

## **Class Years 2017 and Beyond**

### **Undergraduate Program**

The objectives of the undergraduate program in biomedical engineering are as follows:

1. Professional employment in areas such as the medical device industry, engineering consulting, and biotechnology;
2. Graduate studies in biomedical engineering or related fields;
3. Attendance at medical, dental, or other health professional schools.

The undergraduate program in biomedical engineering at Columbia University will prepare graduates:

- (a) an ability to apply knowledge of mathematics, science, and engineering
- (b) an ability to design and conduct experiments, as well as to analyze and interpret data
- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- (d) an ability to function on multidisciplinary teams
- (e) an ability to identify, formulate, and solve engineering problems
- (f) an understanding of professional and ethical responsibility
- (g) an ability to communicate effectively
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- (i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

(l) an understanding of biology and physiology

(m) the capability to apply advanced mathematics (including differential equations and statistics), science, and engineering to solve the problems at the interface of engineering and biology

(n) the ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living materials and systems.

The undergraduate curriculum is designed to provide broad knowledge of the physical and engineering sciences and their application to the solution of biological and medical problems. Students are strongly encouraged to take courses in the order specified in the [accompanying charts](#); implications of deviations should be discussed with a departmental adviser before registration. The first two years provide a strong grounding in the physical and chemical sciences, engineering fundamentals, mathematics, and modern biology. This background is used to provide a unique physical approach to the study of biological systems. The last two years of the undergraduate program provide substantial exposure to fundamentals in biomedical engineering with emphasis in integration of principles of biomedical engineering, quantitative analysis of physiology, and experimental quantification and measurements of biomedical systems. The common core biomedical engineering curriculum provides a broad yet solid foundation in biomedical engineering. The flexible choice of technical electives in the department of biomedical engineering, other departments in the engineering school as well as in other departments in the arts and sciences allows students to broaden their biomedical engineering education to their individual interests for a personalized curriculum. These qualities allow the faculty to prepare students for activity in all contemporary areas of biomedical engineering. Graduates of the program are equipped for employment in the large industrial sector devoted to health care, which includes pharmaceuticals, medical devices, artificial organs, prosthetics and sensory aids, diagnostics, medical instrumentation, and medical imaging. Graduates also accept employment in oversight organizations (FDA, NIH, OSHA, and others), medical centers, and research institutes. They are prepared for graduate study in biomedical engineering and several related areas of engineering and the health sciences. Students can meet entrance requirements for graduate training in the various allied health professions. No more than three additional courses are required to satisfy entrance requirements for most U.S. medical schools.

All biomedical engineering students are expected to register for nontechnical electives, both those specifically required by the School of Engineering and Applied Science and those needed to meet the 27-point total of nontechnical electives required for graduation.

### **First and Second Years**

As outlined in this bulletin, in the first two years all engineering students are expected to complete a sequence of courses in mathematics, physics, chemistry, computer science, engineering, modern biology, English composition, and physical education, as well as nontechnical electives including the humanities. For most of these sequences, the students may choose from two or more tracks. If there is a question regarding the acceptability of a course as a nontechnical elective, please consult the [approved listing of courses](#) or contact your advising dean for clarification.

Please see the charts in this section for a specific description of course requirements.

For students who are interested in the biomedical engineering major, they must take *E1201: Introduction to Electrical Engineering*. For the computer science requirement, students must take *ENGI W1006*. They must take the two-semester *BIOL C2005* and *C2006, Introduction to Biology I & II* in the second year, which gives students a comprehensive overview of modern biology from molecular to organ system levels. In addition, all students must take *APMA E2101: Introduction to Applied Mathematics* in their second year.

### **Third and Fourth Years**

The biomedical engineering programs at Columbia at all levels are based on engineering and biological fundamentals. This is emphasized in our core requirements. All students must take the two-semester introduction to biomedical engineering course, *BMEN E3010* and *E3020 BME I & II*, which provide a broad yet solid foundation in biomedical engineering discipline. In parallel, all students take the two-semester Quantitative Physiology I and II sequence (*BMEN E4001-E4002*) which is taught by biomedical engineering faculty and emphasizes quantitative applications of engineering principles in understanding biological systems and phenomena from molecular to organ system levels. In the fields of biomedical engineering, experimental techniques and principles are fundamental skills that good biomedical engineers must master. Beginning in junior year, all students take the two-semester sequence Biomedical Engineering Laboratory I & II (*BMEN E3810, E3820*). In this two-semester series, students learn through hands-on experience the principles and methods of biomedical engineering experimentation, measurement techniques, quantitative theories of biomedical engineering, data analysis, and independent design of biomedical engineering experiments, in parallel to the *BME I & II* and *Quantitative Physiology I & II* courses. In addition, all students must take *BMEN E4110 Biostatistics for engineers*. In the senior year, students are required to take a two-semester capstone design course, Biomedical engineering design (*BMEN E3910*

and E3920), in which students work within a team to tackle an open-ended design project in biomedical engineering. The underlying philosophy of these core requirements is to provide our biomedical engineering students with a broad knowledge and understanding of topics in the field of biomedical engineering. Parallel to these studies in core courses, students are required to take flexible technical elective courses (21 points) to obtain an in-depth understanding of their chosen interests. A technical elective is defined as a 3000-level or above course taught in SEAS or 3000-level or above courses in Biology, Chemistry, or Biochemistry. At least fifteen points (five courses) of these technical electives must have engineering content while at least two of the five courses have to be from the department of biomedical engineering. The curriculum prepares students who wish to pursue careers in medicine by satisfying most requirements in the pre-medical programs with no more than three additional courses. Some of these additional courses may also be counted as non-engineering technical electives. Please see the [accompanying charts](#) for schedules leading to a bachelor's degree in biomedical engineering.

It is strongly advised that students take required courses during the specific term that they are designated in the course tables, as conflicts may arise if courses are taken out of sequence.

### Technical Elective Requirements

Students are required to take at least 48 points of engineering content course work toward their degree. The 48-point requirement is a criterion established by ABET. Taking into consideration the number of engineering content points conferred by the required courses of the BME curriculum, a portion of technical electives must be clearly engineering in nature (Engineering Content Technical Electives), specifically as defined below:

1. Technical elective courses with sufficient engineering content that can count toward the 48 units of engineering courses required for ABET accreditation:
  - a. All 3000-level or higher courses in the Department of Biomedical Engineering, except *BMEN E4010, E4103, E4104, E4105, E4106, E4107, and E4108*. (Note that only 3 points of *BMEN E3998* may be counted toward technical elective degree requirements.)
  - b. All 3000-level or higher courses in the Department of Mechanical Engineering, except *MECE E4007: Creative engineering and entrepreneurship*
  - c. All 3000-level or higher courses in the Department of Chemical Engineering, except *CHEN E4020: Safeguarding intellectual and business property*

- d. All 3000-level or higher courses in the Department of Electrical Engineering, except *EEHS E3900: History of telecommunications: from the telegraph to the Internet*
  - e. All 3000-level or higher courses in the Civil Engineering and Engineering Mechanics program, except *CIEN E4128, E4129, E4130, E4131, E4132, E4133, E4134, E4135, E4136, and E4140*
  - f. All 3000-level or higher courses in the Earth and Environmental Engineering program
2. Courses from the following departments are not allowed to count toward the required 48 units of engineering courses:
- a. Department of Applied Physics and Applied Mathematics
  - b. Department of Computer Science
  - c. Department of Industrial Engineering and Operations Research
  - d. Program of Materials Science and Engineering

Once 48 points of engineering content are satisfied, students may choose any course above the 3000 level in Columbia Engineering as well as biology, chemistry, and biochemistry as technical electives.

The [accompanying charts](#) describe the eight-semester degree program schedule of courses leading to the bachelor's degree in biomedical engineering.

BIOMEDICAL ENGINEERING PROGRAM: FIRST AND SECOND YEARS (CLASS 2017 BEYOND)				
	SEMESTER I	SEMESTER II	SEMESTER III	SEMESTER IV
<b>MATHEMATICS</b>	MATH V1102 (3) Calculus II	MATH V1201 (3) Calculus III	MATH V1202 (3) Calculus IV	
<b>PHYSICS</b> (Three tracks, choose one)	C1401 (3) —————→ C1601 (3.5) —————→ C2801 (4.5) —————→	C1402 (3) —————→ C1602 (3.5) —————→ C2802 (4.5)	C1403 (3) C2601 (3.5)	
<b>CHEMISTRY</b> (Three tracks, choose one)	CHEM C1403 (3.5) —————→ C1604 (3.5) —————→ C3045 (3.5) —————→	CHEM C1404 (3.5) C1500 (3) (or semester I) C2507 (3) C3046 (3.5), C2507 (3)		
<b>ENGLISH COMPOSITION</b>	C1010 (3) (or any semester)			
<b>COMPUTER SCIENCE</b>	ENGI W1006 (3) (or semester II)			
<b>PHYSICAL EDUCATION*</b>	C1001 (1)	C1002 (1)		
<b>THE ART OF ENGINEERING*</b>		ENGI E1102 (4) (or semester I)		
<b>NOTECHNICAL REQUIREMENTS*</b>	HUMA W1121 (3) or W1123 (3)		HUMA C1001, COCI C1101, or Global Core (3-4)	HUMA C1002, COCI C1102, or Global Core (3-4) ECON W1105 (4) and W1155 recitation (0)
<b>TECHNICAL REQUIREMENTS</b>			ELEN E1201 Intro. To EE (3.5)	APMA E1210 Intro. to Applied Math (3)
			BIOL C2005 Intro. to Biology I (4)	BIOL C2006 Intro. to Biology II (4)
<b>TOTAL POINTS</b>	19.5**	17.5**	17.5**	15**

\*Students can mix these requirements around according to what is available.

\*\*Estimation

BIOMEDICAL ENGINEERING PROGRAM: THIRD AND FOURTH YEARS (CLASS 2017 BEYOND)				
	SEMESTER V	SEMESTER VI	SEMESTER VII	SEMESTER VIII
REQUIRED COURSES	BMEN E3810 BME Laboratory I (3)	BMEN E3820 BME Laboratory II (3)	BMEN E3910 BME Design I (4)	BMEN E3920 BME Design II (4)
	BMEN E3010 BME I (3)	BMEN E3020 BME II (3)	Technical Elective (3)	Technical Elective (3)
	BMEN E4001 Quantitative Physiol. I (3)	BMEN E4002 Quantitative Physiol. II (3)	Technical Elective (3)	Technical Elective (3)
	BMEN E4110 Biostatistics for Engineers (3)	Technical Elective (3)	Technical Elective (3)	Technical Elective (3)
NONTECHNICAL ELECTIVES	3 points	3 points	3 points	
TOTAL POINTS	15	15	16	13

Five of seven technical electives must have engineering science contents and two of them must be taken from biomedical engineering department.

Estimated total credit points: 128.5

Estimated credit points with engineering contents: 51.5

The undergraduate Biomedical Engineering program is designed to provide a solid biomedical engineering through its core requirements while provide the flexible to individualized interests of students. The followings are suggested sample courses for various interest topics that students may consider, but not limited to those choices. All students are encouraged to design their own education paths through the flexible technical electives. Except (1) five of these seven electives must have engineering science contents and (2) two of these seven electives must be BME courses, students have the freedom to choose any combinations of courses above 3000 level. To help students to choose their electives, the following are some suggested sample courses in various interest fields in BME. Students do not need to follow them rigidly and can interchange with any courses that they would like.

#### Cellular Engineering and Tissue Engineering Sample Courses

CHEM C3443 Organic Chemistry I (3.5)

CHEM C3444 Organic Chemistry II (3.5)  
MBCH E3500 Biological Transport Process (3)  
BMEN E4501 Tissue Engineering I (3)  
BMEN E4502 Tissue Engineering II (3)  
BMEN E4210 Thermodynamics of Biological Systems (3)  
BMEN E4550 Micro- and Nanostructures in cellular engineering (3)

Biomechanics Sample Courses

EMEN E3105 Mechanics (4)  
MECE E3100 Mechanics of Fluids (3)  
MECE E3113 Mechanics of Solids (3)  
MECE E3301 Thermodynamics (3)  
BMEN E4300 Solid Biomechanics (3)  
BMEN E4310 Fluid Biomechanics (3)  
BMEN E4340 Biomechanics of Cells (3)

Biosignals and Biomedical Imaging Sample Courses

ELEN E3810 Signals and Systems (3.5)  
BMEN E4420 Biosignal Process and Modeling (3)  
ELEN E4810 Digital Signal Processing (3)  
BMEN E4894 Biomedical Imaging (3)  
BMEN E4430 Principles of MRI (3)  
BMEN E4410 Ultrasound Imaging (3)  
BMEN E4898 Biophotonics (3)

Neuroengineering Sample Courses

ELEN E3810 Signals and Systems (3.5)  
BMEN E4420 Biosignal Process and Modeling (3)  
ELEN E4810 Digital Signal Processing (3)  
BMEN E4894 Biomedical Imaging (3)  
BMEN E4430 Principles of MRI (3)  
BMEB W4020 Computational Neuroscience: Circuits in the Brain



BMEE E4030 Neural Control Engineering (3)

Genomics and System Biology Sample Courses

ELEN E3810 Signals and Systems (3.5)

BMEN E4420 Biosignal Process and Modeling (3)

ECBN E4060 Introduction to genomic information science and technology (3)

CHBM E4321 The genome and the cell (3)

CHEN E4700 Principles of genomic technologies (3)

CHEN E4760 Genomics sequence laboratory (3)

CHEN E4800 Protein Engineering (3)

Quantitative Biology Sample Courses

APMA E4400 Introduction to Biological Modeling (3)

BIOL W4070 The Biology and Physics of Single Molecules (3)

CHEN E4650 Biopolymers (3)

ECBN E4060 Introduction to genomic information science and technology (3)

BMEB W4020 Computational Neuroscience: Circuits in the Brain (3)

BMEN E4300 Solid Biomechanics (3)

BMEN E4310 Fluid Biomechanics (3)

Bioinductive and Biomimetic Materials Sample Courses

CHEM C3443 Organic Chemistry I (3.5)

MBCH E3500 Biological Transport Process (3)

BMEN E4501 Tissue Engineering I (3)

BMEN E4502 Tissue Engineering II (3)

CHEN E4620 Introduction to polymers and soft materials (3)

CHEN E4800 Protein Engineering (3)

CHEN E4640 Polymer Surface and Interface (3)

Biomaterials Sample Courses

CHEM C3443 Organic Chemistry I (3.5)

MBCH E3500 Biological Transport Process (3)  
BMEN E4501 Tissue Engineering I (3)  
BMEN E4502 Tissue Engineering II (3)  
BMEN E4300 Solid Biomechanics (3)  
BMEN E4301 Structure, Mechanics, and Adaptation of Bone (3)  
ELEN EE4944 Principles of Device Microfabrication (3)

*BioMEMS and Nanotechnology Sample Courses*

EMEN E3105 Mechanics (4)  
MECE E3100 Mechanics of Fluids (3)  
MECE E3113 Mechanics of Solids (3)  
MECE E4212 Microelectromechanical Systems  
MEBM E4550 Micro- and Nanostructures in Cellular Engineering (3)  
BMEN E4590 BioMEMS: Cellular and Molecular Applications (3)  
MASE E4090 Nanotechnology

*Robotics and Control of Biological Systems*

EMEN E3105 Mechanics (4)  
MECE E3100 Mechanics of Fluids (3)  
MECE E3113 Mechanics of Solids (3)  
MECE E4431 Space Vehicle Dynamics and Controls  
MEBM E4439 Modeling and Identification of Dynamic Systems  
BMEE E4030 Neural Control Engineering  
MECE E4602 Introduction to Robotics

*Pre-Med and Pre-Health Professional Sample Courses*

CHEM C3443 Organic Chemistry I (3.5)  
CHEM C3444 Organic Chemistry II (3.5)  
EMEN E3105 Mechanics (4)  
MECE E3100 Mechanics of Fluids (3)  
MECE E3113 Mechanics of Solids (3)  
BMEN E4300 Solid Biomechanics (3)  
BMEN E4310 Fluid Biomechanics (3)

(Students need to take CHEM C3543 Organic Chemistry Laboratory (3), PHYS C1493 Introduction to Experimental Physics (3), and PSYC W1001 The Science of Psychology (3))

*Minors in Biomedical Engineering*

1. BIOL C2005 Introduction to Biology I
2. BIOL C2006 Introduction to Biology II
3. BMEN E3010 BME I
4. BMEN E3020 BME II
5. BMEN E4010 Quantitative Physiology I
6. BMEN E4002 Quantitative Physiology II