Bioengineering

Bioengineering is a broad and rapidly evolving field. At the core of its varied options is the goal of advancing human health through scientific discovery and through the development of new biomedical technologies. The Bioengineering Department at Lehigh offers graduate programs leading to the Master of Science and Doctor of Philosophy degrees in Bioengineering, as well as two undergraduate programs, a Bachelor of Science degree in Bioengineering and a Bachelor of Science degree in Biocomputational Engineering.

OUR MISSION

The mission of the Bioengineering Department at Lehigh University is to prepare students to be critical thinkers, problem solvers, innovators, leaders, and life-long learners in the field of Bioengineering. We aim to produce ground-breaking research and new knowledge at the interface of the physical and life sciences, and engineering.

OVERVIEW

As the newest engineering department at Lehigh, we hold true to the Lehigh tradition of world-class excellence in education and research. We accomplish this with outstanding and dedicated faculty members, a vibrant curriculum, state of the art technologies, and a highly integrative and interdisciplinary, research-driven focus.

Lehigh’s graduate program in Bioengineering trains students to combine life and physical sciences and engineering to develop effective and affordable solutions for health care and biotechnology problems. We offer diverse opportunities for advanced studies in areas such as biomaterials, computational bioengineering, biomechanics, optics, nanotechnology, biosensors, biophotonics and bioelectronics. Key research themes are (1) Biocomputations and Modeling, (2) Diagnostics, Sensors, and Devices, and (3) Materials and Therapies. Our graduate students are an integral part of this active and multi-disciplinary research environment.

Our undergraduate curriculum in Bioengineering fuses comprehensive fundamentals in engineering and physical sciences, such as fluid mechanics, physics, chemistry and thermodynamics, with a focus on biological systems and bioengineering applications – and then combines it with valuable hands-on, experiential learning opportunities. The result is a rigorous training regimen that prepares our students to be at the forefront of established and emerging fields such as pharmaceuticals, biomaterials, healthcare, bioelectronics, biomedicine and other biotechnology-related industries.

Lehigh is among the first handful of universities offering an undergraduate degree in Biocomputational Engineering. The undergraduate curriculum in this major provides students a foundation in the basic sciences, mathematics, and computer programming, as well as a rigorous core of interdisciplinary engineering coursework, including subjects such as bioinformatics, machine learning, and signaling in biological systems. The program will equip students to develop new diagnostic tools and software, model the building blocks of life, identify biological systems. The program strongly encourages experiential learning, including two summers of internships, required participation in Lehigh's Capstone Design Projects, and opportunities for undergraduate research for credit.

A total of 132 credit hours are required for graduation with a degree of bachelor of science in bioengineering.
BIOENGINEERING CORE REQUIREMENTS

**General Requirements**
- ENGR 005 Introduction to Engineering Practice 2
- ENGR 010 Applied Engineering Computer Methods 2
- ENGL 001 Critical Reading and Composition 3
- ENGL 002 Research and Argument 3
- ECO 001 Principles of Economics 4

Electives to satisfy HSS depth and breadth requirements 13

Free Electives 5

**Mathematics**
- MATH 021 Calculus I 4
- MATH 022 Calculus II 4
- MATH 023 Calculus III 4
- MATH 205 Linear Methods 3
- MATH 231 Probability and Statistics 3

**Natural Sciences**
- CHM 030 Introduction to Chemical Principles 4
- CHM 031 Chemical Equilibria in Aqueous Systems 4
- CHM 110 Organic Chemistry I 4
- & CHM 111 and Organic Chemistry Laboratory I 4
- PHY 011 Introductory Physics I 5
- & PHY 012 and Introductory Physics Laboratory I 5
- PHY 021 Introductory Physics II 5
- & PHY 022 and Introductory Physics Laboratory II 5
- BIOS 041 Introduction to Cellular and Molecular Biology 4
- & BIOS 042 and Introduction to Cellular and Molecular Biology Laboratory 4

**Integrated Bioengineering**
Required by all Three Tracks
- BIOE 110 Elements of Bioengineering 4
- BIOE 210 Introduction to Engineering Physiology 4
- BIOE 211 Capstone Design Project I 3
- BIOE 212 Capstone Design Project II 2
- BIOE 225 GMP Good manufacturing practice and regulatory affairs for bioengineers 1
- BIOE 226 Ethics in Bioengineering Practice 1
- or PHIL 116 Bioethics 1
- or PHIL 105 Ethics 1

Bioengineering Technical Electives 9

**Engineering Requirement by Track**
Select one of the following tracks:

**Biopharmaceutical Engineering Track**
- CHE 031 Material and Energy Balances of Chemical Processes 3
- BIOE 246 Bioengineering Thermodynamics 4
- BIOE 247 Biological Fluid Mechanics 4
- BIOE 341 Biotechnology I 3
- BIOE 343 Integrated Biotechnology Laboratory 3
- BIOE 349 Metabolic Engineering 3
- or CHE 211 Chemical Reactor Design 3
- MAT 033 Engineering Materials and Processes 3
- CHM 112 Organic Chemistry II 3
- BIOE 2XX elective 3

**Bioelectronic/Biophotonics Track**
- ECE 081 Principles of Electrical Engineering 4
- BIOE 025 Computer-aided Design for Bioengineers 3
- BIOE 331 Integrated Bioelectronics/ Biophotonics Laboratory 2

**Math-intensive elective**

- BIOE 225 GMP Good manufacturing practice and regulatory affairs for bioengineers 3
- BIOE 226 Ethics in Bioengineering Practice 3
- BIOE 227 or PHIL 116 Bioethics 3
- or PHIL 105 Ethics 3

**Biomaterials and Biomechanics Track**
- BIOE 227 GMP Good manufacturing practice and regulatory affairs for bioengineers 3
- BIOE 226 Ethics in Bioengineering Practice 3
- BIOE 227 or PHIL 116 Bioethics 3
- or PHIL 105 Ethics 3

**TYPICAL FOUR-YEAR COURSE SCHEDULE FOR BS IN BIOENGINEERING**

**BIOPHARMACEUTICAL ENGINEERING TRACK**

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**BIOMECHANICS AND BIOMATERIALS TRACK**

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**Total Credits: 132**

**BIOCOMPUTATIONAL ENGINEERING**

**DESCRIPTION**

Biocomputational Engineering is a new academic program at Lehigh that is at the nexus of the biological sciences, engineering, and computer science. The curriculum begins with classes in the mathematics and life & physical sciences, as well as computer...
programming and core engineering principles, which form the foundation for our biocomputations courses that cover a range of subjects, from bioinformatics and machine learning to biophysical models and biomedical signals. In our capstone courses, the students integrate and apply what they have learned in the earlier portion of the curriculum in a hands-on, collaborative setting. Our faculty are drawn from Bioengineering, Computer Science and Engineering, Biological Sciences, Physics, and Industrial and Systems Engineering, which will expose the students in this program to a rich, diverse range of expertise in this exciting discipline. Opportunities for academic research and employment in the field of Biocomputational Engineering are growing dramatically. People with experience in areas such bioinformatics and data analysis are currently in high demand at pharmaceutical, biotechnology, and software companies.

A total of 130 credit hours is required for graduation with a degree of bachelor of science in biocomputational engineering.

### Biocomputational Engineering Core Requirements

#### General Requirements

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<td>Applied Engineering Computer Methods</td>
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<td>BIO 226</td>
<td>Ethics in Bioengineering Practice</td>
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<tr>
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<td>Ethics</td>
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Electives to satisfy depth and breadth requirements 13

Free electives 1

#### Mathematics

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#### Natural Sciences

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<td>BIOS 041</td>
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#### Biocomputational Engineering Core Requirements

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or CSE 326 Fundamentals of Machine Learning 9

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Technical electives: Students must take nine (9) credits of technical electives. Three (3) of the nine credits must include BIOC, BIOE, CSE, and/or ISE courses at the 300-level or higher. The remaining six (6) credits may include engineering courses at the 200-level or higher and/or BIOS/CHM/PHY/MATH courses at the 200-level or higher.

Excluded courses: Courses in professional development, writing, and other non-technical subjects; seminars; BIOS 235.

### Typical Four-Year Course Schedule for BS in Biocomputational Engineering

#### Freshman

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<td>BIOC 241</td>
<td>3</td>
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<tr>
<td>Technical elective 1</td>
<td>3</td>
<td>CSE 308</td>
<td>3</td>
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<tr>
<td>Technical elective 2</td>
<td>3</td>
<td>BIOE 226</td>
<td>1</td>
</tr>
<tr>
<td>HSS 3</td>
<td>4</td>
<td>Technical elective 3</td>
<td>3</td>
</tr>
<tr>
<td>Free elective</td>
<td>4</td>
<td>HSS 4</td>
<td>4</td>
</tr>
</tbody>
</table>

| Total Credits: 130 |

### Graduate Program

Bioengineering offers graduate programs leading to a doctor of philosophy or a master of science degree. The graduate program will train students to solve problems that require the application of interdisciplinary knowledge, combining life sciences, physical sciences, and engineering. The program will emphasize cellular and biomolecular science and engineering, and aims to attract students with diverse academic backgrounds. Students who do not complete the doctor of philosophy have the option to earn a master of science.
Graduate program objectives
1. Understand complexities and challenges associated with working in the field of Bioengineering with an advanced degree.
2. Demonstrate depth of knowledge in Bioengineering and related fields.
3. Be creators of new knowledge and products in the field of Bioengineering.
4. Succeed in a variety of career paths.

Major Requirements

Doctor of Philosophy Degree
Candidates for the doctor of philosophy degree are required to complete a minimum of 72 credits. The curriculum requirements are defined in the table below. Per university policy, graduate students may count no more than 12 credits at the 300-level toward the Ph.D. degree.

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>BIOE 452 Mathematical Methods In Engineering</td>
<td>3</td>
</tr>
<tr>
<td>BIOE 455 Scientific and Professional Communications for Bioengineers</td>
<td>3</td>
</tr>
<tr>
<td>BIOE 410 Advanced Engineering Physiology or BIOE 445 Quantitative Biology</td>
<td>3</td>
</tr>
</tbody>
</table>

Adviser-approved technical electives at the 300-level or higher 15
Six credits of dissertation research 6
Additional 42 credits of electives and/or dissertation research 42
Total Credits 72

Students must pass a qualification exam, typically taken after three semesters of study, a final written dissertation as well as an oral defense of the dissertation.

Master of Science Degree
An oral defense of thesis research is dependent upon the requirements of the student’s adviser.

A minimum of 30 credits is required to complete the Master of Bioengineering degree. The curriculum requirements are defined in the table below. All students are required to complete a common core consisting of three courses, consisting of seven credits: (1) Mathematical Methods in Engineering, (2) Professional Development for Bioengineers, and (3) Advanced Engineering Physiology or Quantitative Biology. The remaining 23 credits are electives in Bioengineering and/or other programs. Students wishing to complete a thesis may use six of their elective credits for thesis research, culminating in a written thesis. Per university policy, graduate students may count no more than 12 credits at the 300-level toward the M.S. degree. Additionally, at least eighteen credits must be coursework with a BIOE designation.

Students in the Master of Bioengineering program have the option to focus their studies in one of three concentrations: (1) Biomechanics, (2) Bioengineering Product Development, or (3) Biocomputations and Biomedical Analytics, or alternately pursue a generalized Master of Bioengineering Program. Students in each concentration area take the common Bioengineering core courses, as well as Bioengineering electives.

1. Biomechanics: The Biomechanics concentration is for students interested in biological and biomimetic materials, as well as their characteristics and applications. Bioengineering courses in this concentration range from general (Introduction to Biomechanics) to specific, including courses such as Soft Materials: Mechanics and Physics, Cardiovascular Bioengineering, and Introduction to Force Spectroscopy. Beyond Bioengineering, students can further develop their expertise through coursework in Chemical and Biomolecular Engineering and Materials Science and Engineering.

2. Bioengineering Product Development: The Bioengineering Product Development concentration is for students interested in the design, development, regulation, and/or commercialization of medical products, including pharmaceuticals and medical devices. Students in this concentration can take Bioengineering courses in Biotechnology, Regulatory Affairs, and Biostatistics, and are encouraged to expand the breadth of their knowledge by taking courses in Industrial and Systems Engineering, Project Management, Technical Entrepreneurship, and General Business. Students in this track are required to complete a Bioengineering Ph.D. degree. Projects course under the guidance of faculty, often under the mentorship of an industry or clinical partner.

3. Biocomputations and Biomedical Analytics: The Biocomputations and Biomedical Analytics concentration is for students interested in the rapidly growing field of computational data sciences, as applied to biotechnology, biological systems, and biopharmaceutical development. Examples of Bioengineering courses in this concentration include Biostatistics, Bioengineering Applications in Machine Learning, Molecular Modeling and Simulations, and Numerical Methods for Scientists and Engineers. To further develop their expertise, students are also encouraged to take courses in Industrial and Systems Engineering and Computer Science and Engineering.

Bio Engineering Courses

BioE 020 Bioengineering Sophomore Research Seminar 1 Credit
Exposure to opportunities for on-campus research in bioengineering. Review of current literature on bioengineering topics through written reports and/or oral presentations. Preparation of written research proposal, including definition of topic, objectives, methodologies, research plans, and expected impact.

BioE 025 Computer-aided Design for Bioengineers 0.3 Credits
Introduction to computer-aided design and analysis using SolidWorks software. Best design practices and hands-on experience in building parts, assemblies, and creating technical 2D drawings. Applications important in the medical product industry, such as diagnostic and clinical equipment, surgical tools, implants, drug delivery systems, and pharmaceutical packaging systems.

BioE 110 Elements of Bioengineering 0.4 Credits
An introduction to the fields of biotechnology and biomedical engineering. The areas include biomechanics, biomaterials, bioinstrumentation, medical imaging, rehabilitation engineering, biosensors, biotechnology and tissue engineering.

Prerequisites: (BIOS 041 and BIOS 042)

BioE 210 Introduction to Engineering Physiology 4 Credits
Mammalian physiology for bioengineering students, with an emphasis on control mechanisms and engineering principles. Basic cell function; biological control systems; muscle; neural; endocrine, circulatory, digestive, respiratory, renal, and reproductive systems; regulation of metabolism and defense mechanisms. Includes laboratory work.

Prerequisites: (BIOS 041 and BIOS 042) and MATH 022

BioE 211 (ENGR 211, MAT 211, ME 211) Capstone Design Project I 3 Credits

Students work on teams, integrating knowledge and skills acquired in their prior course work, to design practical solutions to real-world problems, typically in collaboration with industry, entrepreneurs, faculty, or campus departments. Teams perform in-depth engineering design while considering engineering standards and the project business case. Constraints, including technical, financial, environmental, societal, supply chain, regulatory, and others are considered throughout. Teams produce written reports, oral presentations, and prototypes appropriate for the project.

Prerequisites: BIOE 110 and BIOE 210 and (CHE 031 or MECH 003 or ECE 081)

Can be taken Concurrently: BIOE 210
BIOE 212 (ENGR 212, MAT 212, ME 212) Capstone Design Project II 2 Credits
Students continue developing their solutions from BIOE 211 through prototype fabrication and testing, iteration, and failure mode analysis. New information about the project, as well as new knowledge, standards, and constraints, may be identified, considered and integrated into the solution. Teams are expected to produce a final project-specific prototype, an implementation plan appropriate to the project, as well as related business case financial models. Additional deliverables include written reports and presentations.
Prerequisites: BIOE 211 and BIOE 225
Can be taken Concurrently: BIOE 225

BIOE 225 GMP Good manufacturing practice and regulatory affairs for bioengineers 1 Credit
Review of the principles of the Food and Drug Administration including its history, mission and applied regulations. Understanding of how the FDA works with industry and is integral to the development of new products and technologies. Review and critique of case studies in various parts of the biomedical industry to see how FDA regulations are applied. Validation and analysis of products using failure mode analysis.
Prerequisites: BIOE 110

BIOE 226 Ethics in Bioengineering Practice 1 Credit
Introduction to ethical principles and role of critical thinking in ethical decision-making. Analysis of contemporary issues in bioengineering practice. Topics include biomedical device risk and failure, ethics of clinical trials, animal research, human enhancement, and research conduct.

BIOE 242 Bioengineering Research 1-4 Credits
Research on a topic chosen by students, with a faculty advisor typically from the three bioengineering tracks (biopharmaceutical engineering, bioelectronic/biophotonics or biomechanics and biomaterials). Independent meetings with advising professor will track progress. Includes written reports and/or oral presentations. Consent of instructor required.
Repeat Status: Course may be repeated.

BIOE 246 Bioengineering Thermodynamics 4 Credits
Engineering thermodynamics principles and their application to biological systems. Fundamental thermodynamics concepts, first and second law principles, conservation laws, properties of pure substances and biochemical mixtures under physiological conditions, energy conversion systems, thermodynamic aspects of biological processes.
Prerequisites: PHY 011 and MATH 022 and CHM 031
Can be taken Concurrently: CHM 031

BIOE 247 Biological Fluid Mechanics 4 Credits
Prerequisites: MATH 205

BIOE 257 Biomechanics and Biomaterials 3 Credits
Biomechanical analysis of tissues, microstructure of materials, force and mechanics in rigid and deformable bodies, analysis of biological response and biocompatibility, failure processes of implantable biomaterials/devices, strength of materials, and biomechanics of cells. Biomechanics and biomaterials concepts integrated (1) to examine the theoretical and practical implications of material properties and (2) to examine the biomechanical principles governing system behavior.
Prerequisites: MAT 033 and MECH 003 and MATH 205
Can be taken Concurrently: MATH 205

BIOE 290 Bioengineering Thesis 1-3 Credits
Thesis, guided by a faculty advisor, based on research and/or design projects. Independent meetings with advising professor to track progress. Consent of instructor required.
Prerequisites: BIOE 242 or TE 212

BIOE 300 Apprentice Teaching 1-4 Credits
Repeat Status: Course may be repeated.
BIOE 320 (CSE 320) Biomedical Image Computing and Modeling
3 Credits
Biomedical image modalities, image computing techniques, and imaging informatics systems. Understanding, using, and developing algorithms and software to analyze biomedical image data and extract useful quantitative information: Biomedical image modalities and formats; image processing and analysis; geometric and statistical modeling; image informatics systems in biomedicine. Credit will not be given for both BioE 320 and BioE 420.
Prerequisites: (MATH 205 or MATH 043) and CSE 017
Attribute/Distribution: ND

BIOE 321 Biomolecular & Cellular Mechanics 3 Credits
Mechanics and physics of the components of the cell, ranging in length scale from fundamental biomolecules to the entire cell. The course covers the mechanics of proteins and other biopolymers in 1D, 2D, and 3D structures, cell membrane structure and dynamics, and the mechanics of the whole cell.
Prerequisites: MATH 205 and MATH 231 and PHY 022 and (PHY 013 or PHY 021 or PHY 023)

BIOE 324 (MAT 324) Introduction to Organic Biomaterials 3 Credits
Property, characterization, fabrication and modification of organic materials for biomedical and biological applications; host responses to biomaterials on the molecular, cellular and system level; general introduction to biosensors, drug delivery devices and tissue engineering.
Prerequisites: BIOE 110

BIOE 325 (MAT 325) Inorganic Biomaterials 3 Credits
Fabrication methods for biomedical implants and devices. Selection of metals and ceramics with specific bulk and surface physical as well as chemical properties. The role of materials chemistry and microstructure. Biocompatibility. Case studies (dental and orthopedic implants, stents, nonporous ceramic filters for kidney dialysis).
Prerequisites: BIOE 110 or BIOE 325

BIOE 326 (MAT 326) Biomimetic and Bio-enabled Materials 3 Credits
The structure, function, properties and use of biopolymers, biocomposites, and biomaterials. Biomimetic materials design, including colloids, interfaces, macromolecules, and applications of such materials. Environmental and ethical considerations, such as degradation products when using biomimetic materials. Closed to students who have taken MAT 426 (BioE 426).
Prerequisites: MAT 033 or BIOE 110
Attribute/Distribution: ND

BIOE 331 Integrated Biotechnology Laboratory 2 Credits
Experiments in design and analysis of biotechnological circuits, micropatterning of biological cells, micromanipulation of biological cells using electric fields, analysis of pacemakers, instrumentation and computer interfaces, ultrasound, optical, laser tweezers and advanced imaging and optical microscopy techniques for biological applications.
Prerequisites: (ECE 081 or PHY 190) and (PHY 013 or PHY 021 or PHY 023) and PHY 022 and ECE 121 and ECE 123
Can be taken Concurrently: ECE 121, ECE 123

BIOE 339 Neuronal Modeling and Computation 3 Credits
Neuroscience in a computational, mathematical, and engineering framework. Literature surveys and case studies with simulations. Computational aspects of information processing within the nervous system by focusing on single neuron modeling. Single neurons and how their biological properties relate to neuronal coding. Biophysics of single neurons, signal detection and signal reconstruction, information theory, population coding and temporal coding.
Prerequisites: ENGR 010 and MATH 205

BIOE 341 (CHE 341) Biotechnology I 3 Credits
Applications of material and energy balances; heat, mass, and momentum transfer; enzyme and microbial kinetics; and mathematical modeling to the engineering design and scale-up of bio-reactor systems. Closed to students who have taken CHE 441 (BioE 341 and BioE 441).
Prerequisites: MATH 205 and CHE 031 and (CHM 031 or CHM 041)

BIOE 342 (CHE 342) Biotechnology II 3 Credits
Engineering design and analysis of the unit operations used in the recovery and purification of products manufactured by the biotechnology industries. Requirements for product finishing and waste handling will be addressed. Closed to students who have taken CHE 442 (BioE 342 and BioE 442).
Prerequisites: MATH 205 and CHE 031 and (CHM 031 or CHM 041)

BIOE 343 Integrated Biotechnology Laboratory 0.3 Credits
Biosafety, sterilization, media formulation, biochemical and enzyme assays, recombinant DNA technique, protein and DNA isolation and purification, for microbial fermentation and animal cell culture. Integration of biotechnology techniques for biopharmaceutical production. Consent of instructor required.
Prerequisites: BIOE 110 and (CHE 341 or BIOE 341)

BIOE 344 (CHE 344) Molecular Bioengineering 3 Credits
Kinetics in small systems, stochastic simulation of biochemical processes, receptor-mediated adhesion, dynamics of ion-channels, ligand binding, biochemical transport, surface Plasmon resonance, DNA microarray design, and chemical approaches to systems biology. Senior standing in BIOE.
Prerequisites: (MATH 205 and MATH 231)

BIOE 345 (CHE 345) Quantitative Biology 3 Credits
Basic concepts in molecular and cellular biology as well as biochemistry. Connects these to engineering principles to (1) develop a quantitative understanding of biological systems and (2) understand how modern engineering uses applications of methods and principles in biology. Topics include quantity and length scales in biology, use of statistical mechanics to describe phenomena such as microstates and ligand receptor binding, and application of chemical reaction kinetics to describe biochemical reactions. Closed to students who have taken BIOE 445.
Prerequisites: MATH 205

BIOE 348 Cardiovascular Bioengineering 3 Credits
Review of current and emerging trends in cardiac and vascular device development. Topics include cardiovascular anatomy and physiology principles, molecular and systemic basis of cardiovascular pathologies, techniques for diagnosis and surgical management of select disease manifestations. Medical, bioengineering and biologic parameters influencing the design and selection of interventional devices and endovascular prosthetics, as well as the engineering tools necessary for their evaluation. Consideration of factors contributing to device failure and state of the art in experiments and human clinical trials.
Prerequisites: BIOE 210 and BIOE 247

BIOE 349 Metabolic Engineering 3 Credits
Prerequisites: MATH 205

BIOE 350 Special Topics 1-4 Credits
Special topics of study in bioengineering. Permission of Instructor.
Repeat Status: Course may be repeated.

BIOE 357 Integrated Biostuctural Mechanics Laboratory 3 Credits
Experimental manipulation and analysis of mammalian cells, with a focus on the biomechanical properties of cells, the interface of living and non-living materials, and on bioengineering applications. Experimental techniques include mammalian cell culture, advanced microscopy techniques, preparation of bioactive substrates, microfluidic device fabrication, micropatterning of cells and cell growth in 3D matrices. Consent of instructor required.
Prerequisites: BIOE 110
BIOE 358 Biomechanics 3 Credits
Applications of mechanics to study behavior of anatomical structures and biological tissues of the musculoskeletal system. Specific topics include structure and function of biological tissues, mechanical properties of biological tissues, and analysis of specific tissues (i.e. bone, muscle, and soft connective tissues).
Prerequisites: MECH 003
Can be taken Concurrently: MECH 003

BIOE 359 Biomechanics Laboratory 1 Credit
Applications of mechanics to study behavior of anatomical structures and biological tissues of the musculoskeletal system. Specific topics include structure and function of biological tissues, mechanical properties of biological tissues, and analysis of specific tissues (i.e. bone, muscle, and soft connective tissues).
Prerequisites: MECH 003 and BIOE 358
Can be taken Concurrently: MECH 003, BIOE 358

BIOE 363 (CHE 363) Numerical Methods for Scientists and Engineers 3 Credits
Introduction to numerical methods in science and engineering. Expose students to the numerical solution of a variety of commonly encountered problems, enhance their numerical programming skills, and provide a broad base on which to build more specialized knowledge of computational methods. Topics include solution of linear and nonlinear sets of algebraic equations, linear and logistic regression, ordinary differential equations, Fourier analysis, eigenvalues, partial differential equations by finite difference and finite element methods.
Prerequisites: MATH 205

BIOE 366 (ECE 366) Neural Engineering 3 Credits
Neural system interfaces for scientific and health applications. Basic properties of neurons, signal detection and stimulation instrumentation and microfabricated electrode arrays. Fundamentals of peripheral and central neural signals and EEG, and applications such as neural prostheses, implants and brain-computer interfaces.
Closed to students who have taken BIOE 466, ECE 366, or ECE 466.
Prerequisites: ECE 081

BIOE 367 (CHE 367) Engineering in Medicine 3 Credits
Introduction to the physical basis of disease. Discussion of biomolecular strategies to overcome these changes. Topics include drug delivery, targeting, and tissue engineering, with a focus on infectious disease, cancer, cardiovascular disease, and neurodegenerative disease. Closed to students who have taken CHE 467 (BIOE 367 and BIOE 467).

BIOE 368 (ECE 368) Introduction to Biophotonics and Optical Biomedical Imaging 3 Credits
Optical principles, techniques, and instruments used in biomedical research and clinical medicine. Fundamental concepts of optical imaging and spectroscopy systems, and details of light-tissue interaction. Commercial devices and instruments, as well as novel optical imaging technologies in development. Closed to students who have taken BIOE 468, ECE 368, or ECE 468.
Prerequisites: ECE 202 or PHY 212

BIOE 369 (CHE 369) Advanced Topics in Regulatory Affairs 3 Credits
Regulatory requirements for the development and manufacture of 21st century medical products. Current challenges and innovative technologies in pharmaceuticals and medical devices. Topics include combination products, biosimilars, cell therapeutics, mobile medical applications, 3D-printed products, big data in healthcare, new approaches to process validation. Closed to students who have taken BIOE/CHE 469.
Prerequisites: BIOE 225

BIOE 380 (BIOS 380) Biomolecular & Cellular Biophysics 3-4 Credits
Physical principles of biomolecular and cellular organization. Biomolecular interactions and recognition, molecular motors, physical organization and functioning of cellular membranes, electrical signaling in live cells. Modern techniques in biophysics, molecular spectroscopy, molecular modeling, florescence imaging, electrophysiology, electron microscopy.
Prerequisites: (BIOS 115) and (PHY 013 or PHY 021)

BIOE 407 (CSE 407) Structural Bioinformatics 3 Credits
Computational techniques and principles of structural biology used to examine molecular structure, function, and evolution. Topics include: protein structure alignment and prediction; molecular surface analysis; statistical modeling; QSAR; computational drug design; influences on binding specificity; protein-ligand, -protein, and –DNA interactions; molecular simulation, electrostatics. This course, a version of 307 for graduate students, requires advanced assignments and a collaborative project. Credit will not be given for both BIOE 307 and 407. Consent of instructor required.

BIOE 408 (CSE 408) Bioinformatics: Issues and Algorithms 3 Credits
Computational problems and their associated algorithms arising from the creation, analysis, and management of bioinformatics data. Genetic sequence comparison and alignment, physical mapping, genome sequencing and assembly, clustering of DNA microarray results in gene expression studies, computation of genomic rearrangements and evolutionary trees. This course, a version of 308 for graduate students requires advanced assignments. Credit will not be given for both BIOE 308 (CSE 308) and BIOE 408 (CSE 408). No prior background in biology is assumed.
Prerequisites: CSE 017 or CSE 018
Attribute/Distribution: ND

BIOE 409 Bioengineering Applications in Machine Learning 3 Credits
This course is a graduate-level version of BIOC 309. While the lecture content will be the same as the 300-level course, students enrolled in BIOE 409 will have more advanced assignments. Closed to students who have taken BIOC 309.

BIOE 410 Advanced Engineering Physiology 3 Credits
This course is a graduate-level version of BIOE 310. While the lecture content will be the same as the 300-level course, students enrolled in BIOE 410 will have more advanced assignments. Closed to students who have taken BIOE 310.

BIOE 411 (MAT 411) Introductions to Biomaterials 3 Credits
Application of materials science and engineering principles to biomaterials with a focus on polymers, ceramics, and metals. Synthesis and fabrication of biomaterials, structure-property-function relationships related to biocompatibility and bioactivity; nano- to macro-scale characterization; material-tissue interactions; and applications of biomaterials including implants, devices, drug delivery, tissue engineering and regenerative medicine. MAT 411 will require project-based study. Credit will not be given for both MAT 311 and MAT 411.
Prerequisites: MAT 033

BIOE 415 Bioengineering Statistics 3 Credits
Advanced methods in probability and statistics applied to bioengineering problems focusing on modeling and data analysis. Topics include the following: types of data, types of distributions, parametric and nonparametric analyses, goodness-of-fit, regression, power analysis, and multivariate analysis, life models, simulation, cluster analysis, and Bayesian statistics. Special emphasis is placed on projects and case studies. Credit can not be received for both BIOE/ME 315 and BIOE 415.

BIOE 416 Introduction to Force Spectroscopy 3 Credits
This course is a graduate version of BIOE 316 (ME 316). While the lecture content will be the same as the 300-level course, students in the 400-level class will be expected to complete more advanced assignments. Closed to students who have taken BIOE 316 (ME 316).
BIOE 417 (CHE 417, MAT 417) Soft Materials: Mechanics and Physics 3 Credits
Physical and mechanical behavior of soft materials such as gels, foams, rubbers, soft adhesives, and most biological tissue. Large strain kinematics, stress measures, constitutive relations from the molecular and continuum points of view, and application to problems such as cavitation, freezing, thin structures, fracture, adhesion, surface stress, and electroactive materials.
Prerequisites: CHE 452 or ENGR 452

BIOE 418 (CHE 418, MAT 418) Soft Materials: Rheology and Characterization 3 Credits
See the course description listed for CHE/BIOE/MAT 318. In order to receive 400-level credits, the student must do an additional, more advanced term project, as defined by the instructor at the beginning of the course. Closed to students who have taken CHE/BIOE/MAT 318.

BIOE 420 (CSE 420) Biomedical Image Computing and Modeling 3 Credits
Biomedical image modalities, image computing techniques, and imaging informatics systems. Understanding, using, and developing algorithms and software to analyze biomedical image data and extract useful quantitative information: Biomedical image modalities and formats; image processing and analysis; geometric and statistical modeling; image informatics systems in biomedicine. This course, a graduate version of BioE 320, requires additional advanced assignments. Credit will not be given for both BioE 320 and BIOE 420.
Prerequisites: MATH 205 and CSE 109
Attribute/Distribution: ND

BIOE 421 (CHE 421) Biomolecular & Cellular Mechanics 3 Credits
Mechanics and physics of cell components, from fundamental biomolecules to the entire cell. The mechanics of proteins and other biopolymers in 1D, 2D, and 3D structures, cell membrane structure and dynamics, and the mechanics of the whole cell. This course is a graduate version of ChE 321 (BioE/Phy 321). The lecture content will be the same as in ChE 321 (BioE/Phy 321), but students enrolled in ChE 421 (BioE 421) will have more advanced assignments. Closed to students who have completed ChE 321 (BioE/Phy 321). Must have graduate standing.

BIOE 424 (MAT 424) Introduction to Organic Biomaterials 3 Credits
Property, characterization, fabrication, and modification of organic materials for biomedical and biological applications; host responses to biomaterials on the molecular, cellular, and system level; general introduction to biosensors, drug delivery, and tissue engineering. Graduate version of BioE 324 requiring additional assignments. Credit is not given for both BioE 324 (MAT 324) and BioE 424 (MAT 424).
Prerequisites: MAT 303

BIOE 425 (MAT 425) Inorganic Biomaterials 3 Credits
Fabrication methods for biomedical implant and devices. Selection of metals and ceramics with specific bulk and surface physical as well as chemical properties. The role of materials chemistry and microstructure. Biocompatibility. Case studies (dental and orthopedic implants, stents, nonporous ceramic filters for kidney dialysis). Graduate version of MAT 325; credit will not be given for both MAT 325 and MAT 425.
Prerequisites: MAT 303

BIOE 426 (MAT 426) Biomimetic and Bio-enabled Materials 3 Credits
This course is a graduate version of BIOE 326 (MAT 326). While the lecture content will be the same as the 300-level course, students enrolled in BIOE 426 (MAT 426) will have more advanced assignments. Closed to students who have taken BIOE 326 (MAT 326). Must have graduate standing in Bioengineering or Materials Science and Engineering.
Attribute/Distribution: ND

BIOE 439 (CHE 439) Neuronal Modeling and Computation 3 Credits
This course is a graduate version of BIOE 339 (CHE 339). While the lecture content will be the same as the 300-level course, students in the 400-level class will be expected to complete an independent term project. Closed to students who have completed BIOE 339 (CHE 339). Must have graduate standing in Bioengineering or Chemical Engineering.

BIOE 441 (CHE 441) Biotechnology I 3 Credits
See the course description listed for BioE 341. In order to receive 400-level credits, the student must do an additional, more advanced term project, as defined by the instructor at the beginning of the course. Closed to students who have taken BioE 341 (CHE 341).

BIOE 442 (CHE 442) Biotechnology II 3 Credits
See the course description listed for BIOE 342 (CHE 342). In order to receive 400-level credit, the student must do an additional, more advanced term project, as defined by the instructor at the beginning of the course. Closed to students who have taken BIOE 342 (CHE 342).

BIOE 445 (CHE 445) Quantitative Biology 3 Credits
This course is a graduate-level version of BIOE 345. While the lecture content will be the same as the 300-level course, students enrolled in BIOE 445 will have more advanced assignments. Closed to students who have taken BIOE 345.

BIOE 447 (CHE 447) Molecular Bioengineering 3 Credits
This course is a graduate version of CHE 344 (BioE 344). While the lecture content will be the same as the 300-level course, students enrolled in CHE 447 will have more advanced assignments. Closed to students who have completed CHE 344 (CHE 344).

BIOE 448 Cardiovascular Bioengineering 3 Credits
This course is a graduate-level version of BIOE 348. While the lecture content will be the same as the 300-level course, students enrolled in BIOE 448 will have more advanced assignments. Closed to students who have taken BIOE 448.

BIOE 449 Metabolic Engineering 3 Credits
This course is a graduate version of BIOE 349. While the lecture content will be the same as the 300-level course, students enrolled in BIOE 449 (CHE 449) will have more advanced assignments. Closed to students who have completed BIOE 349. Must have graduate standing in Chemical Engineering or Bioengineering.

BIOE 450 Special Topics 1-3 Credits
Special topics of study in bioengineering. Permission of instructor.

BIOE 451 Bioengineering Research Projects 1-6 Credits
Bioengineering-related research projects, based upon faculty and student interest. Projects may involve interaction with industry or local communities. Department permission required. A maximum of 6 credits of BIOE 451 can be used toward degree requirements. Repeat Status: Course may be repeated.

BIOE 452 (CHE 452, ENGR 452, ME 452) Mathematical Methods In Engineering I 3 Credits
Analytical techniques relevant to the engineering sciences are described. Vector spaces; eigenvalues; eigenvectors. Linear ordinary differential equations; diagonalizable and non-diagonalizable systems. Inhomogeneous linear systems; variation of parameters. Non-linear systems; stability; phase plane. Series solutions of linear ordinary differential equations; special functions. Laplace and Fourier transforms; application to partial differential equations and integral equations. Sturm-Liouville theory. Finite Fourier transforms; planar, cylindrical, and spherical geometries.

BIOE 453 Professional Development for Bioengineers 1 Credit
This course, designed for students enrolled in a Master’s program in Bioengineering, provides the professional skills necessary to prepare students for full-time employment in industry, or alternatively, for enrollment in a doctoral program towards a research career. Topics covered include resume development, networking and interviewing skills, awareness of current and emerging professional opportunities, biomedical ethics, and technical/scientific communication.
BIOE 490 Scienctific and Professional Communications for Bioengineers 3 Credits
Development and practice of critical reading skills through study of articles in the current bioengineering literature, including their societal, regulatory, and real-world context. Build capabilities in analytical and creative thinking and scientific communication, including best practices for presenting data for journal articles, writing research proposals, presenting professional talks and seminars, and understanding the manuscript and proposal review process. Formulate an individual development plan to guide technical and professional development, and provide a framework for communicating with advisers, mentors, and colleagues.

BIOE 456 (CHE 456) Stochastic Processes: Theory and Applications in Biology 3 Credits
Stochastic, or probabilistic, models of cellular processes and other biological systems to describe the inherent randomness of nature. Topics covered include theory and biological applications of Markov chains, the Master Equation, white noise and stochastic integrals, the Fokker-Planck Equation, and noise in gene expression. Some minimal experience in programming and/or Mathematica/Matlab.
Prerequisites: MATH 205

BIOE 463 (CHE 463) Numerical Methods for Scientists and Engineers 3 Credits
See the course description listed for ChE 363 (BIOE 363). This course is graduate version of ChE 363 (BIOE 363). The lecture content will be the same as ChE 363 (BIOE 363), but students enrolled in ChE 463 (BIOE 463) will have more advanced assignments. Closed to students who have taken ChE 363 (BIOE 363). Must have graduate standing or consent of the instructor.

BIOE 466 (ECE 466) Neural Engineering 3 Credits
Neural system interfaces for scientific and health applications. Basic properties of neurons, signal detection and stimulation, instrumentation and microfabricated electrode arrays. Fundamentals of peripheral and central neural signals and EEG, and applications such as neural prostheses, implants and brain-computer interfaces. Closed to students who have taken BIOE 366, ECE 366, or ECE 466. Students enrolled in the course at the 400-level must complete additional advanced assignments, as defined by the course instructor.

BIOE 467 (CHE 467) Engineering in Medicine 3 Credits
See the course description listed for CHE 367 (BIOE 367). In order to receive 400-level credits, the student must do an additional, more advanced term project, as defined by the instructor at the beginning of the course. Closed to students who have taken CHE 367 (BIOE 367), or BIOE 467.

BIOE 468 (ECE 468) Introduction to Biophotonics and Optical Biomedical Imaging 3 Credits
Optical principles, techniques, and instruments used in biomedical research and clinical medicine. Fundamental concepts of optical imaging and spectroscopy systems, and details of light-tissue interaction. Commercial devices and instruments, as well as novel optical imaging technologies in development. Closed to students who have taken BIOE 368, ECE 368, or ECE 468. Students enrolled in the course at the 400-level must complete additional advanced assignments, as defined by the course instructor.

BIOE 469 (CHE 469) Advanced Topics in Regulatory Affairs 3 Credits
This course is a graduate version of BIOE 369 (CHE 369). While the lecture content will be the same as the 300-level course, students enrolled in BIOE 469 (CHE 469) will have more advanced assignments. Closed to students who have taken BIOE/CHE 369.

BIOE 490 Thesis 1-6 Credits
Repeat Status: Course may be repeated.

BIOE 499 Dissertation 1-12 Credits
Biocomputational Engineering Courses
BIOC 213 Fundamentals of Biomedical Signals 3 Credits
Fundamentals of analysis of data obtained from common quantitative techniques, including imaging, EEG, cardiograms, and bioinformatics. Introduction to sampling, Fourier transforms, filters, clustering, and classification. Common tools for data processing and application of programming.
Prerequisites: MATH 205 and PHY 021 and BIOE 210
Can be taken Concurrently: BIOE 210

BIOC 214 Fundamentals of Biological Modeling 3 Credits
Introduction to quantitative biology approaches through modeling. Practical methods of applying basic mathematical modeling and programming. Topics include linear and non-linear models, DNA and protein structures, ligand-receptor binding, reaction kinetics, electrical and mechanical cell dynamics, gene regulatory models, and fundamentals of epidemiology.
Prerequisites: MATH 205 and CSE 017 and PHY 021

BIOC 237 (BIOS 237) Introductory Molecular Modeling and Simulation 3 Credits
Key concepts, methods, and tools used in molecular modeling and simulation. A hybrid lecture/hands-on practice course using the lectures and tools in CHARMM-GUI (http://www.charmm-gui.org/lecture). Topics include (but not limited to) UNIX operating system, text editors, Python programming, scientific programming using Python, PDB (Protein Data Bank), molecular mechanics, minimization, molecular dynamics, Monte Carlo simulation. The understanding of these concepts and algorithms as well as their applications to well-defined practical examples involving currently important biological problems will be emphasized. Key concepts, methods, and tools used in molecular modeling and simulation. A hybrid lecture/hands-on practice course using the lectures and tools in CHARMM-GUI (http://www.charmm-gui.org/lecture). Topics include (but not limited to) UNIX operating system, text editors, Python programming, scientific programming using Python, PDB (Protein Data Bank), molecular mechanics, minimization, molecular dynamics, Monte Carlo simulation. The understanding of these concepts and algorithms as well as their applications to well-defined practical examples involving currently important biological problems will be emphasized.
Prerequisites: CHM 030 or CHM 040
Attribute/Distribution: NS

BIOC 240 Biocomputational Engineering - Capstone 1 3 Credits
Students work in teams on design projects in which they will integrate and apply concepts from numerous courses in the Biocomputational Engineering curriculum. Projects have constraints, including technical feasibility, engineering standards, and economic analysis, as well as global and/or social impact.
Prerequisites: BIOC 214 and BIOC 236

BIOC 241 Biocomputational Engineering - Capstone 2 3 Credits
Students continue their work on Biocomputational Engineering design projects from BIOC 240. Designs from the previous semester will be further developed, such that they have more technical depth and adhere to established constraints and standards.
Prerequisites: BIOC 240

BIOC 309 Bioengineering Applications in Machine Learning 3 Credits
Introduction to machine learning and AI techniques as well as their applications in biomedical data quantification, prediction, and visualization. Topics include principles of bioengineering data modalities and systems, fundamentals of machine learning approaches for biomedical data analysis, such as denoising, standardization, statistical analysis, dimensionality reduction, predictive modeling, as well as computational tools for implementing AI methods.
Prerequisites: MATH 205 and PHY 021