Bioengineering, PhD (Boston)

Biology can inspire engineering. Increasingly, discoveries in the life sciences reveal processes, complexity, and control without analogy in the world of traditional engineering. Current methods of producing nanoscale control over molecules cannot reproduce the organization found in even the simplest organisms. Energy capture, robust control, remediation, and self-assembly are all employed by biosystems with efficiency unparalleled by anything in today's laboratories. At the same time, traditional engineering disciplines struggle to find new approaches to the complex challenges of 21st-century technology. The last 50 years of basic life science research have gradually revealed the layers of complexity intrinsic to biological processes, unmasking the fundamental underpinnings on which biological systems are constructed. Bioinspired engineering has the potential to transform the technological landscape of the 21st century. Astonishingly, it represents merely one of the myriad opportunities presented at the interface of biology and engineering.

The field of bioengineering is broad and includes all research at the interface of engineering and biology—this includes bioprocesses, environmental microbiology, biomaterials and tissue engineering, bioelectricity, biomechanics, biomedical and biological imaging, nanotechnology in medicine and the environment, and engineering design for human interfacing. At Northeastern University, bioengineering PhD students have an opportunity to be trained to appreciate advances in bioengineering across a wide range of disciplines while they perform highly focused and cutting-edge bioengineering research with one of our faculty members.

The PhD in Bioengineering program reflects departmental research strengths in multiple areas. Students accepted to the bioengineering program will undertake a rigorous core curriculum in basic bioengineering science, followed by a flexible selection of electives tailored to their dissertation research.

Research Areas

There are four key areas of research strength in our department.

AREA 1— BIOMEDICAL DEVICES AND BIOIMAGING

The Biomedical Devices and Bioimaging track reflects Northeastern's outstanding research profile in developing transformative and translational instrumentation and algorithms to help understand biological processes and disease. Our department has active federally funded research spanning across a broad spectrum of relevant areas in instrument design, contrast agent development, and advanced computational modeling and reconstruction methods. Example research centers and laboratories include theInstitute for Chemical Imaging of Living Systems (https://coe.northeastern.edu/coe-research/research-centers-institutes/institute-for-chemical-imaging-of-living-systems/), theTranslational Biophotonics Cluster (https://sites.google.com/view/tbpclusternu/home/), and theB-SPIRAL signal processing group (https://web.northeastern.edu/spiral/).

AREA 2—BIOMECHANICS AND MECHANOBIOLOGY

Motion, deformation, and flow of biological systems in response to applied loads elicit biological responses at the molecular and cellular levels that support the physiological function of tissues and organs and drive their adaptation and remodeling. To study these complex interactions, principles of solid, fluid, and transport mechanics must be combined with measures of biological function. The biomechanics and mechanobiology research area embraces this approach and leverages the strong expertise of Northeastern faculty attempting to tie applied loads to biological responses at multiple length and time scales. Northeastern faculty working in this field are centered around the Institute for Mechanobiology (https://nam12.safelinks.protection.outlook.com/?url=https%3A%2F%2Fmechanobiology.northeastern.edu%2F&data=05%7C02%7Cc.pridmore%40northeastern.edu%7C4de345a4039f4567acef08dd3690df82%7Ca8eec281aaa34daeac9b9a398b9215e7%7C0%7C0%7C638726718025303787%7CUnknown%7CTWFpbGZsb3d8eyJFbXB0eU1hcGkiOnRydWUsIlYiOiIwLjAuMDAwMCIsIlAiOiJXaW4zMiIsIkFOIjoiTWFpbCIsIldUIjoyfQ%3D%3D%7C0%7C%7C%7C&sdata=LwBJwtZbgslTmbIbUn07RsMyK5KbYtSowda69UI6CRo%3D&reserved=0), whose mission is to accelerate mechanobiology discoveries and technologies to enhance human health and advance medicine.

AREA 3—MOLECULAR, CELL, AND TISSUE ENGINEERING

Principles for engineering living cells and tissues are essential to address many of the most significant biomedical challenges facing our society today. These application areas include engineering biomaterials to coax and enable stem cells to form functional tissue or to heal damaged tissue; designing vehicles for delivering genes and therapeutics to reach specific target cells to treat a disease; and uncovering therapeutic strategies to curb pathological cell behaviors and tissue phenotypes. At a more fundamental level, the field is at the nascent stages of understanding how cells make decisions in complex microenvironments and how cells interact with each other and their surrounding environment to organize into complex three-dimensional tissues. Advances will require multiscale experimental, computational, and theoretical approaches spanning molecular-cellular-tissue levels and integration of molecular and physical mechanisms, including the role of mechanical forces.

AREA 4—SYSTEMS, SYNTHETIC, AND COMPUTATIONAL BIOENGINEERING

Research groups in systems, synthetic, and computational bioengineering apply engineering principles to model and understand complex biological systems, including differentiation and development, pathogenesis and cancer, and learning and behavior. This involves designing and implementing methods for procuring quantitative and sometimes very large datasets, as well as developing theoretical models and computational tools for interpreting these data. Deciphering the workings of a biological system allows us to identify potential biomarkers and drug targets, to develop protocols for personalized medicine, and more. In addition, we use the design principles of biological systems we discover to engineer and refine new synthetic biological systems for clinical, agricultural, environmental, and energy applications.

Degree Requirements

Completion of the PhD degree requires students to successfully complete the following requirements:

CURRICULUM

The curriculum comprises a strong core of fundamental courses that is coupled with flexible choices of restricted and unrestricted technical electives to provide depth in a particular field of study. The detailed course requirements are outlined below.

For students possessing a baccalaureate in a suitable quantitative or technical field before entering the PhD program, the required course distribution is shown in the table below:

Requirements	Credits
Required core courses	12
Restricted technical electives	8
Unrestricted technical electives	12
Advanced seminar (four semesters)	
Dissertation	
Minimum semester hours required	32

The curriculum for PhD students with "advanced standings," i.e., students with an MS degree in relevant engineering areas awarded at a qualified institution, will be selected from the available core and elective courses under the guidance of the program director and the student's primary advisor. Completion of the PhD degree with an advanced standing requires a minimum of 16 semester hours of coursework to be approved by the graduate director and a completed PhD dissertation.

Requirements	Credits
Required core courses	8
Advisor-approved coursework	8
Advanced seminar (four semesters)	
Dissertation	
Minimum semester hours required	16

QUALIFYING EXAM (WRITTEN AND ORAL)

To qualify to continue in the PhD program, students must pass the bioengineering qualifying examination in the most relevant of the four department research areas. Students will prepare a seven-page written document that will be distributed to the committee before the oral examination. Details of the formal qualification exam procedure and timing are available in the Graduate Handbook *(*https://bioe.northeastern.edu/community/resources-for-current-students/*).* In addition, satisfactory research progress and academic standing are required to pass the exam. The qualifying exam is normally taken in the student's second year.

QUALIFYING EXAM COMMITTEE

The qualifying examination committee is composed of three members of the Department of Bioengineering faculty. At least two of three committee members will be from the student's research area. The student's primary research advisor may not sit on the qualifying exam committee.

PHD DISSERTATION COMMITTEE

Students normally form their dissertation committee within two years of joining the PhD program. The dissertation committee is composed of a minimum of three members, two of whom must be core faculty from the Department of Bioengineering. The student's primary advisor will be a member of and chair the dissertation committee. This advisor must be a member of the core bioengineering faculty or a faculty member from another department who has an affiliation with the bioengineering department. Students are required to meet annually with their PhD dissertation committee to ensure satisfactory research progress.

ANNUAL COMMITTEE MEETINGS AND DISSERTATION PROPOSALS

PhD students must hold their first committee meetings no later than their third year. The first committee meeting requires the student to write a dissertation proposal in the form of an NIH-style R21 proposal research plan that will be distributed to their dissertation committee at least one week prior to the meeting. Thereafter, students are expected to hold annual progress updates with their committee. At the penultimate committee meeting (which must be held at least four months prior to the dissertation defense), the student will prepare and present a final proposal document to the committee. Successful defense of this proposal will allow the student to progress to the PhD dissertation defense.

PHD DISSERTATION DEFENSE

PhD candidates must satisfactorily complete and defend a dissertation describing original research in bioengineering in an open presentation to the Northeastern bioengineering community, followed by a closed meeting with their dissertation committee in which they are expected to defend their work and answer all relevant questions regarding that work, its significance, and its relationship to ongoing work across the broader research community.

DISSERTATION COURSE REQUIREMENTS

After achieving PhD candidacy by passing the qualifying exam, the doctoral candidate, in consultation with their research advisor, must register in two consecutive semesters (may include full summer term) for Dissertation Term 1 (BIOE 9990) and Dissertation Term 2 (BIOE 9991). Upon completion of

this sequence, the student must then register for Dissertation Continuation (BIOE 9996) every semester (in each fall and spring term and also in the summer term if summer is the student's last semester) until the dissertation is completed. Students may not register for Dissertation Continuation (BIOE 9996) until they fulfill the two-semester sequence of Dissertation Term 1 (BIOE 9990) and Dissertation Term 2 (BIOE 9991).

PhD students who have completed the majority of their coursework and not yet reached PhD candidacy should register for Research (BIOE 9986) in a section for which their research or academic advisor is listed as the instructor in the online registration system.

Program Requirements

Complete all courses and requirements listed below unless otherwise indicated.

Milestones

Annual review
Qualifying examination (within two years of entry)
Dissertation committee
Annual committee meetings
Area examination (dissertation prospectus/proposal)
Dissertation defense

Core Requirements

Code	Title	Hours
Seminar		
BIOE 7390	Seminar (Register and complete two semesters)	0
BIOE 7391	Student Seminar (Register and complete once in second year and once in fourth year)	0
Required Core		
BIOE 6100	Medical Physiology	4
BIOE 6200	Mathematical Methods in Bioengineering	4
BIOE 7000	Principles of Bioengineering	4
Restricted Bioengineering Technical Electives		
Complete 8 semester hours from the following:		8
BIOE 5115	Dynamical Systems in Biological Engineering	
BIOE 5235	Biomedical Imaging	
BIOE 5410	Molecular Bioengineering	
BIOE 5411	Applied Molecular Bioengineering	
BIOE 5420	Cellular Engineering	
BIOE 5430	Principles and Applications of Tissue Engineering	
BIOE 5440	The Cell as a Machine	
BIOE 5630	Physiological Fluid Mechanics	
BIOE 5640	Computational Biomechanics	
BIOE 5648	Biomedical Optics	
BIOE 5650	Multiscale Biomechanics	
BIOE 5660	Integrative Mechanobiology	
BIOE 5710	Experimental Systems and Synthetic Bioengineering	
BIOE 5711	Advanced Experimental Systems and Synthetic Bioengineering	
BIOE 5720	Physical Bioengineering	
BIOE 5750	Modeling and Inference in Bioengineering	
BIOE 5770	Machine Learning Methods in Biology and Health	
BIOE 5810	Design of Biomedical Instrumentation	
BIOE 5820	Biomaterials	
BIOE 5860	Engineering Approaches to Precision Medicine I	
BIOE 5870	Engineering Approaches to Precision Medicine II	
ME 5665	Musculoskeletal Biomechanics	
Technical Electives		
Complete 12 semester hours from the electives listed below.		12

Electives Course List

Any course in the following list will serve as an elective course, provided the course is offered and the student satisfies prerequisites and program requirements. Students can take electives outside this list with prior approval from the faculty advisor.

Code	Title	Hours
BINF 6400	Genomics in Bioinformatics	
BIOE 5060	Special Topics in Bioengineering	
BIOE 5115	Dynamical Systems in Biological Engineering	
BIOE 5235	Biomedical Imaging	
BIOE 5250	Regulatory and Quality Aspects of Medical Device Design	
BIOE 5410	Molecular Bioengineering	
BIOE 5411	Applied Molecular Bioengineering	
BIOE 5420	Cellular Engineering	
BIOE 5430	Principles and Applications of Tissue Engineering	
BIOE 5440	The Cell as a Machine	
BIOE 5450	Stem Cell Engineering	
BIOE 5510	Bioengineering Products/Technology Commercialization	
BIOE 5520	Bioengineering Design for Robotic Rehabilitation	
BIOE 5630	Physiological Fluid Mechanics	
BIOE 5640	Computational Biomechanics	
BIOE 5648	Biomedical Optics	
BIOE 5650	Multiscale Biomechanics	
BIOE 5660	Integrative Mechanobiology	
BIOE 5710	Experimental Systems and Synthetic Bioengineering	
BIOE 5711	Advanced Experimental Systems and Synthetic Bioengineering	
BIOE 5720	Physical Bioengineering	
BIOE 5750	Modeling and Inference in Bioengineering	
BIOE 5760	Method and Logic in Systems Biology and Bioengineering	
BIOE 5770	Machine Learning Methods in Biology and Health	
BIOE 5800	Systems, Signals, and Controls for Bioengineers	
BIOE 5810	Design of Biomedical Instrumentation	
BIOE 5820	Biomaterials	
BIOE 5850	Design of Implants	
BIOE 5860	Engineering Approaches to Precision Medicine I	
BIOE 5870	Engineering Approaches to Precision Medicine II	
BIOE 5880	Computational Methods in Systems Bioengineering	
BIOE 7210	A Data Science Toolkit for Human Neuroscience Research	
BIOL 5543	Stem Cells and Regeneration	
BIOL 5601	Multidisciplinary Approaches in Motor Control	
BIOL 6299	Molecular Cell Biology for Biotechnology	
BIOL 6300	Biochemistry	
BIOL 6301	Molecular Cell Biology	
CAEP 6202	Research, Evaluation, and Data Analysis	
CHEM 5612	Principles of Mass Spectrometry	
CHEM 5620	Protein Chemistry	
CHEM 5621	Principles of Chemical Biology	
CHEM 5638	Molecular Modeling	
CHME 5630	Biochemical Engineering	
CHME 5632	Advanced Topics in Biomaterials	
CS 5100	Foundations of Artificial Intelligence	
CS 5200	Database Management Systems	
CS 5310	Computer Graphics	
CS 5330	Pattern Recognition and Computer Vision	
CS 5335	Robotic Science and Systems	

CS 5340	Computer/Human Interaction
CS 5400	Principles of Programming Language
CS 5600	Computer Systems
CS 5800	Algorithms
CS 6120	Natural Language Processing
CS 6140	Machine Learning
CS 6200	Information Retrieval
CS 6410	Compilers
DS 5220	Supervised Machine Learning and Learning Theory
DS 5230	Unsupervised Machine Learning and Data Mining
EECE 5606	Micro- and Nanofabrication
EECE 5642	Data Visualization
EECE 5644	Introduction to Machine Learning and Pattern Recognition
EECE 7200	Linear Systems Analysis
EECE 7202	Electromagnetic Theory 1
EECE 7203	Complex Variable Theory and Differential Equations
EECE 7204	Applied Probability and Stochastic Processes
EECE 7205	Fundamentals of Computer Engineering
EECE 7211	Nonlinear Control
EECE 7213	System Identification and Adaptive Control
EECE 7214	Optimal and Robust Control
EECE 7271	Computational Methods in Electromagnetics
EECE 7310	Modern Signal Processing
EECE 7323	Numerical Optimization Methods
EECE 7337	Information Theory
EECE 7352	Computer Architecture
EECE 7353	VLSI Design
EECE 7364	Mobile and Wireless Networking
EECE 7368	High-Level Design of Hardware-Software Systems
HLTH 5600	Introduction to Patient Safety
HLTH 5610	Patient Safety Science
HLTH 5630	Quality Improvement in Patient Safety
HLTH 5800	AI Across the Health Sciences
HSCI 5150	Methods for Observational Research 1
HSCI 5180	Phenotyping
HSCI 5190	Cohort Building
IE 7315	Human Factors Engineering
ME 5650	Advanced Mechanics of Materials
ME 5654	Elasticity and Plasticity
ME 5655	Dynamics and Mechanical Vibration
ME 5657	Finite Element Method 1
ME 5658	Continuum Mechanics
ME 5659	Control Systems Engineering
ME 5665	Musculoskeletal Biomechanics
ME 6200	Mathematical Methods for Mechanical Engineers 1
ME 6260	Introduction to Microelectromechanical Systems (MEMS)
ME 7238	Finite Element Method 2
ME 7275	Essentials of Fluid Dynamics
NNMD 5470	Nano/Biomedical Commercialization: Concept to Market
OR 6205	Deterministic Operations Research
PHSC 5100	Concepts in Pharmaceutical Science
PHSC 6290	Biophysical Methods in Drug Discovery
PHTH 5210	Biostatistics in Public Health
PHTH 5214	Environmental Health

PHTH 6440	Advanced Methods in Biostatistics
PHYS 5116	Network Science 1
PHYS 7301	Classical Mechanics/Math Methods
PHYS 7321	Computational Physics
PHYS 7741	Physics of Biological Processes and Living Systems 2
PMST 6250	Advanced Physical Pharmacy
PMST 6252	Pharmacokinetics and Drug Metabolism
PMST 6254	Advanced Drug Delivery Systems
PT 5138	Neuroscience
PT 5139	Lab for PT 5138
PT 5150	Motor Control, Development, and Learning
PT 5151	Lab for PT 5150

Dissertation

Code	Title	Hours
BIOE 9990	Dissertation Term 1	
BIOE 9991	Dissertation Term 2	

Program Credit/GPA Requirements

32 total semester hours required
Minimum 3.000 GPA required

Advanced Entry Program Requirements

Complete all courses and requirements listed below unless otherwise indicated.

Milestones

Annual review
Qualifying examination (within two years of entry)
Dissertation committee
Area examination (dissertation prospectus/proposal)
Dissertation defense

Core Requirements

Code	Title	Hours
Seminar		
BIOE 7390	Seminar (Register and complete two semesters)	0
BIOE 7391	Student Seminar (Register and complete once in second year and once in fourth year)	0
Required Core		
BIOE 6200	Mathematical Methods in Bioengineering	4
BIOE 7000	Principles of Bioengineering	4
Approved Coursework		
Complete 8 semester hours from the electives listed below.		8

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EECE 5642	Data Visualization
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EECE 7202	Electromagnetic Theory 1
EECE 7203	Complex Variable Theory and Differential Equations
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ME 5654	Elasticity and Plasticity
ME 5655	Dynamics and Mechanical Vibration
ME 5657	Finite Element Method 1
ME 5658	Continuum Mechanics
ME 5659	Control Systems Engineering
ME 5665	Musculoskeletal Biomechanics
ME 6200	Mathematical Methods for Mechanical Engineers 1
ME 6260	Introduction to Microelectromechanical Systems (MEMS)
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PHTH 6440	Advanced Methods in Biostatistics
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PT 5150	Motor Control, Development, and Learning
PT 5151	Lab for PT 5150

Dissertation

Code	Title	Hours
BIOE 9990	Dissertation Term 1	
BIOE 9991	Dissertation Term 2	

Program Credit/GPA Requirements

16 total semester hours required
Minimum 3.000 GPA required