochemistry/Neuropharmacology (1) (I)
MECHENG 553	Microelectromechanical Systems (3) (I)
MECHENG 599.002	Cellular Engineering (3) (II)

### **Medical Product Development**

*NOTE:* Students in any concentration may take one class from the following list as a technical elective.

BIOMEDE 499.002	Clinical Observation and Needs Finding (2) (I)
BIOMEDE 504	Cellular Biotechnology (3) (II)
BIOMEDE 523	Business of Biology (2.25) (I)
BIOMEDE 588	Global Quality Systems and Regulatory Innovation (2) (II)
BIOMEDE 599.005	Instructional Innovation Incubator (3) (I)
BE 608	Health Care Markets and Public Policies (1.5) (I)
BIOINF 622	Translational Research (2) (I)
CHE 517	Biochemical Engineering (3) (I)
ENR 500	An Introduction to Innovation: Tools for Career Success (3) (I)
ENR 540	Business Math for Innovators (1.5) (II)
ENR 550	Interpersonal Skills: Leveling Up to Leadership (3) (I)
ENR 599.008	IP Strategy (3) (I)
ENR 599.011	Technology-Inspired Business Models (3) (I)
ENR 599.020	Project Management and Consulting (3) (I)
ES 512	Business Basics for Graduate Engineers (3) (II)
ES 720	Commercialization of Biomedicine (1.5) (II)
MECHENG 599.003	Design for Global Health (3) (II)

### **KEY AND ADDITIONAL NOTES:**

Course Department & Number Course Name (# of credits) (term offered)

Terms: I - fall, II - winter, III - spring-summer, IIIa - spring half, IIIb - summer half

Students are responsible for checking the Registrar's Schedule of Classes to ensure that their selected courses are offered and fit their schedule.

Courses with 499/599 designation are in pilot phase and may not be offered in the term indicated.