The Department of Biomedical Engineering was established in 1968 at Case Western Reserve University, founded on the premise that engineering principles provide an important basis for innovative and unique solutions to a wide range of biomedical and clinical challenges. As one of the pioneering programs in the world, the department has established rigorous yet flexible educational programs that are emulated by many other institutions and is a national leader in cutting-edge research in several important areas. The cornerstone of the program is quantitative engineering and analytic methods for biomedical applications, a feature that distinguishes Biomedical Engineering from other biomedical science programs. The department's educational programs provide training in cellular and subcellular mechanisms for understanding fundamental physiological processes, in dealing with biomedical problems at the tissue and organ system level, and in integrating this knowledge in systems approaches to solving clinical problems.

Current degree programs include the BS, MS, ME, combined BS/MS, PhD, MD/MS, and MD/PhD in Biomedical Engineering. In all of the BME programs at Case, the goal is to educate engineers who can apply engineering methods to problems involving living systems. The Case School of Engineering and the School of Medicine are in close proximity on the same campus, and Biomedical Engineering faculty members carry joint appointments in both of these two schools, participating in the teaching, research, and decision-making committees of both. The department is also tightly linked with several major medical centers (University Hospitals, Cleveland Clinic, VA Medical Center, and MetroHealth Medical Center) that are nearby. As a result, there is an unusually free flow of academic exchange and collaboration in research and education among the two schools and the four medical institutions. All of Case Western Reserve's BME programs take full advantage of these close relationships, which adds significant strength to the programs.

Mission
To educate leaders who will integrate principles of both engineering and medicine to create knowledge and discoveries that advance human health and well-being. Our faculty and students play leading roles ranging from basic science discovery to the creation, clinical evolution, and commercialization of new technologies, devices, and therapies. In short, we are "Engineering Better Health."

Background
Graduates in biomedical engineering are employed in industry, hospitals, research centers, government, and universities. Biomedical engineers also use their undergraduate training as a basis for careers in business, medicine, law, consulting, and other professions.

Research
Several research thrusts are available to accommodate various student backgrounds and interests. Strong research collaborations with clinical and basic science departments of the university and collaborating medical centers bring a broad range of opportunities, expertise, and perspective to student research projects.

Biomaterials/Tissue Engineering/Drug and Gene Delivery
Fabrication and analysis of materials for implantation, including neural, orthopaedic, and cardiovascular tissue engineering, biomimetic materials, liposomal and other structures for controlled, targeted drug delivery, and biocompatible polymer surface modifications. Analysis of synthetic and biologic polymers by AFM, nanoscale structure-function relationships of biomaterials. Applications in the nervous system, the cardiovascular system, the musculoskeletal system, and cancer.

Biomedical Imaging
MRI, PET, SPECT, CT, ultrasound, acoustic elastography, optical coherence tomography, cardiac electrical potential mapping, human visual perception, image-guided intervention, contrast agents. In vivo microscopic and molecular imaging, and small animal imaging.

Biomedical Sensing
Optical sensing, electrochemical and chemical fiber-optic sensors, chemical measurements in cells and tissues, endoscopy.

Big Data Analytics and Health Informatics
Radiomics, Radiogenomics, computer-assisted diagnosis, digital pathology, co-registration, cancer detection, decision making, precision medicine, bioinformatics, image informatics, machine learning, pattern recognition, artificial intelligence, deep learning.

Neural Engineering and Neural Prostheses
Neuronal mechanisms; neural interfacing for electric and magnetic stimulation and recording; neural dynamics, ion channels, second messengers; neural prostheses for control of limb movement, bladder, bowel, and respiratory function; neuromodulation systems for movement disorders, epilepsy, pain mitigation, visceral functions; computational modeling and simulation of neural structures.

Transport and Metabolic Systems Engineering
Modeling and analysis of tissue responses to heating (e.g., tumor ablation) and of cellular metabolism related to organ and whole-body function in health (exercise) and disease (cardiac).

Biomechanical Systems
Computational musculoskeletal modeling, bone biomechanics, soft tissue mechanics, control of neuroprostheses for motor function, neuromuscular control systems, human locomotion, cardiac mechanics.

Cardiovascular Systems
Normal cardiac physiology, pathogenesis of cardiac diseases, cardiac development, therapeutic technologies, including cardiac regeneration; electrophysiological techniques, imaging technologies, mathematical modeling, gene regulation, molecular biology techniques; cardiac bioelectricity and cardiac biomechanics.

Undergraduate Programs
The Case Western Reserve undergraduate program leading to the Bachelor of Science degree with a major in biomedical engineering was established in 1972. The BS degree program in BME is accredited by the Engineering Accreditation Commission of ABET, www.abet.org (http://www.abet.org).
Some BS graduates are employed in industry and medical centers. Others continue graduate or professional studies in biomedical engineering and other fields. Students with engineering ability and an interest in medicine may consider the undergraduate biomedical engineering program as an exciting alternative to conventional premedical programs. In addition to the University general education requirements, the undergraduate program has three major components: (1) Engineering Core, (2) BME Core, and (3) BME Speciality Tracks. The Engineering Core provides a fundamental background in mathematics, sciences, and engineering. The BME Core integrates engineering with biomedical science to solve biomedical problems. Hands-on experience in BME is developed through undergraduate laboratory and project courses. In addition, by choosing BME Track Courses, the student can study a specific area in depth. This integrated program is designed to ensure that BME graduates are competent engineers.

### Program Educational Objectives

At the undergraduate level, we direct our efforts toward two educational objectives that describe the performance of alumni 3-6 years after graduation.

1. Our graduates will successfully enter and complete post-baccalaureate advanced degree programs, including those in biomedical engineering.
2. Our graduates will obtain jobs in the biomedical arena and advance to positions of greater responsibility.

### Student Outcomes

As preparation for achieving the above educational objectives, the BS degree program in Biomedical Engineering is designed so that students attain:

- An ability to apply knowledge of mathematics, science, and engineering appropriate to biomedical engineering
- An ability to design and conduct experiments, as well as to analyze and interpret data
- 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
- An ability to function on multi-disciplinary teams
- An ability to identify, formulate, and solve engineering problems
- An understanding of professional and ethical responsibility
- An ability to communicate effectively
- The ability to communicate the impact of engineering solutions in a global, economic, environmental, and societal context
- A recognition of the need for, and an ability to engage in life-long learning
- A knowledge of contemporary issues
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

### Bachelor of Science in Engineering

**Major in Biomedical Engineering**

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduates/degreeprograms), the major requires the following courses:

#### Required Courses

<table>
<thead>
<tr>
<th>Major Courses</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 201</td>
<td>Physiology-Biophysics I</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>EBME 202</td>
<td>Physiology-Biophysics II</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>EBME 306 &amp; EBME 356</td>
<td>Introduction to Biomedical Materials and Introduction to Biomaterials Engineering - Laboratory</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>EBME 308 &amp; EBME 358</td>
<td>Biomedical Signals and Systems and Biomedical Signals and Systems Laboratory</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>EBME 309 &amp; EBME 359</td>
<td>Modeling of Biomedical Systems and Biomedical Computer Simulation Laboratory</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>EBME 310 &amp; EBME 360</td>
<td>Principles of Biomedical Instrumentation and Biomedical Instrumentation Laboratory</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>EBME 370</td>
<td>Principles of Biomedical Engineering Design</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>EBME 380</td>
<td>Biomedical Engineering Design Experience</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Plus one engineering, Mathematics or Natural Science Elective</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Plus 8 Specialty Track Specialization Courses (see below)</td>
<td></td>
<td>24-26</td>
<td></td>
</tr>
</tbody>
</table>

**Total Units** 54-56

#### Natural Sciences, Mathematics or Statistics Elective

Candidates for the Bachelor of Science in Engineering (BSE) degree must fulfill a Natural Sciences, Mathematics or Statistics requirement as part of the Engineering Core, which is designated by the major department. Biomedical Engineering majors may meet this requirement by taking one of the following statistics courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 312</td>
<td>Basic Statistics for Engineering and Science</td>
<td>3</td>
</tr>
<tr>
<td>STAT 313</td>
<td>Statistics for Experimenters</td>
<td>3</td>
</tr>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>STAT 333</td>
<td>Uncertainty in Engineering and Science</td>
<td>3</td>
</tr>
</tbody>
</table>

#### Biomedical Engineering Specialty Tracks

Majors in Biomedical Engineering choose a specialization track, with track specific courses.

Required courses for these tracks are presented in the tables below. These tracks provide the student with a solid background in a well-defined area of biomedical engineering. To meet specific educational needs, students may choose alternatives from among the suggested electives or design unique specialties. These options are flexible and subject to departmental guidelines and faculty approval.

Approval of technical electives (TE): Pre-approved TE are (listed below) need no further approval. Any 300-400 level course offered by a department in the Case School of Engineering may be approved as a TE by a student's academic advisor. Any other course must be approved by petition to the BME Undergraduate Education Committee. Transfer
and study abroad courses must be approved by the BME Program Representative. Courses should be chosen as TE's that are consistent with the track and are consistent with student’s career plans. Students are encouraged to choose electives that form a thematic depth.

**Biomedical Devices and Instrumentation Track**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 245</td>
<td>Electronic Circuits</td>
</tr>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
</tr>
<tr>
<td>EECS 309</td>
<td>Electromagnetic Fields I</td>
</tr>
<tr>
<td>EECS 344</td>
<td>Electronic Analysis and Design</td>
</tr>
<tr>
<td><strong>Approved Tech Elective</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td><strong>Approved Tech Elective</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td><strong>Approved Tech Elective</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td><strong>Con-joiner course: choose one of the following courses:</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td>EBME 320</td>
<td>Medical Imaging Fundamentals</td>
</tr>
<tr>
<td>EBME 327</td>
<td>Bioelectric Engineering</td>
</tr>
</tbody>
</table>

The following courses are pre-approved, technical electives for the Biomedical Devices and Instrumentation track.

**Electronics:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 321</td>
<td>Semiconductor Electronic Devices</td>
</tr>
<tr>
<td>EECS 322</td>
<td>Integrated Circuits and Electronic Devices</td>
</tr>
<tr>
<td>EECS 371</td>
<td>Applied Circuit Design</td>
</tr>
</tbody>
</table>

**Software:** (note many of these courses require EECS 132 instead of ENGR 131)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 233</td>
<td>Introduction to Data Structures</td>
</tr>
<tr>
<td>EECS 313</td>
<td>Signal Processing</td>
</tr>
<tr>
<td>EECS 337</td>
<td>Compiler Design</td>
</tr>
<tr>
<td>EECS 338</td>
<td>Intro to Operating Systems and Concurrent Programming</td>
</tr>
<tr>
<td>EECS 340</td>
<td>Algorithms</td>
</tr>
<tr>
<td>EECS 351</td>
<td>Communications and Signal Analysis</td>
</tr>
<tr>
<td>EECS 354</td>
<td>Digital Communications</td>
</tr>
</tbody>
</table>

**Modeling/Simulation:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 324</td>
<td>Modeling and Simulation of Continuous Dynamical Systems</td>
</tr>
<tr>
<td>EECS 346</td>
<td>Engineering Optimization</td>
</tr>
<tr>
<td>EBME 478</td>
<td>Computational Neuroscience</td>
</tr>
</tbody>
</table>

**Other:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 401D</td>
<td>Biomedical Instrumentation and Signal Processing</td>
</tr>
<tr>
<td>EBME 407</td>
<td>Neural Interfacing</td>
</tr>
<tr>
<td>EBME 421</td>
<td>Bioelectric Phenomena</td>
</tr>
<tr>
<td>EBME 307</td>
<td>Biomechanical Prosthetic Systems</td>
</tr>
<tr>
<td>EBME 320</td>
<td>Medical Imaging Fundamentals</td>
</tr>
<tr>
<td>EBME 421</td>
<td>Bioelectric Phenomena</td>
</tr>
<tr>
<td>EECS 371</td>
<td>Applied Circuit Design</td>
</tr>
<tr>
<td>EECS 304</td>
<td>Control Engineering I with Laboratory</td>
</tr>
<tr>
<td>EECS 313</td>
<td>Signal Processing</td>
</tr>
<tr>
<td>EECS 341</td>
<td>Introduction to Database Systems</td>
</tr>
</tbody>
</table>

Please click here to download the example program of study for the Devices and Instrumentation Track. ([http://bulletin.case.edu/schoolofengineering/biomedicalengineering/Devices_Track_Template_2018.xls](http://bulletin.case.edu/schoolofengineering/biomedicalengineering/Devices_Track_Template_2018.xls))

*Requirements for a minor in Electrical Engineering can be found here [http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext](http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext). These can usually be satisfied by judiciously selecting technical electives. Consult your advisor.

**Biomaterials Track**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 223</td>
<td>Introductory Organic Chemistry I</td>
</tr>
<tr>
<td>EMAC 270</td>
<td>Introduction to Polymer Science and Engineering</td>
</tr>
<tr>
<td>EMAC 351</td>
<td>Physical Chemistry for Engineering</td>
</tr>
<tr>
<td>EMAC 352</td>
<td>Polymer Physics and Engineering</td>
</tr>
<tr>
<td><strong>Approved Tech Elective</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td><strong>Approved Tech Elective</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td><strong>Approved Tech Elective</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td><strong>Con-joiner course: choose one of the following courses:</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td>EBME 316</td>
<td>Biomaterials for Drug Delivery</td>
</tr>
<tr>
<td>EBME 325</td>
<td>Introduction to Tissue Engineering</td>
</tr>
<tr>
<td>EBME 305</td>
<td>Materials for Prosthetics and Orthotics</td>
</tr>
</tbody>
</table>

The following courses are pre-approved, technical electives for the Biomaterials track.

**Polymeric Biomaterials**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 276</td>
<td>Polymer Properties and Design</td>
</tr>
<tr>
<td>EMAC 355</td>
<td>Polymer Analysis Laboratory</td>
</tr>
<tr>
<td>EMAC 370</td>
<td>Polymer Chemistry</td>
</tr>
<tr>
<td>EMAC 376</td>
<td>Polymer Engineering</td>
</tr>
<tr>
<td>EMAC 377</td>
<td>Polymer Processing</td>
</tr>
<tr>
<td>EBME/EMAC 303</td>
<td>Structure of Biological Materials</td>
</tr>
<tr>
<td>EBME 305</td>
<td>Materials for Prosthetics and Orthotics</td>
</tr>
<tr>
<td>EBME 350</td>
<td>Quantitative Molecular, Cellular and Tissue Bioengineering</td>
</tr>
<tr>
<td>EBME 406/EMAC 471</td>
<td>Polymers in Medicine</td>
</tr>
<tr>
<td>EBME 325</td>
<td>Introduction to Tissue Engineering</td>
</tr>
<tr>
<td>EBME 425</td>
<td>Tissue Engineering and Regenerative Medicine</td>
</tr>
</tbody>
</table>

**Hard Materials**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 160</td>
<td>Mechanical Manufacturing</td>
</tr>
<tr>
<td>EMSE 327</td>
<td>Thermodynamic Stability and Rate Processes</td>
</tr>
<tr>
<td>EMSE 335</td>
<td>Strategic Metals and Materials for the 21st Century</td>
</tr>
<tr>
<td>EBME 316</td>
<td>Biomaterials for Drug Delivery</td>
</tr>
<tr>
<td>EBME 426</td>
<td>Nanomedicine</td>
</tr>
<tr>
<td>ECHE 474</td>
<td>Biotransport Processes</td>
</tr>
<tr>
<td>ECHE 340</td>
<td>Biochemical Engineering</td>
</tr>
<tr>
<td>ECHE 360</td>
<td>Transport Phenomena for Chemical Systems</td>
</tr>
<tr>
<td>ECHE 364</td>
<td>Chemical Reaction Processes</td>
</tr>
<tr>
<td>EMAC 376</td>
<td>Polymer Engineering</td>
</tr>
</tbody>
</table>
**Biomedical Computing and Analysis Track**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 302</td>
<td>Discrete Mathematics</td>
</tr>
<tr>
<td>EECS 233</td>
<td>Introduction to Data Structures</td>
</tr>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications</td>
</tr>
<tr>
<td>EECS 324</td>
<td>Modeling and Simulation of Continuous Dynamical Systems</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Approved Tech. Elective</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approved Tech. Elective</td>
<td>3</td>
</tr>
<tr>
<td>Approved Tech. Elective</td>
<td>3</td>
</tr>
</tbody>
</table>

Co-joiner course: choose one of the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 307</td>
<td>Biomechanical Prosthetic Systems</td>
</tr>
<tr>
<td>EBME 327</td>
<td>Bioelectric Engineering</td>
</tr>
<tr>
<td>EBME 350</td>
<td>Quantitative Molecular, Cellular and Tissue Bioengineering</td>
</tr>
<tr>
<td>EBME 361</td>
<td>Biomedical Image Processing and Analysis</td>
</tr>
</tbody>
</table>

The following courses are pre-approved, technical electives for the Biomedical Computing and Analysis track.

**Systems and Control**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 304</td>
<td>Control Engineering I with Laboratory</td>
</tr>
<tr>
<td>EECS 346</td>
<td>Engineering Optimization</td>
</tr>
<tr>
<td>EBME 300</td>
<td>Dynamics of Biological Systems: A Quantitative Introduction to Biology</td>
</tr>
<tr>
<td>EECS 350</td>
<td>Operations and Systems Design</td>
</tr>
<tr>
<td>EECS 352</td>
<td>Engineering Economics and Decision Analysis</td>
</tr>
<tr>
<td>EECS 391</td>
<td>Introduction to Artificial Intelligence</td>
</tr>
<tr>
<td>EBME 398</td>
<td>Biomedical Engineering Research Experience I</td>
</tr>
</tbody>
</table>

**Biomedical Computing & Imaging**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
</tr>
<tr>
<td>EECS 293</td>
<td>Software Craftsmanship</td>
</tr>
<tr>
<td>EECS 313</td>
<td>Signal Processing</td>
</tr>
<tr>
<td>EECS 338</td>
<td>Intro to Operating Systems and Concurrent Programming</td>
</tr>
<tr>
<td>EECS 340</td>
<td>Algorithms</td>
</tr>
<tr>
<td>EECS 341</td>
<td>Introduction to Database Systems</td>
</tr>
<tr>
<td>EECS 343</td>
<td>Theoretical Computer Science</td>
</tr>
<tr>
<td>EECS 391</td>
<td>Introduction to Artificial Intelligence</td>
</tr>
<tr>
<td>EECS 394</td>
<td>Introduction to Information Theory</td>
</tr>
</tbody>
</table>

**Other**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 398</td>
<td>Biomedical Engineering Research Experience I</td>
</tr>
</tbody>
</table>

Please click here to download the example program of study for the Biomedical Computing And Analysis Track (http://bulletin.case.edu/schoolofengineering/biomedicalengineering/Biomedical_Computing_and_Analysis_Template_amr_edit.xls)

*Requirements for a minor in Systems and Control Engineering can be found here (http://bulletin.case.edu/schoolofengineering/elecengcompsci/#undergraduatetext). These can usually be satisfied by judiciously selecting technical electives. Consult your advisor.*

---

**Biomechanics Track**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 160</td>
<td>Mechanical Manufacturing</td>
</tr>
<tr>
<td>EMAE 181</td>
<td>Dynamics</td>
</tr>
<tr>
<td>ECIV 310</td>
<td>Strength of Materials</td>
</tr>
<tr>
<td>EMAE 260</td>
<td>Design and Manufacturing I</td>
</tr>
<tr>
<td>Approved Tech Elective</td>
<td>3</td>
</tr>
<tr>
<td>Approved Tech Elective</td>
<td>3</td>
</tr>
<tr>
<td>Approved Tech Elective</td>
<td>3</td>
</tr>
<tr>
<td>Co-joiner course:</td>
<td>choose one of the following courses:</td>
</tr>
<tr>
<td>EBME 307</td>
<td>Biomechanical Prosthetic Systems</td>
</tr>
</tbody>
</table>

The following courses are pre-approved, technical electives for the Biomechanics track.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAE 250</td>
<td>Computers in Mechanical Engineering</td>
</tr>
<tr>
<td>EMAE 290</td>
<td>Computer-Aided Manufacturing</td>
</tr>
<tr>
<td>EMAE 363</td>
<td>Mechanical Engineering Modern Analysis Methods</td>
</tr>
<tr>
<td>EMAE 390</td>
<td>Advanced Manufacturing Technology</td>
</tr>
<tr>
<td>EMAE 370</td>
<td>Design of Mechanical Elements</td>
</tr>
<tr>
<td>EMAE 372</td>
<td>Structural Materials by Design</td>
</tr>
<tr>
<td>EMAE 350</td>
<td>Mechanical Engineering Analysis</td>
</tr>
<tr>
<td>EMAE 415</td>
<td>Introduction to Musculo-skeletal Biomechanics</td>
</tr>
<tr>
<td>EBME 305</td>
<td>Materials for Prosthetics and Orthotics</td>
</tr>
<tr>
<td>EBME 402</td>
<td>Organ/Tissue Physiology and Systems Modeling</td>
</tr>
<tr>
<td>ECIV 420</td>
<td>Finite Element Analysis</td>
</tr>
<tr>
<td>EBME 398</td>
<td>Biomedical Engineering Research Experience I</td>
</tr>
<tr>
<td>EMSE 372</td>
<td>Structural Materials by Design</td>
</tr>
</tbody>
</table>

Please click here to download the example program of study for the Biomechanics Track (http://bulletin.case.edu/schoolofengineering/biomedicalengineering/X20170302a_BioMechanicsTrack_Generic.xls)

*Requirements for a minor in Polymer Science and Engineering can be found here (http://bulletin.case.edu/schoolofengineering/macromolecularscieng/#undergraduatetext). These can usually be satisfied by judiciously selecting technical electives. Consult your advisor.*

---

**Other**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 398</td>
<td>Biomedical Engineering Research Experience I</td>
</tr>
</tbody>
</table>

Please click here to download the example program of study for the Biomaterials Track (http://bulletin.case.edu/schoolofengineering/biomedicalengineering/Biomaterials_Engg_Generic_Track_Template_gs.xlsx)

*Requirements for a minor in Polymer Science and Engineering can be found here (http://bulletin.case.edu/schoolofengineering/macromolecularscieng/#undergraduatetext). These can usually be satisfied by judiciously selecting technical electives. Consult your advisor.*
**Bachelor of Science in Engineering**  
**Suggested Program of Study: Major in Biomedical Engineering**

The following is an example program of study. Variations depend on advance placements. Students should work with their advisors to map out an individual plan of study.

### First Year

<table>
<thead>
<tr>
<th>Units</th>
<th><strong>Fall</strong></th>
<th><strong>Spring</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Introduction to Biomedical Engineering (EBME 105)(^a)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Principles of Chemistry for Engineers (CHEM 111)(^**)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Calculus for Science and Engineering I (MATH 121)(^**)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Elementary Computer Programming (ENGR 131/EECS 132)(^f)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SAGES First Seminar (FSxx)(^*)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>PHED (2 half semester courses)(^*)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Chemistry of Materials (ENGR 145)(^**)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Calculus for Science and Engineering II (MATH 122)(^**)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>General Physics I - Mechanics (PHYS 121)(^**)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>SAGES University Seminar (USxx)(^*)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>PHED (2 half semester courses)(^*)</td>
<td></td>
</tr>
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</table>

Year Total: 18

### Second Year

<table>
<thead>
<tr>
<th>Units</th>
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<th><strong>Spring</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Physiology-Biophysics I (EBME 201)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Calculus for Science and Engineering III (MATH 223)(^**)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>General Physics II - Electricity and Magnetism (PHYS 122)(^**)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)(^**)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>SAGES University Seminar (USxx)(^*)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Physiology-Biophysics II (EBME 202)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Elementary Differential Equations (MATH 224)(^**)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Introduction to Circuits and Instrumentation (ENGR 210)(^**)</td>
<td></td>
</tr>
</tbody>
</table>

One of the of following:
- BME Track Course\(^d\)
- Science elective\(^e\)
- Breadth elective\(^***\)

Year Total: 17

### Third Year

<table>
<thead>
<tr>
<th>Units</th>
<th><strong>Fall</strong></th>
<th><strong>Spring</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Introduction to Biomedical Materials (EBME 306) &amp; Introduction to Biomaterials Engineering - Laboratory (EBME 356)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BME Track Course(^b)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Professional Communication for Engineers (ENGR 398)(^**)</td>
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</tr>
<tr>
<td>2</td>
<td>Professional Communication for Engineers (ENGR 398)(^**)</td>
<td></td>
</tr>
</tbody>
</table>

Biomedical Signals and Systems (EBME 308) & Biomedical Signals and Systems Laboratory (EBME 358) 4

Breadth elective\(^**\),\(^g\) 3

Principles of Biomedical Instrumentation (EBME 310) & Biomedical Instrumentation Laboratory (EBME 360) 4

Statics and Strength of Materials (ENGR 200)\(^**\) 3

Modeling of Biomedical Systems (EBME 309) & Biomedical Computer Simulation Laboratory (EBME 359) 4

BME Track Course\(^d\) 3

Breadth elective\(^**\),\(^g\) 3

Year Total: 17

### Fourth Year

<table>
<thead>
<tr>
<th>Units</th>
<th><strong>Fall</strong></th>
<th><strong>Spring</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Breadth elective(^**),(^g)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Principles of Biomedical Engineering Design (EBME 370)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BME Track Course(^b)</td>
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<tr>
<td>3</td>
<td>BME Track Course(^b)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Statistics(^g)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Engineering/Math/Science Elective(^e)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BME Track Course(^b)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BME Track Course(^b)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Breadth elective(^**),(^g)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Biomedical Engineering Design Experience (EBME 380)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BME Track Course(^b)</td>
<td></td>
</tr>
</tbody>
</table>

Year Total: 17

Total Units in Sequence: 132

\(\text{a} \) University general education requirement  
\(\text{**} \) Engineering general education requirement  
\(\text{b} \) Courses chosen depending on the BME specialty track as listed above  
\(\text{c} \) At least one engineering, math or natural science elective  
\(\text{d} \) SAGES BME Department Seminar, ENGL 398 Professional Communication for Engineers Professional Communication for Engineers and ENGR 398 Professional Communication for Engineers Professional Communication for Engineers must be taken together  
\(\text{e} \) STAT 312 Basic Statistics for Engineering and Science, STAT 313 Statistics for Experimenters, STAT 332 Statistics for Signal Processing, STAT 333 Uncertainty in Engineering and Science fulfill the statistics requirement. Consult your advisor to determine the most appropriate class  
\(\text{f} \) Biomedical Computing and Analysis track requires EECS 132 Introduction to Programming in Java  
\(\text{g} \) There are four required Breadth Electives. Depending on the specific specialty track, a fifth Breadth Elective may be taken.
Co-op and Internship Programs (http://engineering.case.edu/coop)

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop. Alternatively or additionally, students may obtain employment as summer interns.

BS/MS Program

The BS/MS program is designed to allow highly qualified undergraduate students from the Case BME program to integrate B.S. courses and project work with M.S. courses and research. Normally, the combined program can be completed in 5 years including 3 summers starting after the junior year. The BS/MS program can reduce the time required to receive an MS degree because up to three courses taken during the undergraduate program at Case can be "double counted" towards M.S. requirements and because a research project can begin before the completion of the B.S. degree. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatestudies/gradprofessional/#accelerationtowardgraduatedegreestext)

Admission to the B.S./M.S. program is typically open to BME juniors from Case with a grade point average of 3.2 or higher. Students with slightly lower GPA but with significant research experience and a strong faculty champion can petition the GEC for admission. To be most effective, applications to the BS/MS program should be submitted before the end of Spring semester in the junior year. The final deadline for BS/MS admissions is August 1 before the senior year. This will enable the GEC sufficient time to review the application and allow students to make any required changes to their POS for fall semester.

In general, the following steps should be taken to apply to the BS/MS program:

1. See Advisor to discuss interests (typically in junior year or earlier).
2. See Dean Anderson the Undergraduate office to discuss intentions.
3. Complete a School of Graduate Studies application and submit to the Graduate Studies office for the program of interest (BME).
4. Complete a planned Program of Study form (must be signed by student, Faculty Advisor, Department Chair, and Dean of Undergraduate Studies). (see Appendix for BS/MS PPOS form)

Additional information for BME students:

1. An eligible BME faculty member (primary or secondary) must agree to serve as the M.S. research advisor and a primary BME faculty member (who might be the same person as the research advisor) must agree to be the academic advisor. Obtaining this agreement is the responsibility of the applying student. The BS/MS application must include letters of recommendation from both the research and academic advisor that states that they agree to serve in these roles and that they support the BS/MS application.
2. The BME department does not guarantee financial support during the MS portion of this program. However, the GEC requires students and potential research advisors to discuss and agree to some financial arrangement. The letter of recommendation from the proposed research advisor must therefore indicate that the issue of financial support has been discussed and that some arrangement has been agreed upon. The details of this arrangement do not need to be included in the letter.
3. Complete a standard application to the School of Graduate Studies via the online application system.
4. Complete the BS/MS Planned Program of Study (PPOS) form (in Appendix VI or from the BME website bme.case.edu). Make sure to check the "BS/MS" box and to indicate which courses are to be double-counted (by checking the "double count" box next to the relevant courses on the POS).
5. Obtain an approval signature from the School of Undergraduate Studies on the proposed POS prior to submitting the package (below) to the department.
6. Prepare the application package that includes the following:
   • A current transcript
   • The proposed M.S. Program of Study. Make sure that the Program of Study specifies both the academic and research advisors and includes both of their signatures. This form also needs to indicate the courses that are intended to be "double counted".
   • Only graduate-level courses (400 or higher) can be double counted. This typically means that students should register for 400 level courses to satisfy undergraduate technical electives.
   • It is possible to "double count" three credit hours of EBME 398 Biomedical Engineering Research Experience I. To do this, three credit hours of EBME 651 Thesis M.S. (Thesis Option) or EBME 601 Research Projects (Non-Thesis Option) should replace EBME 398 Biomedical Engineering Research Experience I in the fall or spring of the senior year. You should register for EBME 651 Thesis M.S. or EBME 601 Research Projects (but NOT EBME 398 Biomedical Engineering Research Experience I). However, you must attend the meetings of EBME 398 Biomedical Engineering Research Experience I and also fulfill all of the course requirements for EBME 398 Biomedical Engineering Research Experience I.
   • A maximum of nine (9) credit hrs can be double counted. Typically, these are two 3-credit courses (400 level or high) + 3 credits of EBME 651 Thesis M.S. or EBME 601 Research Projects (in place of EBME 398 Biomedical Engineering Research Experience I).
   • Three (3) reference reports (in sealed envelopes), including letters from your proposed academic and research advisor(s).

7. Submit the proposed POS, transcript, and letters of recommendation to the BME Graduate Coordinator.

No admission decision will be made until the POS is approved by the GEC. After a positive recommendation by the GEC, a letter of conditional admission will be sent. The condition for admission is the submission of GRE scores within 2 months of the completing the B.S. requirements. The student cannot graduate from the B.S./M.S. program without official GRE scores. This is a BME requirement and not a CSE requirement. Note that it is strongly recommended that students plan to take the GRE exam
in the Fall semester of their senior year to be eligible for pre-doctoral fellowships from the National Science Foundation or other sources.

**BS-MS Thesis Option**

21-hrs of course work and 9-hrs of EBME 651 Thesis M.S.

Requirement for completion: 30-hrs and thesis defense

Students can double count 9 credits (up to 3 credits can be at the 300 level)

**BS-MS Non-Thesis Options**

1. **BS-MS Course Only Option**

30-hrs of course work

Requirement for completion: 30-hrs and comprehensive examination

Students can double count 9 credits (up to 3 credits can be at the 300 level)

2. **BS-MS Project Option**

24 to 27-hrs of course work and 3 to 6-hrs of EBME 601 Research Projects

Students can double count 9 credits (up to 3 credits can be at the 300 level)

3. **BS-ME Practice Oriented Option**

18-hrs in engineering (5 courses and capstone projects)

EPOM 400 Leadership and Interpersonal Skills

EPOM 401 Introduction to Business for Engineers

EPOM 403 Product and Process Design and Implementation

EPOM 405 Applied Engineering Statistics (can be double-counted)

EPOM 407 Engineering Economics and Financial Analysis

EPOM 409 Master of Engineering Capstone Project

12-hrs (4 BME technical Courses)

Graduation requirement: 30-hrs and a comprehensive examination

Students can double-count 9 credits (up to 3 credits can be at the 300 level)

**Minor in Biomedical Engineering**

A minor in biomedical engineering is offered to students who have taken the Engineering (technical) Core requirements. The minor consists of an approved set of five EBME courses.

**Required Courses**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 201</td>
<td>Physiology-Biophysics I</td>
<td>3</td>
</tr>
<tr>
<td>EBME 202</td>
<td>Physiology-Biophysics II</td>
<td>3</td>
</tr>
</tbody>
</table>

Elect three of the following with at least one from the BME core *(assumes prerequisites satisfied):*

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 306</td>
<td>Introduction to Biomedical Materials</td>
<td></td>
</tr>
<tr>
<td>EBME 308/358</td>
<td>Biomedical Signals and Systems</td>
<td></td>
</tr>
<tr>
<td>EBME 309/359</td>
<td>Modeling of Biomedical Systems</td>
<td></td>
</tr>
<tr>
<td>EBME 310/360</td>
<td>Principles of Biomedical Instrumentation</td>
<td></td>
</tr>
<tr>
<td>EBME 303</td>
<td>Structure of Biomedical Materials</td>
<td></td>
</tr>
<tr>
<td>EBME 305</td>
<td>Materials for Prosthetics and Orthotics</td>
<td></td>
</tr>
<tr>
<td>EBME 307</td>
<td>Biomechanical Prosthetics Systems</td>
<td></td>
</tr>
<tr>
<td>EBME 316</td>
<td>Biomaterials for Drug Delivery</td>
<td></td>
</tr>
<tr>
<td>EBME 320</td>
<td>Medical Imaging Fundamentals</td>
<td></td>
</tr>
<tr>
<td>EBME 325</td>
<td>Introduction to Tissue Engineering</td>
<td></td>
</tr>
<tr>
<td>EBME 327</td>
<td>Bioelectric Engineering</td>
<td></td>
</tr>
<tr>
<td>EBME 350</td>
<td>Quantitative Molecular, Cellular and Tissue Bioengineering</td>
<td></td>
</tr>
<tr>
<td>EBME 361</td>
<td>Biomedical Image Processing and Analysis</td>
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</tr>
</tbody>
</table>

**Total Units: 15**

* EBME 306 Introduction to Biomedical Materials, EBME 308 Biomedical Signals and Systems (Coreq: EBME 358 Biomedical Signals and Systems Laboratory), EBME 309 Modeling of Biomedical Systems (Coreq: EBME 359 Biomedical Computer Simulation Laboratory), EBME 310 Principles of Biomedical Instrumentation (Coreq: EBME 360 Biomedical Instrumentation Laboratory)

**Graduate Programs**

The objective of the graduate program in biomedical engineering is to educate biomedical engineers for careers in industry, academia, health care, and government and to advance research in biomedical engineering. The department provides a learning environment that encourages students to apply biomedical engineering methods to advance basic scientific discovery; integrate knowledge across the spectrum from basic cellular and molecular biology through tissue, organ, and whole-body physiology and pathophysiology; and to exploit this knowledge to design diagnostic and therapeutic technologies that improve human health.

The unique and rich medical, science, and engineering environment at Case enables research projects ranging from basic science through engineering design and clinical application.

Numerous fellowships and research assistantships are available to support graduate students in their studies.

**Master of Science in Engineering**

The MS program in biomedical engineering provides breadth in biomedical engineering and biomedical sciences with depth in an engineering specialty. In addition, students are expected to develop the ability to work independently on a biomedical research or design project. While there is no set of core required courses, the MS requires a minimum of 30 credit hours. Every program of study must be approved by the graduate education committee. With an MS research thesis (Plan A), a minimum of 18 to 21 credits hours is needed in regular course work and 9 to 12 hours of thesis research (EBME 651 Thesis M.S.). With an MS
project (Plan B), a minimum of 24 to 30 credits hours is needed in regular course work, and 0 to 6 hours of project research (EBME 695 Project M.S.); note that the MS Plan B can be accomplished in 30 credit hours of coursework with a comprehensive final exam for the degree. The Master of Science in Biomedical Engineering degree is also available exclusively online.

Visit http://online-engineering.case.edu/biomedical for more details.

**Master of Science in Engineering with Specialization Translational Health Technology**

This Master’s degree in Biomedical Engineering is designed to develop expertise in translating biomedical ideas into clinical implementation. This degree can be completed in one year for full-time students. It is offered by the Biomedical Engineering department in the Case School of Engineering and takes advantage of the large pool of expertise in Biotechnology on the campus of Case Western Reserve University. It combines aspects of bioengineering, marketing, entrepreneurship, and bioregulatory affairs with ethics and experimental design. The program will require students to take a minimum of 30 credits including a design project.

This "Plan B" program of study requires a comprehensive exam: for this specialization, the exam is frequently an oral project review between the program director and the student, and may include participation from other BME faculty as well as the project clinical mentor, as applicable.

**Special Features:**

- Flexible program to accommodate a professional’s schedule
- Lock-Step Program; Duration 1 year: August to August
- Projects can be done within the place of work

Visit http://engineering.case.edu/Translational-Health-Technology/program-features

**Prerequisite:** Biomedical Engineering Degree or equivalent or consent of program director.

Course curriculum is as follows:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 491</td>
<td>Introduction to Translational Health Technology</td>
<td>2</td>
</tr>
<tr>
<td>PQHS 431</td>
<td>Statistical Methods I</td>
<td>3</td>
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<tr>
<td>BETH 503</td>
<td>Research Ethics and Regulation</td>
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</tr>
<tr>
<td>EBME 473</td>
<td>Fundamentals of Clinical Information Systems</td>
<td>3</td>
</tr>
<tr>
<td>IIME 446</td>
<td>Models of Health Care Systems</td>
<td>1.5</td>
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<tr>
<td>IIME 447</td>
<td>Regulatory Affairs for the Biosciences</td>
<td>1.5</td>
</tr>
<tr>
<td>EBME 472</td>
<td>BioDesign</td>
<td>3</td>
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<tr>
<td>IIME 450</td>
<td>Engineering Entrepreneurship</td>
<td>3</td>
</tr>
<tr>
<td>EBME 695</td>
<td>Project M.S.</td>
<td>4</td>
</tr>
</tbody>
</table>

**Total Units** 24

For the remaining 6 credit hours, students can choose from any 400 level engineering course or biomedical engineering course for which prerequisites are met and approved by the student's advisor or a program director.

**Wireless Health**

The MS degree in Biomedical Engineering (BME) with a specialization in Wireless Health is a "course-only" program of study. Students who complete the 10-course, 30-credit course-only option will have the requisite knowledge to enter and advance the wireless health industry.

For more details, please refer to the Master's Degree (http://engineering.case.edu/sandiego/ms) information on the Case School of Engineering website.

**MD/MS Program**

The MD/MS program is available to qualified medical students from the Case School of Medicine and the Cleveland Clinic Lerner College of Medicine of Case Western Reserve University. Students in this program receive some credit for their medical school studies in completing the MS degree. There are specific admission requirements.

The MD/MS degree is open to Case School of Medicine students in the Cleveland Clinic Lerner College of Medicine (CCLCM) or the University Program (UP), which will award the MD component of the dual degree. An undergraduate degree in engineering is desirable for students entering this program, but other students with an adequate undergraduate preparation (calculus with differential equations, physics, chemistry, and electronic circuits) will be considered. Additional undergraduate courses in instrumentation and signals/systems would be helpful. Students with an insufficient background will be admitted conditionally until they take the remedial undergraduate courses. Remedial courses will not count toward the MS requirements.

Interested students should submit their applications through the BME department, as the department taking responsibility for program management. Students will normally apply to the 10 program during their first year of medical school. Students should submit their medical school application instead of a separate graduate school application, including MCAT scores instead of GRE scores. The application should include a letter specifying the intended track, the department/major field designation, and a statement of purpose for seeking the combined degree.

The MS requirements are the same as the rest of the Case School of Engineering Thesis Option MS degree, i.e., 30 credit hours including nine to twelve hours of thesis registration (EBME 651 Thesis M.S.). Please note that only Thesis Option is available to MS/MD students. Students must complete the normal MD requirements in either the UP or CCLCM Program. Portions of the medical school curriculum earn graded credit toward the MS portion of this degree. Specifically, students in the University Program register for Integrated Biological Science courses (IBIS 401 Integrated Biological Sciences I), as in the MD/PhD program. Students in the CCLCM Program enroll in the 6-credit IBIS 434 Integrated Biological Sciences in Medicine Process of Discovery course in the second year of the CCLCM curriculum. Six credit hours of these medical school courses are applied to the MS component of the dual degree. The balance of required formal courses (12-15 hours or 4-5 courses) must be graduate level engineering concentration courses that provide rigor and depth in a field of engineering relevant to the area of research. All courses must be listed on the BME Program of Study, which must be submitted and formally approved by the BME Graduate Education Committee and subsequently transmitted to the School of Graduate Studies. The Program of Study must be approved prior to registration for the second engineering course. Students must earn a minimum of a B grade in each graduate engineering course, and have a minimum overall GPA of 3.25.
### PhD Program in Biomedical Engineering

The PhD program requires a minimum of 36 credit hours of courses beyond the BS degree. A student’s overall Program of Study must clearly demonstrate adequate depth in a field of biomedical engineering relevant to the student's research area. There are 12 credit hours of required core courses, which include the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 401D</td>
<td>Biomedical Instrumentation and Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>EBME 433</td>
<td>Advanced Topics for Physiological Systems Analysis</td>
<td>4</td>
</tr>
<tr>
<td>EBME 602</td>
<td>Special Topics</td>
<td>1</td>
</tr>
<tr>
<td>CBIO 453</td>
<td>Cell Biology I</td>
<td>3</td>
</tr>
</tbody>
</table>

The following “breadth” courses are also required:

- Two semesters of:
  - EBME 611 BME Departmental Seminar I
  - EBME 612 BME Departmental Seminar II

- Two semesters of:
  - EBME 613 Topic Seminars for NeuroEngineering Students
  - EBME 614 Topic Seminars for NeuroEngineering Students
  - EBME 615 Topic Seminars for Imaging Students
  - EBME 616 Topic Seminars for Imaging Students
  - EBME 617 Topic Seminars for Biomaterials Students
  - EBME 618 Topic Seminars for Biomaterials Students
  - EBME 619 Topic Seminars for Miscellaneous Biomedical Engineering Students
  - EBME 620 Topic Seminars for Miscellaneous Biomedical Engineering Students
  - EBME 570 Graduate Professional Development for Biomedical Engineers

Three semesters of teaching experience:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 400T</td>
<td>Graduate Teaching I</td>
<td></td>
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<tr>
<td>EBME 500T</td>
<td>Graduate Teaching II</td>
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</tr>
<tr>
<td>EBME 600T</td>
<td>Graduate Teaching III</td>
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</tbody>
</table>

The remaining courses can be chosen with significant flexibility to meet the career goals of the student and to satisfy the departmental requirements of depth and breadth. Programs of study must include one graduate level course in biomedical sciences and one course whose content is primarily mathematical, in addition to at least two courses with significant engineering content. More details on these requirements and accepted depth and breadth courses can be found in the Department of Biomedical Engineering’s Graduate Education Committee Handbook. Eighteen hours of EBME 701 Dissertation Ph.D. are also required. PhD programs of study are reviewed and must be accepted by the Graduate Education Committee, the department chair and the School of Graduate Studies.

### MD/PhD Programs

Students with outstanding qualifications may apply to either of two MD/PhD programs. Students interested in obtaining a combined MD/PhD with an emphasis on basic research in biomedical engineering, are strongly encouraged to explore the Medical Scientist Training Program (MSTP), administered by the School of Medicine. The MD/PhD programs require approximately 7-8 years of intensive study after the BS. Interested students should apply through the MSTP office in the Medical School.

### Graduate Certificate

Graduate Certificates are discipline independent and intended to enable knowledgeable entry into the field of study. They are prescribed 3-course, 9-credit subsets of our MS degree offerings.

#### Wireless Health Required Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME/EECS 480A</td>
<td>Introduction to Wireless Health</td>
<td>3</td>
</tr>
<tr>
<td>EBME/EECS 480B</td>
<td>The Human Body</td>
<td>3</td>
</tr>
<tr>
<td>EBME/EECS 480C</td>
<td>Biomedical Sensing Instrumentation</td>
<td>3</td>
</tr>
</tbody>
</table>

For more details, please refer to the [Graduate Certificate](http://engineering.case.edu/sandiego/gc) information on the Case School of Engineering - San Diego website.

### Facilities

The Department of Biomedical Engineering has major facilities in both the Case School of Engineering and the School of Medicine. In the Case School of Engineering, the Wickenden Building provides office space for the majority of faculty, as well as extensive non-clinical research laboratories and centers. Also, a number of faculty have their offices and laboratories in the School of Medicine in the Biomedical Research Building and the Wolstein Building. In addition, many faculty also have major laboratory activities in the various medical centers in Cleveland.

Major interdisciplinary centers include: the Neural Engineering Center, the Case Center for Imaging Research (CCIR), the Center for Biomaterials, and the Center for Computational Imaging & Personalized Diagnostics. The Neural Engineering Center is a major facility for basic research and preclinical testing, with a focus on neural recording and controlling neural activity to increase our understanding of the nervous system and to develop neural prostheses. The Case Center for Imaging Research, located in the Department of Radiology at University Hospitals, has capabilities in imaging structure and function from the molecular level to the tissue-organ level, using many modalities, including ultrasound, MRI, CT, PET, SPECT, bioluminescence, and light. The CCIR has the ability for full translation of discoveries along a continuum from molecules to mice to man. The Center for Biomaterials includes laboratories for biomaterials microscopy, biopolymer and biomaterial interfaces, and molecular...
simulation. The Center for Computational Imaging & Personalized Diagnostics develops, evaluates, and applies novel quantitative image analysis, computer vision, signal processing, segmentation, multi-modal co-registration tools, pattern recognition, and machine learning tools for disease diagnosis, prognosis, and theragnosis in the context of breast, lung, prostate, head and neck, and brain tumors. The center is also developing new radiogenomic and radio-path-omic approaches to study correlations of disease markers across multiple length scales, modalities, and functionalities - from gene and protein expression to spectroscopy to digital pathology and to multi-parametric radiographic imaging. Also available are biomedical sensing laboratories that include facilities for electrochemical sensing, chemical measurements in individual cells, and minimally invasive physiological monitoring. High-fidelity patient simulation and clinical decision-making research are done in collaboration with the School of Nursing's simulation center.

The FES (Functional Electrical Stimulation) Center, with laboratories at CWRU and in three medical centers, develops techniques for restoration of movement in paralysis, control of the nervous system, and implantable technology. The APT (Advanced Platform Technology) Center develops advanced technologies that serve the clinical needs of veterans and others with motor and sensory deficits, limb loss, and other disabilities.

The Case-Coulter Translational Research Partnership (CCTR) is an endowed program that promotes translational research and supports collaborative translational research projects to address unmet or poorly met clinical needs. The overarching goal of the program is to improve patient care and accelerate the delivery of healthcare technology from academia to the marketplace. The CCTRP, in particular, fosters collaborations between clinicians and the CWRU Biomedical Engineering faculty to achieve its goals.

The Biomedical Engineering faculty and students have access to the many facilities and major laboratories of both the Case School of Engineering and School of Medicine. In addition, faculty have numerous collaborations at University Hospitals, MetroHealth Medical Center, Louis Stokes Cleveland VA Medical Center, and the Cleveland Clinic. These provide extensive research resources in a clinical environment for both undergraduate and graduate students.

**Primary Appointments**

Robert F. Kirsch, PhD  
(Northwestern University)  
*Professor and Chair; Executive Director, Functional Electrical Stimulation Center*

Restoration of movement using neuroprostheses; neuroprosthesis control system design; natural control of human movements; brain-computer interfacing; biomechanics of movement; computer-based modeling; and system identification

A. Bolu Ajiboje, PhD  
(Northwestern University)  
*Assistant Professor*

Development and control of brain-computer-interface (BCI) technologies for restoring function to individuals with nervous system injuries
Miklos Gratzl, PhD
(Technical University of Budapest, Hungary)
Associate Professor
Biomedical sensing and diagnostics in vitro and in vivo; electrochemical and optical techniques; BioMEMS for cellular transport; cancer multidrug resistance at the single cell level; and silver sensor for multi-analyte patient monitoring

Kenneth Gustafson, PhD
(Arizona State University)
Associate Professor
Neural engineering; neural prostheses; neurophysiology and neural control of genitourinary function; devices to restore genitourinary function; and functional neuromuscular stimulation

Efstathios (Stathis) Karathanasis, PhD
(University of Houston)
Associate Professor
Fabricating multifunctional agents that facilitate diagnosing; treating and monitoring of therapies in a patient-specific manner

Zheng-Rong Lu, PhD
(Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences)
M. Frank and Margaret Domiter Rudy Professor of Biomedical Engineering
Drug delivery and molecular imaging; novel targeted imaging agents for molecular imaging; novel MRI contrast agents; image-guided therapy and drug delivery; polymeric drug delivery systems; multi-functional delivery systems for nucleic acids

Anant Madabhushi, PhD
(Rutgers University)
F. Alex Nason Professor II
Quantitative image analysis; Multi-modal, multi-scale correlation of massive data sets for disease diagnostics, prognostics, theragnostics; cancer applications

Cameron McIntyre, PhD
(Case Western Reserve University)
Professor of Biomedical Engineering and Molecular Medicine
Theoretical modeling of the interaction between electric fields and the nervous system; deep brain stimulation

J. Thomas Mortimer, PhD
(Case Western Reserve University)
Professor Emeritus
Neural control and prostheses; electrical activation of neural tissue; and membrane properties and electrodes

P. Hunter Peckham, PhD
(Case Western Reserve University)
Donnell Institute Professor; Distinguished University Professor
Rehabilitation engineering in spinal cord injury; neural prostheses; and functional electrical stimulation and technology transfer

Andrew M. Rollins, PhD
(Case Western Reserve University)
Professor
Biomedical optics; real-time in-vivo microstructural, functional, and molecular imaging using optical coherence tomography; diagnosis and guided therapy for cancer, cardiovascular, and opthalmic disease

Gerald M. Saidel, PhD
(The Johns Hopkins University)
Professor; Director, Center for Modeling Integrated Metabolic Systems
Mass and heat transport and metabolism in cells, tissues, and organ systems; mathematical modeling and simulation of dynamic and spatially distributed systems; optimal nonlinear parameter estimation and design of experiments

Nicole Seiberlich, PhD
(University of Würzburg)
Elmer Lincoln Lindseth Associate Professor in Biomedical Engineering
Advanced signal processing and data acquisition techniques for rapid Magnetic Resonance Imaging (MRI)

Anirban Sen Gupta, PhD
(The University of Akron)
Associate Professor
Targeted drug delivery; targeted molecular imaging; image-guided therapy; platelet substitutes; novel polymeric biomaterials for tissue engineering scaffolds

Sam Senyo, PhD
(University of Illinois)
Assistant Professor
Cardiovascular regeneration; microenvironment; stable isotopes; biomaterials, microfabrication; and drug delivery

Pallavi Tiwari, PhD
(Rutgers University)
Assistant Professor
Developing Image Analysis and Machine Learning Tools for Neuroimaging applications

Ronald J. Triolo, PhD
(Drexel University)
Professor, Orthopaedics, University Hospitals-Case Medical Center, VA Medical Center, MetroHealth Medical Center
Neural prostheses, rehabilitation engineering and restoration of lower extremity function, biomechanics of human movement quantitative analysis and control of gait, standing balance and seated posture

Dustin J. Tyler, PhD
(Case Western Reserve University)
Kent Hale Smith Professor for the Case School of Engineering II
Neuromimetic neuroprostheses; laryngeal neuroprostheses; clinical implementation of nerve electrodes; cortical neuroprostheses; minimally invasive implantation techniques; and modeling of neural stimulation and neuroprostheses

Horst A. von Recum, PhD
(University of Utah)
Professor
Affinity-based delivery of small molecule drugs and biomolecules for applications in device infection, HIV, orthopedics, cardiovascular, ophthalmology and cancer; directed differentiation of stem cells for tissue engineering applications, such as endothelial cells, cardiomyocytes, motor neurons and T-cells
Satish Viswanath, PhD  
(Rutgers University)  
**Assistant Professor**  
Medical image analysis, image radiomics, and machine learning schemes, focused on the use of post-processing, co-registration, and biological quantitation; with applications in image-guided interventions, directed guidance, and quantitative evaluation of response to treatment in gastrointestinal cancers and inflammatory diseases

David L. Wilson, PhD  
(Rice University)  
**Robert J. Herbold Professor**  
Biomedical image processing; digital processing and quantitative image quality of X-ray fluoroscopy images; interventional MRI

Xin Yu, ScD  
(Harvard-MIT)  
**Professor**  
Magnetic resonance imaging and spectroscopy; applications of MRI and MRS to cardiovascular research

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**Secondary Appointments**

Rigoberto Advincula, PhD  
(University of Florida)  
**Professor, Macromolecular Science & Engineering**  
Design, synthesis, and characterization of polymers and nanostructured materials capable of controlled-assembly, tethering, and self-organization in ultrathin films

Ozan Akkus, PhD  
(Case Western Reserve)  
**Professor, Mechanical Aerospace Engineering**  
Development of novel biomaterials that will substitute bone and soft tissues, bioinspired from the synthesis of bone such that ductile biocompatible polymer matrices are subjected to mineralization. Tendon replacement strategy involves alignment of collagen monomers by a novel electrochemical method to obtain strong bundles

Jay Alberts, PhD  
(Arizona State University)  
**Assistant Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)**  
Neural basis of upper extremity motor function and deep brain stimulation in Parkinson's disease

Harirhara Baskaran, PhD  
(Pennsylvania State University)  
**Associate Professor, Chemical and Biomolecular Engineering**  
Design and build microvascular flow analogs that can be used to overcome nutrient limitations in tissue-engineered products

Jonathan Baskin, MD  
(New York University)  
**Associate Professor, Chief, Otolaryngology-Head & Neck Surgery, University Hospitals-Case Medical Center, VA Medical Center**  
Bioengineering of bone substitutes using nanotechnology

Arnold Caplan, PhD  
(Johns Hopkins University)  
**Professor, Biology**  
Development and refinement of the technology necessary to isolate a rare stem cell, the mesenchymal stem cell (MSC)

M. Cenk Cavusoglu, PhD  
(University of California, Berkeley)  
**Professor, Electrical Engineering & Computer Science**  
Robotics, systems and control theory, human-machine interfaces emphasizing medical robotics, haptics, virtual environments, surgical simulation, and bio-system modeling and simulation

John Chae, MD  
(New Jersey Medical School)  
**Professor, Physical Medicine and Rehabilitation, MetroHealth Medical Center**  
Stroke rehabilitation, neuromuscular electrical stimulation to restore upper and lower extremity function after stroke

Hillel J. Chiel, PhD  
(Massachusetts Institute of Technology)  
**Professor, Biology**  
Biomechanical and neural basis of feeding behavior in the marine mollusk Aplysia californica, neuromechanical system modeling, analysis of neural network dynamics

Margot Damaser, PhD  
(University of California)  
**Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)**  
Biomechanics and neural control of the female pelvic floor and lower urinary tract in normal and dysfunctional cases

Kathleen Derwin, PhD  
(University of Michigan)  
**Assistant Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)**  
Tendon mechanobiology and tissue engineering

Isabelle Deschenes, PhD  
(Laval University)  
**Professor, Cardiology, MetroHealth Medical Center**  
Molecular mechanisms of cardiac arrhythmias, ion channels structure-function

Agata Exner, PhD  
(Case Western Reserve University)  
**Professor, Radiology, University Hospitals-Case Medical Center**  
Development and imaging characterization of drug delivery for cancer chemotherapy; interventional radiology

Christopher Flask, PhD  
(Case Western Reserve University)  
**Associate Professor, Radiology, University Hospitals-Case Medical Center**  
Development of Quantitative and Molecular MRI Imaging Methods, MRI Physics

Roger French, PhD  
(Massachusetts Institute of Technology)  
**Professor, Materials Science and Engineering, Macromolecular Science and Engineering, Physics**  
Lifetime and degradation science, photovoltaics, OLED and LED lighting and displays, polymer degradation
Kiyotaka Fukamachi, MD, PhD
(Kyushu University)
Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)
Research activities entail promoting human health through the development of various surgical treatments for heart failure, encompassing a broad range of options

Linda M. Graham, MD
(University of Michigan)
Professor, Surgery, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)
Cell movement and vascular healing, vascular tissue engineering

Mark Griswold, PhD
(University of Wuerzburg, Germany)
Professor, Radiology, University Hospitals-Case Medical Center
Rapid magnetic resonance imaging, image reconstruction and processing and MRI hardware/instrumentation

Vikas Gulani, MD, PhD
(University of Illinois)
Associate Professor, Radiology, University Hospitals-Case Medical Center
Diffusion tensor imaging and diffusion anisotropy, MRI microscopy, body MRI, and functional MRI

Umut A Gurkan, PhD
(Purdue University)
Assistant Professor, Mechanical and Aerospace Engineering, Orthopaedics
Micro/nano engineered systems and biomedical technologies

Alex Y. Huang, MD, PhD
(Johns Hopkins University)
Associate Professor, Pediatrics, Pathology, University Hospitals-Case Medical Center/Rainbow Babies and Children’s Hospital
Study various aspects of anti-tumor immune responses, immune – host – pathogen interaction, T cell-mediated memory immunity, and chemokine - receptor biology

Michael Jenkins, PhD
(Case Western Reserve University)
Assistant Professor, Pediatrics, Biomedical Engineering
Biomedical imaging and instrumentation to determine congenital heart defects

Michael W. Keith, MD
(Ohio State University)
Professor, Orthopaedic Surgery, MetroHealth Medical Center
Restoration of motor function in hands

Kandice Kottke-Marchant, MD, PhD
(Case Western Reserve University)
Professor and Chair, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)
Thrombosis, hemostasis and vascular disease, hypercoagulable states, bleeding disorders, endothelial cell function, atherosclerosis

Vinod Labhasetwar, PhD
(Nagpur University, India)
Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)
Cancer treatment and detection, delivery of anti-oxidant enzymes in stroke and development of a non-stent approach to inhibition of restenosis

Kenneth R. Laurita, PhD
(Case Western Reserve University)
Associate Professor, Cardiology, MetroHealth Medical Center
Cellular mechanisms of cardiac arrhythmias using fluorescent imaging of transmembrane potential and intracellular calcium in the intact heart

Zhenghong Lee, PhD
(Case Western Reserve University)
Professor, Radiology, Nuclear Medicine, University Hospitals-Case Medical Center
Quantitative PET and SPECT imaging, multimodal image registration, 3D visualization, molecular imaging and small animal imaging systems

Kenneth Loparo, PhD
(Case Western Reserve University)
Professor, Electrical Engineering & Computer Science
Stability and control of nonlinear and stochastic systems; systems biology

Mehran Mehregany, PhD
(Massachusetts Institute of Technology)
Professor, Electrical Engineering & Computer Science
Micro/nano-electromechanical systems, silicon carbide semiconductor technology and microsystems, wireless health

Pedram Mohseni, PhD
(University of Michigan)
Associate Professor, Electrical Engineering & Computer Science
Biomicrosystems, biomedical microtelemetry, biological-electronic interfaces, microelectronics for neurotechnology and wireless integrated sensing/actuating systems

George F. Muschler, MD
(Northwestern University)
Professor, Molecular Medicine, Orthopaedic Surgery, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)
Bone biology, skeletal reconstruction, aging, osteoporosis

Raymond F. Muzic, Jr., PhD
(Case Western Reserve University)
Professor, Radiology, Biomedical Engineering, Oncology; University Hospitals-Case Medical Center
Quantitative analysis of biomedical imaging data, physiologic modeling, optimal experiment design, assessment of new radiopharmaceuticals, imaging response to therapy, and in vivo quantification of receptor concentration
Ela Plow, PhD PT  
(University of Minnesota)  
*Assistant Professor, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)*  
Neurological recovery in clinical rehabilitation, neural mechanisms of Functional Electrical Stimulation (FES)-based rehabilitative technique; tailored brain stimulation, tailored rehabilitation, patient specific treatments, functional neuroimaging, Transcranial Magnetic Stimulation (TMS), Transcranial Direct Current Stimulation (TDCS), Diffusion Tensor Imaging (DTI)

Tarun Podder, PhD  
(University of Hawaii)  
*Associate Professor, Radiation Oncology*  
Student mentoring and faculty collaboration

Anand Ramamurthi, PhD  
(Oklahoma State University)  
*Associate Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)*  
Artificial heart valves, tissue engineering, biomaterials, thrombosis

Julie Renner, PhD  
(Purdue University)  
*Assistant Professor*  
Development of protein engineered materials for use in and study of electrochemical systems

Clare Rimnac, PhD  
(Lehigh University)  
*Professor, Mechanical and Aerospace Engineering*  
Orthopaedic implant performance and design, mechanical behavior of hard tissues

Mark S. Rzeszotarski, PhD  
(Case Western Reserve University)  
*Professor, Radiology, MetroHealth Medical Center*  
Radiological imaging, computed tomography, medical education

Dawn Taylor, PhD  
(Arizona State University)  
*Assistant Professor, Molecular Medicine, Cleveland Clinic Lerner College of Medicine (Lerner Research Institute)*  
Restoration of movement and function to paralysis victims through the application of electrical current to the peripheral nerves

Jeffrey Ustin, MD  
(Stanford University School of Medicine)  
*Assistant Professor, Anesthesiology, University Hospitals*  
Synthetic platelet technology, robot assisted atrial fibrillation ablation, endotracheal tube technology

Jennell Vick, PhD  
(University of Washington, Seattle)  
*Assistant Professor, Communication Sciences, Pediatrics, Biomedical Engineering*  
Motor control, collaboration with faculty and student mentoring

Albert L. Waldo, MD  
(State University of New York, Downstate)  
*Professor, Medicine/Cardiology, University Hospitals-Case Medical Center*  
Cardiac electrophysiology and cardiac excitation mapping

Benjamin Walter, MD  
(MCP-Hahnemann School of Medicine, Philadelphia)  
*Associate Professor, Neurology*  
Neuromodulation with deep brain stimulation; student committee member and advisor

Russell Wang, DDS, MSD  
(Indiana University)  
*Associate Professor, Comprehensive Care, School of Dental Medicine*  
Dental implant design, instrumentation, bone regeneration, 3D printing of biomaterials, biomechanics of bone fracture, biomaterials for maxillofacial reconstruction

Gary Wnek, PhD  
(University of Massachusetts, Amherst)  
*Professor, Macromolecular Science and Engineering*  
Synthetic mimics of nerve, collagen solvent processing and drug delivery from polymer fibers

Xiong Yu, PhD, P.E.  
(Purdue University School of Civil Engineering)  
*Associate Professor, Civil Engineering*  
Materials and sensors innovations with emphasis on interdisciplinary innovation to improve intelligence and durability

Nicholas P. Ziats, PhD  
(Case Western Reserve University)  
*Professor, Pathology, University Hospitals-Case Medical Center*  
Vascular grafts, vascular cells, blood vessels

Christian Zorman, PhD  
(Case Western Reserve University)  
*Associate Professor, Electrical Engineering & Computer Science*  
Development of enabling materials for micro- and nanosystems

**Research Appointments**

Musa L. Audu, PhD  
(Case Western Reserve University)  
*Research Associate Professor*  
Human musculoskeletal modeling and development of control systems for rehabilitation of individuals with spinal cord injury and other balance disorders, design of rehabilitation devices for physically challenged individuals

Cong Truc Huynh, PhD  
(Sungkyunkwan University)  
*Research Assistant Professor*  
Polymeric drug delivery systems, biomaterials for functional tissue regeneration

Oju Jeon, PhD  
(Hanyang University)  
*Research Associate Professor*  
Development of biomaterials to create 3D bioprinted constructs for tissue engineering and regenerative medicine
Pubudu Peiris, PhD  
(Cleveland State University)  
Research Assistant Professor  
Development of impactful therapeutic and diagnostic agents for hard-to-treat and lethal forms of cancer

Tina Vrabec, PhD  
(Case Western Reserve University)  
Research Assistant Professor  
Novel waveforms, electrode designs, and electrode materials for control of the nervous system as applied to motor block, pain, and the autonomic system

Ethan Walker, MD, PhD  
(National Medical University; Institute of Tuberculosis & Pulmonology of the Academy of Medical Science of Ukraine)  
Research Assistant Professor  
Development of a live-time imaging technique to rapidly and reliably identify basal and squamous skin cancer in the margins of conventionally resected skin cancer samples that would significantly impact the quality of patient care

Xinning Wang, PhD  
(The Chinese University of Hong Kong)  
Research Assistant Professor  
Development of novel molecular image probes for the diagnosis of cancer, development of molecular cancer therapeutic approaches

Mei Zhang, PhD  
(Wuahan University)  
Research Assistant Professor  
Nanotechnology for cancer diagnosis and treatment, imaging and manipulation of tumor microenvironment, cancer immunotherapy, adoptive T cell immunotherapy

Adjunct Faculty

Niloy Bhadra, MD, PhD  
(Case Western Reserve University)  
Adjunct Assistant Professor  
Experimental and computational studies of high frequency waveforms for reversible conduction block of peripheral nerves, design, testing and implementation of neuroprosthetic systems for the upper limb

Kath Bogie, D. Phil  
(University of Oxford)  
Adjunct Assistant Professor, Biomedical Engineering (VA Medical Center)  
Wound prevention and treatment in individuals with paralysis and in the biomechanics of wheelchairs and seating for people with limited mobility

Michael Bruckman, PhD  
(University of South Carolina)  
Adjunct Assistant Professor  
Engineering viral nanoparticles for MRI detection of atherosclerosis in mice

Scott Bruder, MD, PhD  
(Case Western Reserve University)  
Adjunct Professor  
Advising MD/PhD students regarding careers in industry

Hossein Ghassemi, PhD  
(McGill University)  
Adjunct Assistant Professor  
Teaching, student mentoring and collaboration with faculty

Richard C. Burgess, MD, PhD  
(Case Western Reserve University)  
Adjunct Professor of Biomedical Engineering (Neurological Computing, Cleveland Clinic)  
Magnetoencephalography, electrophysiological monitoring, EEG processing, medical informatics

Andrew Cornwell, PhD  
(Case Western Reserve University)  
Adjunct Assistant Professor  
Electrical stimulation of the nervous system, especially for use in rehabilitation of neurological disorders

William J. Dupps, MD, PhD  
(The Ohio State University)  
Adjunct Associate Professor (Cole Eye Institute and Biomedical Engineering, Cleveland Clinic)  
Application of engineering tools to the diagnosis and management of biomechanical disorders such as keratoconus and glaucoma

Stephen Fening, PhD  
(Ohio University)  
Adjunct Associate Professor  
Patient care through translational research and commercialization

Jennifer Greene-Roos, PhD  
(Case Western Reserve University)  
Adjunct Assistant Professor (Cleveland Cord Blood Center)  
Umbilical cord monocytes for non-healing wounds and gene therapy to treat HIV infected lymphoma patients; collaboration with faculty and student mentoring

Elizabeth C. Hardin, PhD  
(University of Massachusetts)  
Adjunct Assistant Professor of Biomedical Engineering, (VA Medical Center)  
Neural prostheses and gait mechanics, improving gait performance with neural prostheses using strategies developed in conjunction with forward dynamics, musculoskeletal models

Thomas Hering, PhD  
(Case Western Reserve University)  
Adjunct Associate Professor (Orthopaedic Surgery, Washington University)  
Cartilage, extracellular matrix biochemistry and molecular biology; transscriptional regulation of chondrogenesis

Joseph Jankowski, PhD, MBA  
(Case Western Reserve University)  
Adjunct Professor  
Administration of multi-party translation and commercialization programs, intellectual property management, technology-based opportunity assessment, commercialization

Kevin L. Kilgore, PhD  
(Case Western Reserve University)  
Adjunct Assistant Professor, Biomedical Engineering, Orthopaedics, (MetroHealth Medical Center)  
Functional electrical stimulation; neuroprostheses
Nicola Lai, PhD  
(University of Pisa, Italy)  
Adjunct Associate Professor (Old Dominion University)  
Quantitative understanding of regulation of energy transfer and metabolism

Mary Laughlin, MD  
(State University of New York)  
Adjunct Professor (Cleveland Cord Blood Center)  
Development of monocytes, hematopoietic stem cells

Paul Marasco, PhD  
(Vanderbilt University)  
Adjunct Associate Professor  
Neural plasticity, sensory neurophysiology, brain organization, sensory integration with prosthetic devices

Aaron S. Nelson, MD  
(Medical College of Ohio)  
Adjunct Assistant Professor, Medical Director, MIMvista Corporation (Cleveland, OH)  
Multimodality and quantitative imaging for neurologic and cardiac disorders, oncology and radiation oncology

Marc Penn, MD, MD, PhD, FACC  
(Case Western Reserve University)  
Adjunct Professor (Director of Research, Summa Cardiovascular Institute, Summa Health System)  
Strategies for cardiovascular cell therapy to treat cardiac dysfunction

Suguna Rachakonda, PhD, MBA  
(University of Hyderabad)  
Adjunct Assistant Professor  
Consultation on technology commercialization

Fredy R. Zypman, PhD  
(Case Western Reserve University)  
Adjunct Professor  
Theoretical and computational applied physics, reconstruction of forces at the nanoscale from experimental atomic force microscopy measurements, and applications to electric and mechanical phenomena in soft matter including interactions in electrolytes; friction at the nanoscale; random systems

Courses

**EBME 105. Introduction to Biomedical Engineering. 3 Units.**  
This course introduces students to a wide variety of biomedical engineering fields including: biomaterials, biomechanics, biomedical devices & instrumentation, and biomedical computing & analysis. Emphasis is given to recognizing the difference between medical technology as a subject area vs. career tracks within which this subject area is: imagined, designed, fabricated and used. Students learn to distinguish the difference between how a scientist, an engineer, and a clinician are trained and interact with medical technology. Foundational topics like: engineering design, structure-function relationship, biomimicry, and biocompatibility are presented at an introductory level. Students well served by this course include: freshmen trying to decide if they want to major in biomedical engineering, freshman who know they want to major in biomedical engineering but are not certain which track they wish to pursue, and upper classmen in non-biomedical engineering majors who are looking for deeper insight into what this fast growing field is about.

**EBME 201. Physiology-Biophysics I. 3 Units.**  
Fundamental concepts of physiology from the cells to organ systems. Cell structure and function: DNA-RNA related enzyme/protein synthesis, membrane permeation (receptors/channels/gates), cellular biochemistry and energetic metabolic functions. Essential systems-level concepts include endocrinology, immunology, cellular/capillary/interphase transport, regulation of fluid volume, solutes, and pH. Liver, renal and respiratory physiology. Basic concepts in thermodynamics, transport and kinetics provide a framework for quantitative analysis and modeling of systems physiology. Prereq: Must have declared major or minor in Biomedical Engineering.

**EBME 202. Physiology-Biophysics II. 3 Units.**  
This course is an extension of EBME 201 that will include structure and function of (1) the nervous system, including vision, somatic and proprioceptive sensation, and control of movement, (2) skeletal and smooth muscle, (3) cardiac muscle and the cardiovascular system, and (4) the metabolic system. The material will be taught from a quantitative and functional perspective, with some examples of human pathophysiology. Prereq: EBME 201.

**EBME 300. Dynamics of Biological Systems: A Quantitative Introduction to Biology. 3 Units.**  
This course will introduce students to dynamic biological phenomena, from the molecular to the population level, and models of these dynamical phenomena. It will describe a biological system, discuss how to model its dynamics, and experimentally evaluate the resulting models. Topics will include molecular dynamics of biological molecules, kinetics of cell metabolism and the cell cycle, biophysics of excitability, scaling laws for biological systems, biomechanics, and population dynamics. Mathematical tools for the analysis of dynamic biological processes will also be presented. Students will manipulate and analyze simulations of biological processes, and learn to formulate and analyze their own models. This course satisfies a laboratory requirement for the biology major. Offered as BIOL 300 and EBME 300.
EBME 303. Structure of Biological Materials. 3 Units.
Structure of proteins, nucleic acids, connective tissue and bone, from molecular to microscopic levels. An introduction to bioengineering biological materials and biomimetic materials, and an understanding of how different instruments may be used for imaging, identification and characterization of biological materials. Offered as: EBME 303 and EMAC 303. Recommended preparation: EBME 201, EBME 202, and EMAC 270.

EBME 305. Materials for Prosthetics and Orthotics. 3 Units.
A synthesis of skeletal tissue structure and biology, materials engineering, and strength of materials concepts. This course is centered on deepening the concept of biocompatibility and using it to pose and solve biomaterials problems. We cover: fundamental concepts of materials used for load bearing medical applications, wear, corrosion, and failure of implants. Structure and properties of hard tissues and joints are presented using a size hierarchy motif. Tools and analysis paradigms useful in the characterization of biomaterials are covered in the context of orthopedic and dental applications. Prereq: EBME 306 and EBME 370 or Requisites Not Met permission.

EBME 306. Introduction to Biomedical Materials. 3 Units.
Biomaterials design and application in different tissue and organ systems. The relationship between the physical and chemical structure of biomaterials, functional properties, and biological response. Recommended preparation: EBME 201 and EBME 202.

EBME 307. Biomechanical Prosthetic Systems. 3 Units.
Introduction to the basic biomechanics of human movement and applications to the design and evaluation of artificial devices intended to restore or improve movement lost due to injury or disease. Measurement techniques in movement biomechanics, including motion analysis, electromyography, and gait analysis. Design and use of upper and lower limb prostheses. Principles of neuroprostheses with applications to paralyzed upper and lower extremities. Recommended preparation: Consent of instructor and senior standing. Prereq: EBME 308.

EBME 308. Biomedical Signals and Systems. 3 Units.

EBME 309. Modeling of Biomedical Systems. 3 Units.
Mathematical modeling and computational methods applied to biomedical systems. Spatially lumped and distributed models of electrical, mechanical, and chemical processes applied to cells, tissues, organ, and whole-body systems. Prereq: EBME 202 and EBME 308. Coreq: EBME 359.

EBME 310. Principles of Biomedical Instrumentation. 3 Units.
Physical, chemical, and biological, and system principles for biomedical measurements. Modular blocks and system integration. Sensors for displacement, force, pressure, flow, temperature, biopotentials, chemical composition of body fluids and biomaterial characterization. Patient safety related to instrumentation will also be covered. Prereq: EBME 308. Coreq: EBME 360.

EBME 316. Biomaterials for Drug Delivery. 3 Units.
The teaching objective is to provide students with a basic understanding of the principles of design and engineering of well-defined molecular structures and architectures intended for applications in controlled release and organ-targeted drug delivery. The course will discuss the therapeutic basic of drug delivery based on drug pharmacodynamics and clinical pharmacokinetics. Biomaterials with specialized structural and interfacial properties will be introduced to achieve drug targeting and controlled release. Offered as EBME 316 and EBME 416. Prereq: EBME 306.

EBME 318. Biomedical Engineering Laboratory. 1 Unit.
Experiments for measurement, assisting, replacement, or control of various biomedical systems. Students choose a few lab experiences from a large number of offerings relevant to all BME sequences. Experiments are conducted primarily in faculty labs with 3-8 students participating. Recommended preparation: ENGR 210. Prereq: BME Major, EBME 201, EBME 202 and Prereq or Coreq: EBME 308.

EBME 320. Medical Imaging Fundamentals. 3 Units.
General principles, instrumentation, and biomedical applications of medical imaging. Topics include: x-ray, ultrasound, MRI, nuclear imaging, image reconstruction, and image quality. Recommended preparation: EBME 308, ENGR 210, and EBME 202 or equivalent.

EBME 325. Introduction to Tissue Engineering. 3 Units.
The goal of this course is to present students with a firm understanding of the primary components, design principles, and engineering concepts central to the field of tissue engineering. First, the biological principles of tissue formation during morphogenesis and wound repair will be examined. The cellular processes underlying these events will be presented with an emphasis on microenvironment regulation of cell behavior. Biomimetic approaches to controlling cell function and tissue formation via the development of biomaterial systems will then be investigated. Case studies of regeneration strategies for specific tissues will be presented in order to examine the different tissue-specific engineering strategies that may be employed. Special current topics in tissue engineering will also be covered. Recommended preparation: EBME 306, BIOL 362, and CHEM 223.

EBME 327. Bioelectric Engineering. 3 Units.

EBME 328. Biomedical Engineering R&D Training. 1 Unit.
This course will provide research and development in the laboratory of a mentoring faculty member. Varied R&D experiences will include activities in biomedical instrumentation, tissue engineering, imaging, drug delivery, and neural engineering. Each Student must identify a faculty mentor, and together they will create description of the training experience prior to the first class. Prereq: EBME 201 and EBME 202.

EBME 350. Quantitative Molecular, Cellular and Tissue Bioengineering. 3 Units.
EBME 356. Introduction to Biomaterials Engineering - Laboratory. 1 Unit.
This is a core BME Laboratory course directed at providing Biomedical Engineering undergraduate students 'hands on' experience in a component of biomaterials engineering, specifically, biocompatibility. To that end, the course will focus on blood compatibility (hemocompatibility) of biomaterials, by teaching students how to analyze the interaction of blood components (proteins, platelets, RBCs) on biomedical relevant coated versus uncoated polymer surfaces. The students will learn important characterization techniques like contact angle measurement, UV-Vis spectroscopy and optical microscopy in the context of characterizing blood interactions with materials. Prereq: EBME 201 and EBME 202. Prereq or Coreq: EBME 306.

EBME 358. Biomedical Signals and Systems Laboratory. 1 Unit.
Computational laboratory experiences with biomedical applications. Numerical methods with MATLAB applications in biomedical engineering. Coreq: EBME 308.

EBME 359. Biomedical Computer Simulation Laboratory. 1 Unit.

EBME 360. Biomedical Instrumentation Laboratory. 1 Unit.
A laboratory which focuses on the basic components of biomedical instrumentation and provides hands-on experience for students in EBME 310, Biomedical Instrumentation. The purpose of the course is to develop design skills and laboratory skills in analysis and circuit development. Coreq: EBME 310.

EBME 361. Biomedical Image Processing and Analysis. 3 Units.
Principles of image processing and analysis with applications to clinical and biomedical research. Topics include image filtering, registration, morphological processing, segmentation, classification, and 3D image visualization. There will be interesting, realistic computer projects in Matlab. Offered as EBME 361 and EBME 461. Prereq: EBME 308.

EBME 370. Principles of Biomedical Engineering Design. 3 Units.
Students learn and implement the design process to produce working prototypes of medical devices with potential commercial value to meet significant clinical needs. Critical examination of contemporary medical problems is used to develop a specific problem statement. The class is divided into teams of 3 to 4 students. Each team integrates their knowledge and skills to design a device to meet their clinical need. Project planning and management, including resource allocation, milestones, and documentation, are required to ensure successful completion of projects within the allotted time and budget. Formal design reviews by a panel of advisors and outside medical device experts are required every four weeks. Every student is required to give oral presentations at each formal review and is responsible for formal documentation of the design process, resulting in an executive summary and complete design history file of the project. The course culminates with a public presentation of the team's device to a panel of experts. This course is expected to provide the student with a real-world, capstone design experience. Recommended preparation: EBME 310 Prereq: Senior standing or requisites not met permission.

EBME 380. Biomedical Engineering Design Experience. 3 Units.
This course is the culmination of the BME educational experience in which the student will apply acquired skills and knowledge to create a working device or product to meet a medical need. Students will learn how to apply engineering skills to solve problems and physically realize a project design. The course structure includes regular meetings with a faculty project advisor, regular reports of accomplished activity, hands on fabrication of devices, and several lectures from leading engineers from industry and academia that have first hand experience in applying the principles of design to Biomedical Engineering. Students will also provide periodic oral progress reports and a final oral presentation with a written design report. Counts as SAGES Senior Capstone. Prereq: EBME 370 and Senior standing or requisites not met permission.

EBME 389. Biomedical Engineering Research Experience I. 3 Units.
Biomedical engineering seniors can participate in a research project under the supervision of any qualified CWRU faculty member with the approval of a Primary BME faculty member. Guided by the supervising faculty member, each student develops and performs a research or design project. Students are encouraged to work with others in the faculty laboratory, but they must make a major contribution to the project. A research project is expected to include a significant engineering component, such as design and/or analysis. A design project must include a significant research component, such as applying the developed design to solve an actual biomedical problem. This course requires a final technical report and a short oral presentation by the student. In advance of registration, all students must submit a course proposal (see FORMS on the BME web site). This proposal must be approved by their research mentor and submitted via email for approval by the course instructor. This course can qualify as a technical elective if the project includes material pertinent to the student's BME track and is approved in advance by the BME faculty member responsible for the BME track. To be approved as a technical elective, the project proposal should identify the new technical material the student will master, and a plan for assessing mastery.

EBME 399. Biomedical Engineering Research Experience II. 3 Units.
Continuation of EBME 398. Consent of Instructor required. Prereq: EBME 398.

EBME 400T. Graduate Teaching I. 0 Unit.
This will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to consist of direct student contact, but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational opportunity for the student. Recommended preparation: UNIV 400, BME Ph.D. student.

EBME 401B. Biomedical Instrumentation and Signal Processing. 3 Units.
Graduate students with various undergraduate backgrounds will learn the fundamental principles of biomedical measurements that integrate instrumentation and signal processing with problem-based hands-on experience. Recommended preparation: Undergraduate circuit and signal processing class.

EBME 402. Organ/Tissue Physiology and Systems Modeling. 4 Units.
Graduate students with various undergraduate backgrounds will learn the fundamental principles of organ and tissue physiology as well as systems modeling. Prereq: Graduate Status.
EBME 406. Polymers in Medicine. 3 Units.
This course covers the important fundamentals and applications of polymers in medicine, and consists of three major components: (i) the blood and soft-tissue reactions to polymer implants; (ii) the structure, characterization and modification of biomedical polymers; and (iii) the application of polymers in a broad range of cardiovascular and extravascular devices. The chemical and physical characteristics of biomedical polymers and the properties required to meet the needs of the intended biological function will be presented. Clinical evaluation, including recent advances and current problems associated with different polymer implants. Recommended preparation: EBME 306 or equivalent. Offered as EBME 406 and EMAC 471. Prereq: Graduate Standing.

EBME 407. Neural Interfacing. 3 Units.
Neural interfacing refers to the principles, methods, and devices that bridge the boundary between engineered devices and the nervous system. It includes the methods and mechanisms to get information efficiently and effectively into and out of the nervous system to analyze and control its function. This course examines advanced engineering, neurobiology, neurophysiology, and the interaction between all of them to develop methods of connecting to the nervous system. The course builds on a sound background in Bioelectric Phenomenon to explore fundamental principles of recording and simulation, electrochemistry of electrodes in biological tissue, tissue damage generated by electrical stimulation, materials and material properties, and molecular functionalization of devices for interfacing with the nervous system. Several examples of the state-of-art neural interfaces will be analyzed and discussed. Recommended preparation: EBME 401. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 410. Medical Imaging Fundamentals. 3 Units.
Physical principles of medical imaging. Imaging devices for x-ray, ultrasound, magnetic resonance, etc. Image quality descriptions. Patient risk. Recommended preparation: EBME 308 and EBME 310 or equivalent. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 416. Biomaterials for Drug Delivery. 3 Units.
The teaching objective is to provide students with a basic understanding of the principles of design and engineering of well-defined molecular structures and architectures intended for applications in controlled release and organ-targeted drug delivery. The course will discuss the therapeutic basic of drug delivery based on drug pharmacodynamics and clinical pharmacokinetics. Biomaterials with specialized structural and interfacial properties will be introduced to achieve drug targeting and controlled release. Offered as EBME 316 and EBME 416. Prereq: EBME 306 and PHRM 309 or graduate standing.

EBME 419. Applied Probability and Stochastic Processes for Biology. 3 Units.
Applications of probability and stochastic processes to biological systems. Mathematical topics will include: introduction to discrete and continuous probability spaces (including numerical generation of pseudo random samples from specified probability distributions), Markov processes in discrete and continuous time with discrete and continuous sample spaces, point processes including homogeneous and inhomogeneous Poisson processes and Markov chains on graphs, and diffusion processes including Brownian motion and the Ornstein-Uhlenbeck process. Biological topics will be determined by the interests of the students and the instructor. Likely topics include: stochastic ion channels, molecular motors and stochastic ratchets, actin and tubulin polymerization, random walk models for neural spike trains, bacterial chemotaxis, signaling and genetic regulatory networks, and stochastic predator-prey dynamics. The emphasis will be on practical simulation and analysis of stochastic phenomena in biological systems. Numerical methods will be developed using a combination of MATLAB, the R statistical package, MCell, and/or URDME, at the discretion of the instructor. Student projects will comprise a major part of the course. Offered as BIOL 319, EECS 319, MATH 319, SYBB 319, BIOL 419, EBME 419, MATH 419, PHOL 419, and SYBB 419.

EBME 421. Bioelectric Phenomena. 3 Units.
The goal of this course is to provide working knowledge of the theoretical methods that are used in the fields of electrophysiology and bioelectricity for both neural and cardiac systems. These methods will be applied to describe, from a theoretical and quantitative perspective, the electrical behavior of excitable cells, the methods for recording their activity and the effect of applied electrical and magnetic fields on excitable issues. A team modeling project will be required. Recommended preparation: differential equations, circuits. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 425. Tissue Engineering and Regenerative Medicine. 3 Units.
This course will provide advanced coverage of tissue engineering with a focus on stem cell-based research and therapies. Course topics of note include stem cell biology and its role in development, modeling of stem cell function, controlling stem cell behavior by engineering materials and their microenvironment, stem cells’ trophic character, and state-of-the-art stem cell implementation in tissue engineering and other therapeutic strategies. Prereq: PhD student in an engineering program or EBME 325 or requisites not met permission.

EBME 426. Nanomedicine. 3 Units.
EBME 427. Movement Biomechanics and Rehabilitation. 3 Units.
Introduction to the basic biomechanics of human movement and applications to the design and evaluation of artificial devices intended to restore or improve movement lost due to injury or disease. Measurement techniques in movement biomechanics, including motion analysis, electromyography, and gait analysis. Design and use of upper and lower limb prostheses. Principles of neuroprostheses with applications to paralyzed upper and lower extremities. Term paper required. Recommended preparation: Consent of instructor and graduate standing. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 431. Physics of Imaging. 3 Units.
Description of physical principles underlying the spin behavior in MR and Fourier imaging in multi-dimensions. Introduction of conventional, fast, and chemical-shift imaging techniques. Spin echo, gradient echo, and variable flip-angle methods. Projection reconstruction and sampling theorems. Bloch equations, T1 and T2 relaxation times, rf penetration, diffusion and perfusion. Flow imaging, MR angiography, and functional brain imaging. Sequence and coil design. Prerequisite may be waived with consent of instructor. Recommended preparation: PHYS 122 or PHYS 124 or EBME 410. Offered as EBME 431 and PHYS 431.

EBME 432. Quantitative Analysis of Physiological Systems. 3 Units.

EBME 433. Advanced Topics for Physiological Systems Analysis. 4 Units.

EBME 440. Translational Research for Biomedical Engineers. 3 Units.
Translational Research (TR) in the Biomedical Engineering context means translating laboratory discoveries or developments into improved health care. Topics and activities include: Interdisciplinary teamwork and communication; Research ethics and human subjects protection; Regulation and oversight of human subjects and animal research; Clinical validation study design and biostatistics; Intellectual property, technology transfer and commercialization; Physician shadowing; Attending Grand Rounds and Morbidity-Mortality conferences; Preparing IRB and IACUC protocols; Final integrative project. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 447A. Rehabilitation for Scientists and Engineers. 0 Unit.
Medical, psychological, and social issues influencing the rehabilitation of people with spinal cord injury, stroke, traumatic brain injury, and limb amputation. Epidemiology, anatomy, pathophysiology and natural history of these disorders, and the consequences of these conditions with respect to impairment, disability, handicap, and quality of life. Students will directly observe the care of patients in each of these diagnostic groups throughout the full continuum of care starting from the acute medical and surgical interventions to acute and subacute rehabilitation, outpatient medical and rehabilitation management and finally to community re-entry.

EBME 447B. Rehabilitation for Scientists and Engineers. 3 Units.
Medical, psychological, and social issues influencing the rehabilitation of people with spinal cord injury, stroke, traumatic brain injury, and limb amputation. Epidemiology, anatomy, pathophysiology and natural history of these disorders, and the consequences of these conditions with respect to impairment, disability, handicap, and quality of life. Students will directly observe the care of patients in each of these diagnostic groups throughout the full continuum of care starting from the acute medical and surgical interventions to acute and subacute rehabilitation, outpatient medical and rehabilitation management and finally to community re-entry. Coreq: EBME 447A.

EBME 451. Molecular and Cellular Physiology. 3 Units.
This course covers cellular and molecular basics for graduate students with little or no prior biology background. The emphasis of EBME 451 is on the molecular and cellular mechanisms underlying physiological processes. Structure-function relationship will be addressed throughout the course. The primary goal of the course is to develop understanding of the principles of the physiological processes at molecular and cellular level and to promote independent thinking and ability to solve unfamiliar problems. This course is no longer a core course of the Biomedical Engineering graduate curriculum but serves as a fundamentals course to prepare students for the graduate cellular and molecular physiology core. Prereq: Graduate standing.

EBME 460. Advanced Topics in NMR Imaging. 3 Units.
Frontier issues in understanding the practical aspects of NMR imaging. Theoretical descriptions are accompanied by specific examples of pulse sequences, and basic engineering considerations in MRI system design. Emphasis is placed on implications and trade-offs in MRI pulse sequence design from real-world versus theoretical perspectives. Recommended preparation: EBME 431 or PHYS 431. Offered as EBME 460 and PHYS 460. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 461. Biomedical Image Processing and Analysis. 3 Units.
Principles of image processing and analysis with applications to clinical and biomedical research. Topics include image filtering, registration, morphological processing, segmentation, classification, and 3D image visualization. There will be interesting, realistic computer projects in Matlab. Offered as EBME 361 and EBME 461. Prereq: EBME 401.

EBME 465. Biomedical Optical Imaging. 3 Units.
Fundamentals of biomedical optics (biophotonics) with a focus on concepts and instrumentation behind light-based imaging of biological tissues. Topics include: essentials of optics and photonics, light-tissue interactions, optical imaging, conventional and advanced microscopies, optical coherence tomography. Course will include hands-on labs and demonstrations. Prereq: EBME 308 and (Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above) or Requisites Not Met permission.
EBME 467. Commercialization and Intellectual Property Management. 3 Units.
This interdisciplinary course covers a variety of topics, including principles of intellectual property and intellectual property management, business strategies and modeling relevant to the creation of start-up companies and exploitation of IP rights as they relate to biomedical-related inventions. The goal of this course is to address issues relating to the commercialization of biomedical-related inventions by exposing law students, MBA students, and Ph.D. candidates (in genetics and proteomics) to the challenges and opportunities encountered when attempting to develop biomedical intellectual property from the point of early discovery to the clinic and market. Specifically, this course seeks to provide students with the ability to value a given technological advance or invention holistically, focusing on issues that extend beyond scientific efficacy and include patient and practitioner value propositions, legal and intellectual property protection, business modeling, potential market impacts, market competition, and ethical, social, and healthcare practitioner acceptance. During this course, law students, MBA students, and Ph.D. candidates in genomics and proteomics will work in teams of five (two laws students, two MBA students and one Ph.D. candidate), focusing on issues of commercialization and IP management of biomedical-related inventions. The instructors will be drawn from the law school, business school, and technology-transfer office. Please visit the following website for more information: fusioninnovate.com. Offered as LAWS 5341, MGMT 467, GENE 467, EBME 467 and EECS 467.

EBME 471. Principles of Medical Device Design and Innovation. 3 Units.
Translational research leading to medical device innovation is highly interdisciplinary, requiring a systematic, structured approach to bringing new medical technologies to market. This course provides the fundamental principles of the Biodesign innovation process, providing the student the essential tools to (A) identify unmet clinical needs, (B) create innovative medical device concepts that respond to a primary unmet need, and (C) understand the process for translating these concepts into the market. In short, the student learns the fundamental principles for the process of identify, invent, implement in the field of Biodesign.

EBME 472. BioDesign. 3 Units.
Medical device innovations that would have been considered science fiction a decade ago are already producing new standards of patient care. Innovation leading to lower cost of care, minimally invasive procedures and shorter recovery times is equally important to healthcare business leaders, educators, clinicians, and policy-makers. Innovation is a driver of regional economic development and wealth creation in organizational units ranging in size from the start-up to the Fortune 500 companies. In a broader context, the pace of translational research leading to product and service innovation is highly interdisciplinary; thus, new products and services result from team efforts, marked by a systematic, structured approach to bringing new medical technologies to market and impacting patient care. In this course we examine medical technology innovations in the context of (A) addressing unmet clinical needs, (B) the process of inventing new medical devices and instruments, and (C) subsequent implementation of these advances in patient care. In short, the student learns the process of "identify, invent, implement" in the field of BioDesign. Offered as EBME 472, IIME 472 and SYBB 472.

EBME 473. Fundamentals of Clinical Information Systems. 3 Units.
Technology has played a significant role in the evolution of medical science and treatment. While we often think about progress in terms of the practical application of, say, imaging to the diagnosis and monitoring of disease, technology is increasingly expected to improve the organization and delivery of healthcare services, too. Information technology plays a key role in the transformation of administrative support systems (finance and administration), clinical information systems (information to support patient care), and decision support systems (managerial decision-making). This introductory graduate course provides the student with the opportunity to gain insight and situational experience with clinical information systems (CIS). Often considered synonymous with electronic medical records, the "art" of CIS more fundamentally examines the effective use of data and information technology to assist in the migration away from paper-based systems and improve organizational performance. In this course we examine clinical information systems in the context of (A) operational and strategic information needs, (B) information technology and analytic tools for workflow design, and (C) subsequent implementation of clinical information systems in patient care. Legal and ethical issues are explored. The student learns the process of "plan, design, implement" through hands-on applications to select CIS problems, while at the same time gaining insights and understanding of the impacts placed on patients and health care providers. Offered as EBME 473, IIME 473 and SYBB 421.

EBME 474. Biotransport Processes. 3 Units.
Biomedical mass transport and chemical reaction processes. Basic mechanisms and mathematical models based on thermodynamics, mass and momentum conservation. Analytical and numerical methods to simulate in vivo processes as well as to develop diagnostic and therapeutic methods. Applications include transport across membranes, transport in blood, tumor processes, bioreactors, cell differentiation, chemotaxis, drug delivery systems, tissue engineering processes. Recommended preparation: EBME 350 or equivalent. Offered as EBME 474 and ECHE 474.

EBME 478. Computational Neuroscience. 3 Units.
Computer simulations and mathematical analysis of neurons and neural circuits, and the computational properties of nervous systems. Students are taught a range of models for neurons and neural circuits, and are asked to implement and explore the computational and dynamic properties of these models. The course introduces students to dynamical systems theory for the analysis of neurons and neural learning, models of brain systems, and their relationship to artificial and neural networks. Term project required. Students enrolled in MATH 478 will make arrangements with the instructor to attend additional lectures and complete additional assignments addressing mathematical topics related to the course. Recommended preparation: MATH 223 and MATH 224 or BIOL 300 and BIOL 306. Offered as BIOL 378, MATH 378, BIOL 478, EBME 478, EECS 478, MATH 478 and NEUR 478.

EBME 480A. Introduction to Wireless Health. 3 Units.
Study of convergence of wireless communications, microsystems, information technology, persuasive psychology, and health care. Discussion of health care delivery system, medical decision-making, persuasive psychology, and wireless health value chain and business models. Understanding of health information technology, processing of health monitoring data, wireless communication, biomedical sensing techniques, and health monitoring technical approaches and solutions. Offered as EECS 480A and EBME 480A.
EBME 480B. The Human Body. 3 Units.
Study of structural organization of the body. Introduction to anatomy, physiology, and pathology, covering the various systems of the body. Comparison of elegant and efficient operation of the body and the related consequences of when things go wrong, presented in the context of each system of the body. Introduction to medical diagnosis and terminology in the course of covering the foregoing. Offered as EECS 480B and EBME 480B.

EBME 480C. Biomedical Sensing Instrumentation. 3 Units.
Study of principles, applications, and design of biomedical instruments with special emphasis on transducers. Understanding of basic sensors, amplifiers, and signal processing. Discussion of the origin of biopotential, and biopotential electrodes and amplifiers (including biotelemetry). Understanding of chemical sensors and clinical laboratory instrumentation, including microfluidics. Offered as EECS 480C and EBME 480C. Prereq: EECS/EBME 480A, EECS/EBME 480B

EBME 480D. The Health Care Delivery Ecosystem. 3 Units.
Health care delivery across the continuum of care in the United States, including health policy and reform, financing of care, comparative health systems, population health, public health, access to care, care models, cost and value, comparative effectiveness, governance, management, accountability, workforce, and the future. Discussions of opportunities and challenges for wireless health, integrated into the foregoing topics. Perspective on health care delivery in other countries. Offered as EECS 480D and EBME 480D.

EBME 480E. Wireless Communications and Networking. 3 Units.
Essentials of wireless communications and networking, including teletraffic engineering, radio propagation, digital and cellular communications, wireless wide-area network architecture, speech and channel coding, modulation schemes, antennas, security, networking and transport layers, and 4G systems. Hands-on learning of the anatomy of a cell phone, and a paired wireless health device and its gateway. Offered as EECS 480E and EBME 480E.

EBME 480F. Physicians, Hospitals and Clinics. 3 Units.
Rotation through one or more health care provider facilities for a first-hand understanding of care delivery practice, coordination, and management issues. First-hand exposure to clinical personnel, patients, medical devices and instruments, and organizational workflow. Familiarity with provider protocols, physician referral practices, electronic records, clinical decision support systems, acute and chronic care, and inpatient and ambulatory care. Offered as EECS 480F and EBME 480F.

EBME 480G. Introduction to Medical Informatics. 3 Units.
Current state and emerging trends in Medical Informatics (MI) and associated health information systems. Principles, data, data management, system interoperability, patient privacy, information security, electronic records, telehealth, regulatory issues, clinical decision support, mobile documentation, devices and wireless communications in healthcare. Impact of wireless technology on emerging health information systems and processes. Offered as EECS 480G and EBME 480G.

EBME 480H. Introduction to Health Information Technology Implementation. 3 Units.
Current state and emerging trends in the implementation and adoption of health information technology (HIT). Macroergonomics; Technology transfer and adoption; Systems adoption life cycle; Impact of regulation; Decision and work transformation; HIT specification and acquisition; Contracting issues; Implementation, use, and evaluation; Impact of wireless technology on emerging processes. Offered as EECS 480H and EBME 480H. Prereq: EBME 480M.

EBME 480P. Advanced Biomedical Instrumentation. 3 Units.
Analysis and design of biosensors in the context of biomedical measurements. Base sensors using electrochemical, optical, piezoelectric, and other principles. Binding equilibria, enzyme kinetics, and mass transport modalities. Adding the "bio" element to base sensors and mathematical aspects of data evaluation. Applications to clinical problems and biomedical research. Offered as EECS 480P and EBME 480P.

EBME 480Q. Regulatory Policy and Regulations. 3 Units.
Introduction of wireless health technologies: spectrum, licensed versus unlicensed; personal area networks; body area networks; ultra-wideband low energy level short-range radios; wireless local area networks; wide area networks. The Federal system: separation of powers; the executive branch and its departments; the House of Representatives and its committees; the Senate and its committees; the FCC; policy versus regulatory versus legislative. What is a medical device: FDA; classification system; radiation-emitting products; software; RF in medical devices; converged medical devices; international aspects. Regulation of health information technology and wireless health: American Recovery and Reinvestment Act; Patient Protection and Affordable Care Act; FCC/FDA MoU; CMS and Reimbursement; privacy and security. Offered as EECS 480Q and EBME 480Q.

EBME 480R. User Experience Engineering. 3 Units.
Social, cognitive, behavioral, and contextual elements in the design of healthcare technology and systems. User-centered design paradigm from a broad perspective, exploring dimensions of product user experience and learning to assess and modify the design of healthcare technology. Practical utilization of user centered design method and assessment techniques for approaching a design problem. Offered as EECS 480R and EBME 480R.

EBME 480S. Wireless Health Product Development. 3 Units.
Integrating application requirements, market data, concept formulation, design innovation, and manufacturing resources for creating differentiated wireless health products that delight the user. Learning user-centric product development best practices, safety, security and privacy considerations, and risk management planning. Understanding the regulatory process. Identifying and managing product development tradeoffs. Offered as EECS 480S and EBME 480S. Prereq: EBME 480R.

EBME 4891. Introduction to Translational Health Technology. 2 Units.
Introduction to Translational Health Technology serves as the orientation and launch of the year-long Masters of Translational Health Technology program. Sessions are designed to orient students to this fast-paced, lock-step, interdisciplinary program so they are adequately coached and prepared for the road ahead in the translation of leading-edge research into patient care. In addition to providing specific instructional elements, this course also helps set program expectations, norms, and metrics of successful student performance. The course of study includes invited capstone project presentations by the incumbent (prior year) students or other graduate students; such project discussions enable: (A) BME masters degree students completing their studies a chance to reflect on their research and project work and, (B) for new students completing orientation to develop first-hand experience with the process of inquiry and debate relating to the field of translational health technology.
EBME 500T. Graduate Teaching II. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to consist of direct student contact, but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational opportunity for the students. Recommended preparation: EBME 400T, BME Ph.D. student.

EBME 507. Motor System Neuroportheses. 3 Units.
Fundamentals of neural stimulation and sensing, neurophysiology and pathophysiology of common neurological disorders, general implantation and clinical deployment issues. Specialist discussions in many application areas such as motor prostheses for spinal cord injury and stroke, cochlear implants, bladder control, stimulation for pain management, deep brain stimulation, and brain computer interfacing. Prereq: Graduate standing.

EBME 570. Graduate Professional Development for Biomedical Engineers. 1 Unit.
Students will be trained in topics including public speaking, grant writing, notebook management, professionalism, etc. Prereq: Graduate standing.

EBME 600T. Graduate Teaching III. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to consist of direct student contact, but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational opportunity for the students. Recommended preparation: EBME 500T, BME Ph.D. student.

EBME 601. Research Projects. 1 - 18 Units.

EBME 602. Special Topics. 1 - 18 Units.

EBME 611. BME Departmental Seminar I. .5 Unit.
Lectures by invited speakers on subjects of current interest in biomedical engineering. Students will be evaluated on reading and preparation of questions for select speakers, as well as weekly participation. Between this course and EBME 612 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters.

EBME 612. BME Departmental Seminar II. .5 Unit.
Lectures by invited speakers on subjects of current interest in biomedical engineering. Students will be evaluated on reading and preparation of questions for select speakers, as well as weekly participation. Between this course and EBME 611 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters.

EBME 613. Topic Seminars for NeuroEngineering Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in NeuroEngineering. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 614 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 614. Topic Seminars for NeuroEngineering Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in NeuroEngineering. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 613 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 615. Topic Seminars for Imaging Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Imaging. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 616 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 616. Topic Seminars for Imaging Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Imaging. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 615 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 617. Topic Seminars for Biomaterials Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 618 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 618. Topic Seminars for Biomaterials Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 617 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 619. Topic Seminars for Miscellaneous Biomedical Engineering Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in outside of NeuroEngineering, Imaging, and Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 620 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 620. Topic Seminars for Miscellaneous Biomedical Engineering Students. .5 Unit.
Lectures by students in the seminar series on subjects of current interest to biomedical engineering students outside of NeuroEngineering, Imaging, and Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 619 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 651. Thesis M.S.. 1 - 18 Units.

EBME 695. Project M.S.. 1 - 9 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in the EBME Plan B MS Program.
EBME 701. Dissertation Ph.D.. 1 - 9 Units.
Ph.D. candidates only. Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.