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 populations at risk of diseases, shore up health care data acquisition methods and security, and design clinical research trials, among other and not-yet-conceived applications.

For more information, please visit our website: http://www.lehigh.edu/bioe/

UNDERGRADUATE PROGRAMS

PROGRAM EDUCATIONAL OBJECTIVES

The Bioengineering Department has established the following set of Program Educational Objectives for our undergraduate programs. Several years after graduation, we expect that:

1. Graduates in professional practice function effectively as responsible and collaborative professionals in Bioengineering/Biocomputational Engineering, or in a related field.

2. Graduates engage in lifelong learning.

STUDENT OUTCOMES

The Bioengineering Department has established that by graduation students will attain:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors

3. an ability to communicate effectively with a range of audiences

4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

BIOENGINEERING

DESCRIPTION

The B.S. in Bioengineering degree provides a structured curriculum comprised of three tracks. Biopharmaceutical Engineering is for students whose interests lie in genomics, proteomics, bioinformatics, recombinant DNA, protein engineering, bioprocessing, drug synthesis and delivery. The Bioelectronics/photonics track covers education and research dealing with signal processing, biosensors, MEMs, biochips for DNA sequencing, laser and fiber based optical technology for biomedical applications. The Biomechanics and Biomaterials track encompasses applications of engineering principles to an understanding of biology and physiology, ranging from cells and tissues to organs and systems.

The B.S. in Bioengineering will prepare students for careers in established and emerging fields that require combining engineering principles with the life sciences. Potential paths open to students include the health care, biomedical, pharmaceutical, biomaterials, and other biotechnology related industries through careers in medicine or graduate studies.

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 [1]	3
MATH 231	Probability and Statistics [1]	3
Natural Sciences		
CHM 030	Introduction to Chemical Principles	4

CHM 031	Chemical Equilibria in Aqueous Systems	4
CHM 110 & CHM 111	Organic Chemistry I and Organic Chemistry Laboratory I	4
PHY 011 & PHY 012	Introductory Physics I and Introductory Physics Laboratory I	5
PHY 021 & PHY 022	Introductory Physics II and Introductory Physics Laboratory II	5
BIOS 041 & BIOS 042	Introduction to Cellular and Molecular Biology 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	
or PHIL 105	Ethics	
Bioengineering Technical Electives [2]		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	
MAT 033	Engineering Materials and Processes	3
CHM 112	Organic Chemistry II	3
BIOE 2XX elective [3]		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
BIOC 213	Fundamentals of Biomedical Signals	3
ECE 123 & ECE 121	Electronic Circuits and Electronic Circuits Laboratory	5
ECE 202	Introduction to Electromagnetics	3
MECH 003	Fundamentals of Engineering Mechanics	3
MAT 033	Engineering Materials and Processes	3
Math-intensive elective [4]		3
Biomechanics and Biomaterials Track		
MECH 003	Fundamentals of Engineering Mechanics	3
MAT 033	Engineering Materials and Processes	3
BIOE 025	Computer-aided Design for Bioengineers	3
BIOE 246	Bioengineering Thermodynamics	4
BIOE 247	Biological Fluid Mechanics	4
BIOE 257	Biomechanics	3
BIOE 311	Introduction to Biomaterials	3
BIOE 357	Integrated Biostructural Mechanics Laboratory	3
Math-intensive elective [4]		3

1

All students must achieve a minimum of a C- in both MATH 205 and MATH 231 for the B.S. in Bioengineering.

2

All students must take nine (9) credits of technical electives. Three (3) of the nine credits must be BIOE electives at the 300-level or higher. The remaining six (6) credits may be engineering courses (any program) at the 200-level or higher, and/or BIOS/CHM/PHY/MATH courses at the 200-level or higher. Other classes that may contribute to the remaining six credits include: BIOE 020, BIOE 025 (when not a requirement), CSE 003, CSE 004, CSE 007, CSE 012, CSE 017, PHY 121, PHY 122, PHY 123, CHM 112 (when not a requirement), CHM 113, BIOS 115, BIOS 116.
Excluded courses: Courses in professional development, writing, and other non-technical subjects; seminars; BIOS 235.

3

Students in the Biopharmaceutical Engineering track must take one BIOE elective at the 200-level or higher that is not required for their major or track. Excluded courses: BIOE 242, BIOE 290.

4

Select one of the following math-intensive electives: BIOE 315, BIOE 321, BIOE 341, BIOE 345, BIOE 349, BIOE 363, BIOC 213, BIOC 309, or ECE 337.

TYPICAL FOUR-YEAR COURSE SCHEDULE FOR BS IN BIOENGINEERING

BIOPHARMACEUTICAL ENGINEERING TRACK

Freshman

Fall	Credits	Spring	Credits
ENGR 005	2	MATH 022	4
ENGR 010	2	BIOS 041 & BIOS 042	4
MATH 021	4	ENGL 002	3
ENGL 001	3	Select one from the following:[1]	4-5
Select one from the following:[1]	4-5	CHM 030	-
CHM 030	-	PHY 011 & PHY 012	-
PHY 011 & PHY 012	-		
	15-16		**15-16**

Sophomore

Fall	Credits	Spring	Credits
BIOE 110	4	BIOE 210	4
CHE 031	3	BIOE 246	4
MATH 023	4	MATH 205	3
PHY 021 & PHY 022	5	CHM 031	4
	16		**15**

Junior

Fall	Credits	Spring	Credits
BIOE 225	1	BIOE 211	3
BIOE 341	3	BIOE 247	4
MATH 231	3	CHM 112	3
CHM 110 & CHM 111	4	ECO 001	4
Technical elective 1	3	HSS 2	4

HSS 1	4		
	18		**18**

Senior

Fall	Credits	Spring	Credits
BIOE 212	2	BIOE 226	1
BIOE 343	3	BIOE 2XX elective	3
BIOE 349	3	Technical elective 3	3
MAT 033	3	HSS 4	4
Technical elective 2	3	Free electives	5
HSS 3	4		
	18		**16**

Total Credits: 131-133

1

One course is taken in the fall and the other course is taken in the spring. Consult your adviser.

BIOELECTRONICS/BIOPHOTONICS TRACK

Freshman

Fall	Credits	Spring	Credits
ENGR 005	2	MATH 022	4
ENGR 010	2	BIOS 041 & BIOS 042	4
MATH 021	4	ENGL 002	3
ENGL 001	3	Select one of the following:[1]	4-5
Select one from the following:[1]	4-5	CHM 030	-
CHM 030	-	PHY 011 & PHY 012	-
PHY 011 & PHY 012	-		
	15-16		**15-16**

Sophomore

Fall	Credits	Spring	Credits
BIOE 110	4	BIOE 210	4
ECE 081	4	ECE 123 & ECE 121	5
MATH 023	4	MATH 205	3
PHY 021 & PHY 022	5	CHM 031	4
		Free electives	2
	17		**18**

Junior

Fall	Credits	Spring	Credits
BIOE 025	3	BIOE 211	3
BIOE 225	1	BIOE 331	2
MECH 003	3	BIOC 213	3
MAT 033	3	MATH 231	3
CHM 110 & CHM 111	4	ECO 001	4
HSS 1	4		
	18		**15**

Senior

Fall	Credits	Spring	Credits
BIOE 212	2	BIOE 226	1
ECE 202	3	Math-intensive elective	3
Technical elective 1	3	Technical elective 3	3
Technical elective 2	3	HSS 3	4
HSS 2	4	HSS 4	4
Free electives	3		
	18		**15**

Total Credits: 131-133

1

One course is taken in the fall and the other course is taken in the spring. Consult your adviser.

BIOMECHANICS AND BIOMATERIALS TRACK

Freshman

Fall	Credits	Spring	Credits
ENGR 005	2	MATH 022	4
ENGR 010	2	BIOS 041 & BIOS 042	4
MATH 021	4	ENGL 002	3
ENGL 001	3	Select one from the following:[1]	4-5
Select one of the following:[1]	4-5	CHM 030	-
CHM 030	-	PHY 011 & PHY 012	-
PHY 011 & PHY 012	-		
	15-16		**15-16**

Sophomore

Fall	Credits	Spring	Credits
BIOE 110	4	BIOE 210	4
MECH 003	3	BIOE 246	4
MATH 023	4	MAT 033	3
PHY 021 & PHY 022	5	MATH 205	3
		CHM 031	4
	16		**18**

Junior

Fall	Credits	Spring	Credits
BIOE 025	3	BIOE 211	3
BIOE 225	1	BIOE 247	4
BIOE 311	3	BIOE 257	3
CHM 110 & CHM 111	4	BIOE 357	3
HSS 1	4	MATH 231	3
Free electives	2		
	17		**16**

Senior

Fall	Credits	Spring	Credits
BIOE 212	2	BIOE 226	1
ECO 001	4	Math-intensive elective	3
Technical elective 1	3	Technical elective 3	3
Technical elective 2	3	HSS 3	4
HSS 2	4	HSS 4	4
		Free electives	3
	16		**18**

Total Credits: 131-133

[1]

One course is taken in the fall and the other course is taken in the spring. Consult your adviser.

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		
ENGR 005	Introduction to Engineering Practice	2
ENGR 010	Applied Engineering Computer Methods	2
ECO 001	Principles of Economics	4
BIOE 226	Ethics in Bioengineering Practice	1
or PHIL 105	Ethics	
or PHIL 116	Bioethics	
Electives to satisfy depth and breadth requirements		13
Free electives		
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
BIOS 041 & BIOS 042	Introduction to Cellular and Molecular Biology and Introduction to Cellular and Molecular Biology Laboratory	4
BIOS 115 & BIOS 116	Genetics and Genetics Laboratory	4
PHY 011 & PHY 012	Introductory Physics I and Introductory Physics Laboratory I	5
PHY 021 & PHY 012	Introductory Physics II and Introductory Physics Laboratory I	5
Biocomputational Engineering Core Requirements		
CSE 007	Introduction to Programming	4
CSE 017	Programming and Data Structures	3
CSE 308	Bioinformatics: Issues and Algorithms	3
BIOE 210	Introduction to Engineering Physiology	4
BIOE 345	Quantitative Biology	3
BIOE 363	Numerical Methods for Scientists and Engineers	3
or PHY 380	Introduction to Computational Physics	
BIOC 211	Capstone Design Project I	3
BIOC 212	Capstone Design Project II	2
BIOC 213	Fundamentals of Biomedical Signals	3
BIOC 237	Introductory Molecular Modeling and Simulation	3
BIOC 309	Bioengineering Applications in Machine Learning	3
ISE 240	Introduction to Deterministic Optimization Models in Operations Research	3
ISE 172	Algorithms in Systems Engineering	4
Technical electives [1]		**9**

[1]

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, and/or CHM 110/111/112/113.
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

Fall	Credits	Spring	Credits
ENGR 005	2	MATH 022	4
ENGR 010	2	PHY 011 & PHY 012	5
MATH 021	4	ENGL 002	3
CHM 030	4	ECO 001	4
ENGL 001	3		
	15		**16**

Sophomore

Fall	Credits	Spring	Credits
CSE 007	4	BIOC 237	3
MATH 205	3	CSE 017	3
PHY 021 & PHY 022	5	MATH 231	3
CHM 031	4	BIOS 041 & BIOS 042	4
		HSS 1	4
	16		**17**

Junior

Fall	Credits	Spring	Credits
BIOC 309	3	BIOE 210	4
ISE 240	3	BIOC 211	3
MATH 023	4	BIOC 213	3
BIOS 115 & BIOS 116	4	BIOE 363 or PHY 380	3
HSS 2	4	ISE 172	4
	18		**17**

Senior

Fall	Credits	Spring	Credits
BIOC 212	2	BIOE 226	1
Technical elective 1	3	BIOE 345	3
Technical elective 2	3	CSE 308	3
HSS 3	4	Technical elective 3	3

Free elective	5	HSS 4	4
	17		**14**

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.

BIOE 452	Mathematical Methods In Engineering I	3
BIOE 455	Scientific and Professional Communications for Bioengineers	3
BIOE 410	Advanced Engineering Physiology	3
or BIOE 445	Quantitative Biology	
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 electives 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) Biomaterials, (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. **Biomaterials**: The Biomaterials 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 Biomaterials) 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 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.

BIOE 452	Mathematical Methods In Engineering I	3
BIOE 453	Professional Development for Bioengineers	1
BIOE 410	Advanced Engineering Physiology	3
or BIOE 445	Quantitative Biology	
Bioengineering electives at the 300-level or higher		11
Adviser-approved technical electives		12
Total Credits		**30**

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 0,4 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 (BIOC 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 (BIOC 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 0,4 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 0,4 Credits
Fluid and mass transport and their applications in biological systems. Mass conservation. Momentum and energy balances in fluid flow. Incompressible fluid flow with inviscid and viscous applications. Dimensional analysis. Fluid flow in pipes and porous media. Diffusion and convection.
Prerequisites: MATH 205

BIOE 257 Biomechanics 3 Credits
Overview of biomechanics. Application of fundamental laws of mechanics to biological systems. Systems examined include: strength of materials, biomechanics of cells, biomechanical analysis of tissues, rigid body kinematics, microstructure of materials and resultant mechanical properties, concepts of force and mechanics of rigid and deformable bodies, and failure processes of implantable biomaterials/devices. Exposure to current research in the field.
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 307 (CSE 307) 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. Tutorials on UNIX systems and research software support an interdisciplinary collaborative project in computational structural biology. Credit will not be given for both CSE 307 and CSE 407. Must have junior standing or higher.
Prerequisites: BIOS 120 or CSE 109 or CHM 113 or MATH 231

BIOE 308 (CSE 308) 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. 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
Attribute/Distribution: ND

BIOE 310 Advanced Engineering Physiology 3 Credits
An in-depth examination of human physiological processes using a quantitative, model-oriented approach. Organ systems examined include the nervous, musculoskeletal, cardiovascular, respiratory, renal, immune, and endocrine systems. Mathematical models, computer simulations, and engineering analyses will be used to describe the performance of human organ systems and to study physiological processes.
Prerequisites: MATH 205 and BIOE 210

BIOE 311 (MAT 311) Introduction to Biomaterials 3 Credits
Application of materials science and engineering principles to biomedical materials 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.
Prerequisites: MAT 033

BIOE 315 (ME 315) 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.
Prerequisites: MATH 231

BIOE 316 (ME 316) Introduction to Force Spectroscopy 3 Credits
Fundamentals of major force spectroscopy methods, including atomic force microscopy, optical tweezers, and magnetic tweezers. Principles of force measurement, force calibration, and signal and noise. Applications to the mechanical properties of biomaterials, such as polymer elasticity, protein folding, nanoindentation, and structural transitions in macromolecules. Closed to students who have taken BIOE 416.
Prerequisites: MECH 003

BIOE 318 (CHE 318, MAT 318) Soft Materials: Rheology and Characterization 3 Credits
Characterization of soft materials using rheological techniques. Fundamentals of rheology and rheological characterization applied to materials such as polymers, glassy liquids and polymeric gels. Closed to students who have taken CHE/BIOE/MAT 418. Instructor permission or graduate status required.

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: MAT 033

BIOE 326 (MAT 326) Biomimetic and Bio-enabled Materials 3 Credits
The structure, function, properties and use of biopolymers, biocomposites, and biominerals. 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 Bioelectronics/Biophotonics Laboratory 2 Credits
Experiments in design and analysis of bioelectronics circuits, micropattering of biological cells, micromanipulation of biological cells using electric fields, analysis of pacemakers, instrumentation and computer interfaces, ultrasound, optic, 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
Quantitative perspective of cellular metabolism and biochemical pathways. Methods for analyzing stoichiometric and kinetic models, mass balances, flux in reaction networks, and metabolic control. Solving problems using advanced mathematics and computer programming.
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 Biostructural 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 370 (CHE 370) The Engineering of Brewing, Winemaking, and Distilling 0,3 Credits
An open-ended and experiential exploration of the engineering principles required for the brewing of beer, winemaking, and distilling of spirits.
Prerequisites: (BIOE 341 or CHE 211) and (BIOE 246 or CHE 212)

BIOE 372 Drug Delivery and Nanomedicine 3 Credits
Fundamental principles of controlled drug delivery, including drug release systems and their mechanisms, physiological barriers, and routes of delivery. Impact of nanotechnology on designing advanced drug delivery technologies, such as targeted drug therapies, controlled release systems for tissue engineering/ regenerative medicine, and non-viral gene delivery systems. Credit will not be given for both BIOE 372 and 472.
Prerequisites: MATH 022 and CHM 031

BIOE 373 Tissue Engineering and Regenerative Medicine 3 Credits
Introduction to tissue engineering and regenerative medicine principles used to develop potential treatments for broad range of injuries and pathologies. Building blocks for engineering tissues, including cells, biomaterials, and bioactive cues. Criteria for selection of cell source, scaffold design and fabrication methods, and tools for control of cellular microenvironment. Consideration of economic, social, and ethical aspects of tissue engineering. Credit will not be given for both BIOE 373 and BIOE 473.
Prerequisites: CHM 031

BIOE 383 Introduction to Bioimaging and Microscopy 0,3 Credits
Principles, technologies, and instrumentation of numerous modern imaging modalities, including X-ray, computed tomography, magnetic resonance imaging, ultrasound, and positron emission tomography. Fundamental concepts to advanced systems and their applications. Hands-on experience with advanced research microscopes and exposure to cutting edge imaging instrumentation. Discussion of articles in current literature. Credit will not be given for both BIOE 383 and BIOE 483.
Prerequisites: 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 BIOC 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 biomedical materials 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, creasing, 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 033

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 033

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 BioE 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 (CHE 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 455 Scientific 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 472 Drug Delivery and Nanomedicine 3 Credits
This course is a graduate-level version of BIOE 372. While the lecture content will be the same as BIOE 372, students enrolled in BIOE 472 will have more advanced assignments. Credit will not be given for both BIOE 372 and BIOE 472.

BIOE 473 Tissue Engineering and Regenerative Medicine 3 Credits
This course is a graduate-level version of BIOE 373. While the lecture content will be the same as BIOE 373, students enrolled in BIOE 473 will have more advanced assignments. Credit will not be given for both BIOE 373 and BIOE 473.

BIOE 483 Introduction to Bioimaging and Microscopy 0,3 Credits
This course is a graduate-level version of BIOE 383. While the lecture content will be the same as BIOE 383, students enrolled in BIOE 483 will have more advanced assignments. Credit will not be given for both BIOE 383 and BIOE 483.

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

BIOE 499 Dissertation 1-12 Credits

Biocomputational Engineering Courses

BIOC 211 (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: CSE 007 and BIOC 237
Can be taken Concurrently: BIOC 237

BIOC 212 (BIOE 212, ENGR 212, MAT 212, ME 212) Capstone Design Project II 0,2 Credits
Students continue developing their solutions from BIOC 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: BIOC 211 and BIOC 309
Can be taken Concurrently: BIOC 309

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