The faculty and students of the Johns Hopkins Department of Biomedical Engineering, founded more than 50 years ago, are engineering the future of medicine. Consistently ranked the #1 BME program in the nation, we are pushing the boundaries of discovery and innovation, pioneering new and emerging disciplines of biomedical engineering that in turn drive our academic programs.

Biomedical engineering is an interdisciplinary endeavor, and new discoveries and technological advances require a variety of experimental and computational approaches. Our unique positioning within the Johns Hopkins Whiting School of Engineering and the Johns Hopkins School of Medicine provides students and faculty with opportunities to engage with other leading engineers, scientists, and physicians. Together, we are developing the disruptive technologies that will transform the practice of medicine and improve human health. Many of these technologies are currently used in the clinic to diagnose and treat diseases, from cardiac arrhythmias and sepsis to Alzheimer’s and cancer. Examples of Hopkins BME advances include new drug delivery methods, diagnostic imaging devices, artificial organs and orthopedic implants, prosthetic limbs, and patient-specific quantitative models of disease.

Hopkins BME is training the next generation of leaders in biomedical engineering through academic programs at three levels:

1. an undergraduate program, leading to a B.S. degree
2. three master’s programs, leading to an MSE degree in biomedical engineering, with course-based or thesis-based options; an MSE in bioengineering innovation and design; or dual MSE and MS degrees from Johns Hopkins BME and Tsinghua University in Beijing, China, respectively
3. a doctoral program, leading to a Ph.D. degree

At both the undergraduate and graduate levels, we are transforming the BME educational landscape through BME 2.0, an integrative learning experience in which every student is an active participant in our discovery, innovation, and translation efforts. Supported by our personalized advising program, students at all levels will specialize in one of several cutting-edge biomedical engineering focus areas derived from our research expertise. These focus areas include:

- biomedical data science
- biomedical imaging and instrumentation
- computational medicine
- genomics and systems biology
- neuroengineering
- regenerative and immune engineering

Through project-based courses and hands-on learning experiences, our students will apply their knowledge in these areas to solve real-world clinical, design, and engineering problems. Combined with advanced research and design opportunities, these experiences ensure that our graduates are well prepared for careers in industry, medicine, or research.

Facilities

Situated on both the Homewood and School of Medicine campuses, our research and educational spaces are equipped to support a broad range of interdisciplinary discovery and innovation efforts.

At the School of Medicine campus, faculty members maintain laboratories supplied with a wide variety of equipment in the Traylor, Ross, Rangos, Miller, and Smith research buildings. This location fosters a close association with other basic biomedical science programs and provides access to the clinical environment of one of the nation’s top-ranked hospitals.

The Homewood campus is home to Clark Hall, a dedicated BME space that features research laboratories, classrooms, and conference spaces. Clark Hall also houses the BME Design Studio, a premiere workspace where students can design and develop solutions to clinical and global health challenges. To maintain close ties with clinical collaborators, the Design Studio is connected around-the-clock to similar BME student design spaces located on the School of Medicine campus. BME students at all levels, from freshman to graduate students, are able to work in our design spaces and research labs, ensuring that they can begin practicing the discipline on their very first day at Hopkins.

Additional Hopkins BME amenities include physiology teaching laboratories, microscope facilities, a microfabrication laboratory, tissue culture rooms, a fully-staffed mechanical shop, conference and seminar spaces that allow broadcasting throughout the university, and state-of-the-art 3-D printing facilities designed to support a broad range of prototyping needs.

Our faculty and students also have access to ample resources through our affiliations with several of the Johns Hopkins institutes and centers that have emerged from Hopkins BME research activities. Hotbeds for interdisciplinary scientific collaborations, these centers and institutes, all of which are directed or co-directed by Hopkins BME faculty, include the Institute for Computational Medicine, Center for Imaging Science, Carnegie Center for Surgical Innovation, Translational Tissue Engineering Center, Kavli Neuroscience Discovery Institute, Mathematical Institute for Data Science, and Center for Hearing and Balance. Hopkins BME is also home to the Center for Bioengineering Innovation and Design, which oversees our renowned graduate design program. In addition to these affiliated centers and institutes, our faculty have ongoing collaborations with scientists and physicians throughout the various Johns Hopkins divisions, including the Applied Physics Lab, School of Public Health, Krieger School of Arts and Sciences, and Carey Business School.

The profoundly interdivisional nature of Hopkins BME provides students with access to a wide range of university resources, including computing laboratories, libraries, and core facilities for microscopy, flow cytometry, sequencing and genetics, creating CRISPR/Cas9-based transgenic strains, and more. These amenities allow our students to produce the innovative technologies and groundbreaking research discoveries that result in patents, start-up companies, high-impact publications, and a better standard of health care for people across the globe.

Undergraduate Programs

The mission of the undergraduate programs is to provide state-of-the-art biomedical engineering education to students in order that they may continue their education in graduate, medical, and professional schools or pursue careers in industry. To this end, our responsibility is as much to the future as it is to the present. Through a strong research and educational environment, we strive to empower our students to explore and define their own frontiers as well as instill the ethical principles that will foster rewarding professional endeavors. The B.S. in Biomedical Engineering degree program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.
The biomedical engineering program normally leads to the bachelor of science degree and requires at least 129 credits. The B.S. program is recommended for students who plan careers in engineering or who plan to attend graduate school in engineering. If a student wishes to take a more flexible program with less emphasis on engineering, a B.A. program is also available. Either the B.S. or the B.A. program can meet the needs of a student who plans graduate study in a nonengineering area.

The undergraduate program provides a strong foundation in mathematics, engineering, and science. It emphasizes preparation for advanced study in an area related to biomedical engineering and is broad enough to accommodate students who plan graduate work in biology, medicine, engineering, biophysics, physiology, or biomedical engineering.

Our fundamental focus is to instill a passion for learning, scientific discovery, innovation and entrepreneurial spirit, and societal impact on an extraordinary group of students who will become:

• Adept at applying their engineering and biological training to solving problems related to health and healthcare that are globally relevant and based on ethically sound principles.
• Leaders in their respective careers in biomedical engineering or interrelated areas of industry, government, academia, and clinical practice.
• Engaged in life-long learning by continuing their education in graduate or professional school or through opportunities for advanced career or professional training.

Each student plans a curriculum suited to his or her goals with the assistance of a faculty advisor. Upon completion of the B.S. in biomedical engineering, students will demonstrate the ability to:

• apply knowledge of advanced mathematics, life sciences, natural sciences, and principles of engineering to problems at the interface of engineering, biology, and medicine and mathematically model and simulate biological systems using computers.
• design and conduct experiments, as well as analyze and interpret data; formulate hypotheses for experiments, including those on living systems; devise procedures for experiments, including those on living systems; collect and validate data using appropriate equipment; display, describe, summarize, and interpret experimental results in a lab report; relate the experimental results to previous work, including the interaction between living and non-living materials and systems; and practice lab safety.
• 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; identify a need and define the biomedical engineering problem to be solved, determine the constraints to the problem and assess the successful likelihood for different approaches, undergo the design process of creation, synthesis, and integration and evaluate success of the design to meet the desired need.
• function on multidisciplinary teams; understand team goals and complementary roles and expertise of each team member; share opinions and viewpoints with other team members; and assume and fulfill individual responsibilities within a team.
• identify, formulate, and solve engineering problems; conceptualize the engineering problem, formulate a solution to the problem, and solve problems using experimental, mathematical and/or computational tools.
• understand professional and ethical responsibility; understand the guidelines for ethical and responsible use of animals for research; understand professional and ethical standards in the workplace and properly reference the work of others.
• communicate effectively; synthesize, summarize, and explain technical content in a written report; and synthesize, summarize, and explain technical content in an oral presentation.
• understand the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; understand the contributions biomedical engineers can play in academia, industry, and government; and understand how biomedical engineering solutions are of benefit inside and outside the U.S.
• recognize the need for, and gain an ability to engage in, life-long learning; use library resources, professional journals, and Internet effectively; update technical literacy to understand contemporary issues; and recognize the need for self-assessment.
• comprehend contemporary issues; understand recent developments in biomedical engineering; understand differing viewpoints in academia, government, industry, and business; and gain the ability to search and critically evaluate scientific literature.
• use the techniques, skills, and modern engineering tools necessary for engineering practice; gain proficiency in computer simulations and mathematical analysis tools; create mathematical models; develop laboratory skills applied to living systems; and utilize data acquisition systems.

The program also encourages individual study and research and gives academic credit for them. Students are welcome to work in laboratories on the Homewood campus or at the Medical Institutions in East Baltimore.

Bachelor of Science in Biomedical Engineering

Students seeking the B.S. degree are encouraged to focus their studies on one of five subspecialties that incorporates traditional engineering disciplines and biomedical applications. See the Biomedical Engineering Undergraduate Advising Manual for specific on focus areas, lists of recommended mathematics and engineering electives, limitations on credits for courses with overlapping material, and the design content of engineering courses.

Requirements for the B.S. Degree

(See also General Requirements for Departmental Majors [http://catalog.jhu.edu/undergrad-students/academic-policies/requirements-for-a-bachelors-degree].)

The B.S. degree in biomedical engineering requires 129 credits. The courses listed below must either be taken or passed by examination for advanced credit. All courses used to satisfy degree requirements must be taken for a grade (no satisfactory/unsatisfactory grading may be counted). No more than 6 credits of engineering, science, or mathematics courses in which a grade of D was received may be counted.

Basic Sciences (18 credits) 1

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.171.101</td>
<td>General Physics: Physical Science Major I</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.107</td>
<td>General Physics for Physical Sciences Majors (AL)</td>
<td></td>
</tr>
<tr>
<td>AS.171.102</td>
<td>General Physics: Physical Science Major II</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.108</td>
<td>General Physics for Physical Sciences Majors (AL)</td>
<td></td>
</tr>
<tr>
<td>AS.173.111</td>
<td>General Physics Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>AS.173.112</td>
<td>General Physics Laboratory II</td>
<td>1</td>
</tr>
</tbody>
</table>
AS.030.101 Introductory Chemistry I 3
AS.030.102 Introductory Chemistry II 3
AS.030.105 Introductory Chemistry Laboratory I 1
AS.030.106 Introductory Chemistry Laboratory II 1

**Mathematics (20 credits)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.108 Calculus I</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.109 Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.202 Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.211 Honors Multivariable Calculus</td>
<td></td>
</tr>
<tr>
<td>EN.553.291 Linear Algebra and Differential Equations</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.311 Probability and Statistics for the Biological Sciences and Engineering</td>
<td>3-4</td>
</tr>
<tr>
<td>or EN.553.310 Probability &amp; Statistics</td>
<td></td>
</tr>
<tr>
<td>or EN.553.413 Applied Statistics and Data Analysis</td>
<td></td>
</tr>
<tr>
<td>or EN.553.430 Introduction to Statistics</td>
<td></td>
</tr>
<tr>
<td>or EN.553.431 Statistical Methods in Imaging</td>
<td></td>
</tr>
<tr>
<td>or EN.553.433 Monte Carlo Methods</td>
<td></td>
</tr>
<tr>
<td>or EN.560.348 Probability &amp; Statistics in Civil Engineering</td>
<td></td>
</tr>
</tbody>
</table>

**Humanities and Social Sciences (18 credits)**

These courses should form a coherent program, relevant to the student's goals, with at least one course at the 300-level or higher. They should include:

- One course in which ethical and social issues related to technology or medicine is recommended.
- At least two semesters of writing-intensive courses.

**Biomedical Core (30 credits)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.580.111 BME Modeling and Design</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.221 Molecules and Cells</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.241 Statistical Physics</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.242 Biological Models and Simulations</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.243 Linear Signals and Systems</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.244 Nonlinear Dynamics of Biological Systems</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.246 Systems and Controls</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.248 Systems Biology of the Cell</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.421 Systems Bioengineering I</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.423 Systems Bioengineering Lab I</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.422 Systems Bioengineering II</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.424 Systems Bioengineering Lab</td>
<td>2</td>
</tr>
<tr>
<td>Career Exploration in BME</td>
<td>4</td>
</tr>
</tbody>
</table>

**Focus Area (21 credits)**

Each student is required to complete one of six Biomedical Engineering focus areas.

**Design (6 credits)**

Among the technical elective courses offered, at least 6 credits must come from an approved list of design options.

**Computer Programming**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.500.112 Gateway Computing</td>
<td>3</td>
</tr>
</tbody>
</table>

**Free Electives**

Students can choose from any area.

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1 Students who receive credit for AP Physics I and/or Physics II will receive a waiver for the laboratory course. This will reduce the required number of credits for Basic Sciences by 1 or 2 credits. Students are still required to complete at least 129 total credits for the degree.

2 Students who take an approved math course and receive 3 credits will have a total of 19 credits. Students are still required to complete at least 129 total credits for the degree.

3 See Writing Requirement (http://e-catalog.jhu.edu/undergrad-students/academic-policies/requirements-for-a-bachelors-degree).

4 Career Exploration in BME is a 0-credit self-identified set of career related events (lectures, panels, journal clubs, etc.) beginning in the spring semester of year one and continuing until graduation. Career Exploration is administered through a Community Blackboard site; students will be enrolled by the department.
Building on the foundation of the core curriculum, each student is required to take a cohesive sequence of advanced engineering encompassing one of six Biomedical Engineering focus areas. A student’s choice of focus area is made during the sophomore year and is based on their experience with the Biomedical Engineering Core and how they wish to apply their skill, knowledge, and passion:

**Biomedical Data Science**—The past decade has seen major advances in our ability to acquire data on human health across multiple spatio-temporal scales. This wealth of data poses challenges that have never before been confronted. At the heart of these is understanding how massive data sets are best analyzed to discover new knowledge about the function of living systems in health and disease, and how this knowledge can be harnessed to provide improved, more affordable health care.

**Biomedical Imaging and Instrumentation**—Although being distinct disciplines, experience substantial overlap and enjoy significant synergies in our department. Course-based and research opportunities span fundamental development of imaging technologies, incorporation of these technologies into instruments, and translation into the clinic. In addition to collecting anatomical data, students will learn how data analysis and computer simulations are used to generate truly functional images that allow a physician to understand an organ or tissue from the smallest scale to the systems level.

**Computational Medicine**—This is an emerging discipline devoted to the development of quantitative approaches for understanding the mechanisms, diagnosis and treatment of human disease through applications of mathematics, engineering and computational science. The core approach of CM is to develop computational models of the molecular biology, physiology, and anatomy of disease, and apply these models to improve patient care.

**Genomics and Systems Biology**—This area uses advanced mathematical and modeling approaches to understand how the multiple scales that make up the human body maintain health and contribute to disease. Understanding life begins at the smallest of scales requiring a detailed understanding of how molecules assemble into the molecular machines that create cells that in turn constitute the tissues and organs that make up the human body. Understanding these multi-scale interactions is a staggering challenge that requires new approaches that combine network analysis theory with new ways of visualizing and manipulating biological networks across multiple spatial and temporal scales.

**Neuroengineering**—Neuroengineering is an emerging and fast growing basic and translational research avenue within today’s biomedical and bioengineering fields. The main focus of neuroengineering is to use engineering tools to modulate central, peripheral and autonomic nervous system function. It aims at developing new engineering oriented technologies within the medical field for screening, diagnosis, prognosis, rehabilitation, repair, and regeneration. Brain computer interface, deep brain stimulation, and cell replacement therapy are exemplar disciplines developed by utilizing core engineering approaches to understand pathologies and treat patients with neurological disorders.

**Regenerative and Immune Engineering**—This area has traditionally focused on understanding and harnessing the power of stem cells in concert with developing new biomaterials to guide cell behavior and reconstruct tissues and organs ranging from bone, cartilage, liver, pancreas, skin, blood vessel, and peripheral nerve. To complement these efforts designed to meet critical health care needs, immunoengineering approaches are used not only augment regeneration, but also to treat diseases such as cancer.

Courses in a focus area must be taken for a total of 21 or more credits. At least 15 credits must come from the relevant upper-level engineering course list; a maximum of six credits from the non-upper-level engineering course list may be used. Please refer to [www.bme.jhu.edu/undergraduate/resources.htm](http://www.bme.jhu.edu/undergraduate/resources.htm) for applicable courses designed for each focus area by faculty members with research interests appropriate to the area; all faculty members are active participants in shaping the undergraduate curriculum.

At least 6 credits must come from an approved list of design options. There are many combinations of courses, programs and independent study opportunities to satisfy this requirement. This is discussed in detail in the Undergraduate Handbook. Please refer to [http://www.bme.jhu.edu/undergraduate/documents/BME-Undergraduate-Handbook.pdf](http://www.bme.jhu.edu/undergraduate/documents/BME-Undergraduate-Handbook.pdf).

### Biomedical Data Science Focus Area - Upper-Level Engineering Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.520.414</td>
<td>Image Processing &amp; Analysis</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.415</td>
<td>Image Process &amp; Analysis II</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.422</td>
<td>Medical Imaging Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.434</td>
<td>Digital Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.447</td>
<td>Information Theory</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.473</td>
<td>Magnetic Resonance in Medicine</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.410</td>
<td>Biomechanics of the Cell</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.400</td>
<td>Project in Design: Pharmacokinetics</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.409</td>
<td>Dynamic Modeling and Control</td>
<td>4</td>
</tr>
<tr>
<td>EN.540.414</td>
<td>Computational Protein Structure Prediction and Design</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.421</td>
<td>Project in Design: Pharmacodynamics</td>
<td>3</td>
</tr>
<tr>
<td>EN.553.361</td>
<td>Introduction to Optimization</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.362</td>
<td>Introduction to Optimization II</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.371</td>
<td>Cryptology and Coding</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.391</td>
<td>Dynamical Systems</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.400</td>
<td>Mathematical Modeling and Consulting</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.413</td>
<td>Applied Statistics and Data Analysis</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.420</td>
<td>Introduction to Probability</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.426</td>
<td>Introduction to Stochastic Processes</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.430</td>
<td>Introduction to Statistics</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.431</td>
<td>Statistical Methods in Imaging</td>
<td>3</td>
</tr>
<tr>
<td>EN.553.433</td>
<td>Monte Carlo Methods</td>
<td>3</td>
</tr>
<tr>
<td>EN.553.436</td>
<td>Data Mining</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.450</td>
<td>Computational Molecular Medicine</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.463</td>
<td>Network Models in Operations Research</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.472</td>
<td>Graph Theory</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.492</td>
<td>Mathematical Biology</td>
<td>3</td>
</tr>
<tr>
<td>EN.553.720</td>
<td>Probability Theory I</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.721</td>
<td>Probability Theory II</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.730</td>
<td>Statistical Theory</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.731</td>
<td>Statistical Theory II</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.420</td>
<td>Build-a-Genome</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.431</td>
<td>Introduction to Computational Medicine I</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.437</td>
<td>Neuro Data Design I</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.438</td>
<td>Neuro Data Design II</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.439</td>
<td>Models of the Neuron</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.445</td>
<td>Networks</td>
<td>3</td>
</tr>
</tbody>
</table>
Biomedical Engineering

Biomedical Data Science Focus Area - 200-Level Engineering Courses
(maximum of 3 credits from this list may count in focus area)

EN.580.446 Physical Epigenetics 3
EN.580.447 Computational Stem Cell Biology 3
EN.580.460 Theory of Cancer 3
EN.580.462 Representations of Choice 3
EN.580.468 The Art of Data Science 3
EN.580.480 Precision Care Medicine 3
EN.580.481 Precision Care Medicine 3
EN.580.488 Foundations of Computational Biology and Bioinformatics II 3
EN.580.491 Learning Theory 3
EN.580.492 Build-a-Genome Mentor 4
EN.580.689 Computational Personal Genomics 3
EN.580.694 Statistical Connectomics 3
EN.601.315 Databases 3
EN.601.318 Operating Systems 3
EN.601.320 Parallel Programming 3
EN.601.325 Declarative Methods 3
EN.601.350 Introduction to Genomic Research 3
EN.601.402 Digital Health and Biomedical Informatics 1
EN.601.433 Intro Algorithms 3
EN.601.434 Randomized and Big Data Algorithms 3
EN.601.443 Security & Privacy in Computing 3
EN.601.447 Computational Genomics: Sequences 3
EN.601.448 Computational Genomics: Data Analysis 3
EN.601.455 Computer Integrated Surgery I 4
EN.601.456 Computer Integrated Surgery II 3
EN.601.457 Computer Graphics 3
EN.601.461 Computer Vision 3
EN.601.463 Algorithms for Sensor-Based Robotics 3
EN.601.464 Artificial Intelligence 3
EN.601.465 Natural Language Processing 4
EN.601.466 Information Retrieval and Web Agents 3
EN.601.475 Machine Learning 3
EN.601.476 Machine Learning: Data to Models 3
EN.601.482 Machine Learning: Deep Learning 3
EN.601.485 Probabilistic Models of the Visual Cortex 3

Contact the department advising office for course additions.

Biomedical Data Science Focus Area - Non Upper-Level Engineering Courses
(maximum of 3 credits from this list may count in focus area)

EN.580.112 BME Design Group 3
EN.580.211 BME Design Group 3
EN.580.212 BME Design Group 3
EN.580.311 BME Design Group 3
EN.580.312 BME Design Group 3
EN.580.411 BME Design Group 3
EN.580.412 BME Design Group 3
EN.580.580 Senior Design Project 3
EN.580.581 Senior Design Project 3

Students may use a maximum of 3 research credits as a non-upper-level engineering course.

Computational Medicine Focus Area - Upper-Level Engineering Courses

EN.520.315 Intro. to Bio-Inspired Processing of Audio-Visual Signals 3
EN.520.432 Medical Imaging Systems 3
EN.520.473 Magnetic Resonance in Medicine 3
EN.520.601 Introduction to Linear Systems Theory 3
EN.530.343 Design and Analysis of Dynamical Systems 3
EN.530.676 Locomotion II: Dynamics 3
EN.540.400 Project in Design: Pharmacokinetics 3
EN.540.421 Project in Design: Pharmacodynamics 3
EN.540.638 Advanced Topics in Pharmacokinetics and Pharmacodynamics I 3
EN.553.386 Scientific Computing: Differential Equations 4
EN.553.391 Dynamical Systems 4
EN.553.420 Introduction to Probability 4
EN.553.426 Introduction to Stochastic Processes 4
EN.553.430 Introduction to Statistics 4
EN.553.436 Data Mining 4
EN.553.450 Computational Molecular Medicine 4
EN.580.430 Systems Pharmacology and Personalized Medicine 3
EN.580.431 Introduction to Computational Medicine I 4
EN.580.437 Neuro Data Design I 4
EN.580.438 Neuro Data Design II 4
EN.580.439 Models of the Neuron 4
EN.580.445 Networks 3
EN.580.446 Physical Epigenetics 3
EN.580.447 Computational Stem Cell Biology 3
EN.580.460 Theory of Cancer 3
EN.580.462 Representations of Choice 3
EN.580.468 The Art of Data Science 3
EN.580.480 Precision Care Medicine 3
EN.580.481 Precision Care Medicine 3
EN.580.488 Foundations of Computational Biology and Bioinformatics II 3
EN.580.491 Learning Theory 3
EN.580.492 Intro Algorithms 3
EN.580.588 Foundations of Computational Biology & Bioinformatics II 3
EN.580.688 Computational Personal Genomics 3
EN.580.694 Statistical Connectomics 3
EN.601.350 Introduction to Genomic Research 3
EN.601.447 Computational Genomics: Sequences 3
EN.601.448 Computational Genomics: Data Analysis 3
EN.601.452 Computational Biomedical Research 3
EN.601.455 Computer Integrated Surgery I 4
EN.601.456 Computer Integrated Surgery II 3
EN.601.461 Computer Vision 3

Biomedical Engineering 5
Computational Medicine Focus Area - 200-Level Engineering Courses
(maximum of 3 credits from this list may count in focus area)
EN.601.226 Data Structures 4
EN.601.229 Computer System Fundamentals 3
EN.601.231 Automata & Computation Theory 3

Computational Medicine Focus Area - Non Upper-Level Engineering Courses
(maximum of 3 credits from this list may count in focus area)
AS.250.353 Computational Biology 3
EN.580.112 BME Design Group 3
EN.580.211 BME Design Group 3
EN.580.212 BME Design Group 3
EN.580.311 BME Design Group 3
EN.580.312 BME Design Group 3
EN.580.411 BME Design Group 3
EN.580.412 BME Design Group 3
EN.580.580 Senior Design Project 3
EN.580.581 Senior Design Project 3

Students may use a maximum of 3 research credits as a non-upper-level engineering course.

Genomics and Systems Biology Focus Area - Upper-Level Engineering Courses
EN.510.311 Structure Of Materials 3
EN.510.316 Biomaterials I 3
EN.510.407 Biomaterials II: Host response and biomaterials applications 3
EN.520.315 Intro. to Bio-Inspired Processing of Audio-Visual Signals 3
EN.520.353 Control Systems 3
EN.520.372 Programmable Device Lab 3
EN.520.414 Image Processing & Analysis 3
EN.520.415 Image Process & Analysis II 3
EN.520.432 Medical Imaging Systems 3
EN.520.454 Control Systems Design 3
EN.520.465 Digital Communications I 3
EN.520.636 Feedback Control in Biological Signaling Pathways 3
EN.530.327 Introduction to Fluid Mechanics 3
EN.530.343 Design and Analysis of Dynamical Systems 3
EN.530.414 Computer-Aided Design 3
EN.530.420 Robot Sensors/Actuators 4
EN.530.426 Biofluid Mechanics 3
EN.530.445 Introduction to Biomechanics 3
EN.530.446 Experimental Methods in Biomechanics 3
EN.530.448 Biosolid Mechanics 3
EN.540.303 Transport Phenomena I 3
EN.540.304 Transport Phenomena II 4
EN.540.400 Project in Design: Pharmacokinetics 3
EN.540.409 Dynamic Modeling and Control 4
EN.540.414 Computational Protein Structure Prediction and Design 3
EN.540.421 Project in Design: Pharmacodynamics 3
EN.553.436 Data Mining 4
EN.553.361 Introduction to Optimization 4
EN.553.362 Introduction to Optimization II 4
EN.553.371 Cryptology and Coding 4
EN.553.386 Scientific Computing: Differential Equations 4
EN.553.391 Dynamical Systems 4
EN.553.400 Mathematical Modeling and Consulting 4
EN.553.420 Introduction to Probability 4
EN.553.426 Introduction to Stochastic Processes 4
EN.553.430 Introduction to Statistics 4
EN.580.418 Principles of Pulmonary Physiology 3
EN.580.420 Build-a-Genome 4
EN.580.430 Systems Pharmacology and Personalized Medicine 3
EN.580.431 Introduction to Computational Medicine I 4
EN.580.434 Bioelectricity 3
EN.580.435 Applied Bioelectrical Engineering I 1.5
EN.580.436 Applied Bioelectrical Engineering II 1.5
EN.580.439 Models of the Neuron 4
EN.580.441 Cellular Engineering 3
EN.580.445 Networks 3
EN.580.446 Physical Epigenetics 3
EN.580.447 Computational Stem Cell Biology 3
EN.580.448 Biomechanics of the Cell 3
EN.580.456 Introduction to Rehabilitation Engineering 3
EN.580.457 Introduction to Rehabilitation Engineering: Design Lab 3
EN.580.460 Theory of Cancer 3
EN.580.466 Statistical Methods in Imaging 3
EN.580.471 Principles of Design of BME Instrumentation 4
EN.580.571 Honors Instrumentation (Intersession) will count as an additional 2 credits in the focus area.
EN.580.472 Medical Imaging Systems 3
EN.580.473 Modern Biomedical Imaging Instrumentation and Techniques 3
EN.580.488 Foundations of Computational Biology and Bioinformatics II 3
EN.580.491 Learning Theory 3
EN.580.492 Build-a-Genome Mentor 4
EN.580.625 Structure and Function of the Auditory and Vestibular Systems 3
EN.580.630 Theoretical Neuroscience 3
EN.580.688 Foundations of Computational Biology & Bioinformatics II 3
EN.580.694 Statistical Connectomics 3

Contact the department advising office for course additions.
**Courses**

**Imaging and Instrumentation Focus Area - Upper-Level Engineering**

(maximum of 3 credits from this list may count in focus area)

<table>
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<tr>
<td>EN.520.415</td>
<td>Image Process &amp; Analysis II</td>
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<td>EN.520.414</td>
<td>Image Processing &amp; Analysis</td>
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<tr>
<td>EN.520.413</td>
<td>Advanced Micro-Processor Lab</td>
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<td>EN.520.412</td>
<td>Control Systems Design</td>
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<tr>
<td>EN.520.483</td>
<td>Bio-Photonics Laboratory</td>
<td>3</td>
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<tr>
<td>EN.520.491</td>
<td>CAD Design of Digital VLSI Systems (Juniors/Seniors)</td>
<td>3</td>
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Students may use a maximum of 3 research credits as a non-upper-level engineering course.

**Genomics and Systems Biology Focus Area - 200-Level Engineering Courses**

(maximum of 3 credits from this list may count in focus area)

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<th>Course Code</th>
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<td>EN.520.213</td>
<td>Circuits</td>
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<td>EN.520.214</td>
<td>Signals and Systems</td>
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<td>EN.520.216</td>
<td>Introduction To VLSI</td>
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<td>EN.520.230</td>
<td>Mastering Electronics</td>
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<tr>
<td>EN.530.201</td>
<td>Statics and Mechanics of Materials</td>
<td>4</td>
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<tr>
<td>EN.530.215</td>
<td>Mechanics-Based Design</td>
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**Genomics and Systems Biology Focus Area - Non Upper-Level**

(maximum of 3 credits from this list may count in focus area)

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<td>AS.080.305</td>
<td>Neuroscience: Cellular and Systems I</td>
<td>3</td>
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<td>EN.580.112</td>
<td>BME Design Group</td>
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<td>EN.580.211</td>
<td>BME Design Group</td>
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<td>EN.580.212</td>
<td>BME Design Group</td>
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<td>EN.580.311</td>
<td>BME Design Group</td>
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<td>EN.580.312</td>
<td>BME Design Group</td>
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<td>BME Design Group</td>
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<td>EN.580.412</td>
<td>BME Design Group</td>
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<td>EN.580.580</td>
<td>Senior Design Project</td>
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<td>EN.580.581</td>
<td>Senior Design Project</td>
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Students may use a maximum of 3 research credits as a non-upper-level engineering course.

**Imaging and Instrumentation Focus Area - Upper-Level Engineering Courses**

<table>
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<th>Course Code</th>
<th>Course Title</th>
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<tr>
<td>EN.510.311</td>
<td>Structure Of Materials</td>
<td>3</td>
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<tr>
<td>EN.510.313</td>
<td>Mechanical Properties of Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.314</td>
<td>Electronic Properties of Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.316</td>
<td>Biomaterials I</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.403</td>
<td>Materials Characterization</td>
<td>3</td>
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<tr>
<td>EN.510.407</td>
<td>Biomaterials II: Host response and biomaterials applications</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.422</td>
<td>Micro and Nano Structured Materials &amp; Devices</td>
<td>3</td>
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<td>EN.510.430</td>
<td>Biomaterials Lab</td>
<td>3</td>
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<tr>
<td>EN.520.315</td>
<td>Intro. to Bio-Inspired Processing of Audio-Visual Signals</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.349</td>
<td>Microprocessor Lab I</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.353</td>
<td>Control Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.372</td>
<td>Programmable Device Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.414</td>
<td>Image Processing &amp; Analysis</td>
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<tr>
<td>EN.520.415</td>
<td>Image Process &amp; Analysis II</td>
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**Biomedical Engineering**
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>EN.520.493</td>
<td>Imaging Instrumentation</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.492</td>
<td>Biomedical Photonics</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.740</td>
<td>Surgery For Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.601.315</td>
<td>Databases</td>
<td>3</td>
</tr>
<tr>
<td>EN.601.454</td>
<td>Augmented Reality</td>
<td>3</td>
</tr>
<tr>
<td>EN.601.455</td>
<td>Computer Integrated Surgery I</td>
<td>4</td>
</tr>
<tr>
<td>EN.601.456</td>
<td>Computer Integrated Surgery II</td>
<td>3</td>
</tr>
<tr>
<td>EN.601.457</td>
<td>Computer Graphics</td>
<td>3</td>
</tr>
<tr>
<td>EN.601.461</td>
<td>Computer Vision</td>
<td>3</td>
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<tr>
<td>EN.601.463</td>
<td>Algorithms for Sensor-Based Robotics</td>
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<tr>
<td>EN.601.475</td>
<td>Machine Learning</td>
<td>3</td>
</tr>
<tr>
<td>EN.601.485</td>
<td>Probabilistic Models of the Visual Cortex</td>
<td>3</td>
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</table>

Contact the department advising office for course additions.

**Imaging and Instrumentation Focus Area - 200-Level Engineering Courses**
(maximum of 3 credits from this list may count in focus area)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tr>
<td>EN.520.214</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.405</td>
<td>Real Analysis I</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.443</td>
<td>Fourier Analysis</td>
<td>4</td>
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<tr>
<td>EN.580.112</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.211</td>
<td>BME Design Group</td>
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</tr>
<tr>
<td>EN.580.212</td>
<td>BME Design Group</td>
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<tr>
<td>EN.580.311</td>
<td>BME Design Group</td>
<td>3</td>
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<td>EN.580.312</td>
<td>BME Design Group</td>
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<td>EN.580.411</td>
<td>BME Design Group</td>
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<tr>
<td>EN.580.412</td>
<td>BME Design Group</td>
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<tr>
<td>EN.580.580</td>
<td>Senior Design Project</td>
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<td>EN.580.581</td>
<td>Senior Design Project</td>
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</table>

Students may use a maximum of 3 research credits as a non-upper-level engineering course.

**Neuroengineering Focus Area - Upper-Level Engineering Courses**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.520.315</td>
<td>Intro. to Bio-Inspired Processing of Audio-Visual Signals</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.349</td>
<td>Microprocessor Lab I</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.353</td>
<td>Control Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.372</td>
<td>Programmable Device Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.407</td>
<td>Introduction to the Physics of Electronic Devices</td>
<td>3</td>
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<tr>
<td>EN.520.424</td>
<td>FPGA Synthesis Lab</td>
<td>3</td>
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<tr>
<td>EN.520.432</td>
<td>Medical Imaging Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.435</td>
<td>Digital Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.448</td>
<td>Electronics Design Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.450</td>
<td>Advanced Micro-Processor Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.454</td>
<td>Control Systems Design</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.465</td>
<td>Digital Communications I</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.491</td>
<td>CAD Design of Digital VLSI Systems (Juniors/ Seniors)</td>
<td>3</td>
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<tr>
<td>EN.520.492</td>
<td>Mixed-Mode VLSI Systems</td>
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<tr>
<td>EN.520.495</td>
<td>Microfabrication Laboratory</td>
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<td>EN.530.414</td>
<td>Computer-Aided Design</td>
<td>3</td>
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<tr>
<td>EN.530.420</td>
<td>Robot Sensors/Actuators</td>
<td>4</td>
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<tr>
<td>EN.530.421</td>
<td>Mechatronics</td>
<td>3</td>
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<tr>
<td>EN.530.446</td>
<td>Experimental Methods in Biomechanics</td>
<td>3</td>
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<tr>
<td>EN.530.646</td>
<td>Robot Devices, Kinematics, Dynamics, and Control</td>
<td>4</td>
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<tr>
<td>EN.530.672</td>
<td>Biosensing &amp; BioMEMS</td>
<td>3</td>
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<tr>
<td>EN.540.403</td>
<td>Colloids and Nanoparticles</td>
<td>3</td>
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<tr>
<td>EN.540.440</td>
<td>Micro/Nanotechnology. The Science and Engineering of Small Structures</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.434</td>
<td>Bioelectricity</td>
<td>3</td>
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<tr>
<td>EN.580.435</td>
<td>Applied Bioelectrical Engineering I</td>
<td>1.5</td>
</tr>
<tr>
<td>EN.580.436</td>
<td>Applied Bioelectrical Engineering II</td>
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<tr>
<td>EN.580.441</td>
<td>Cellular Engineering</td>
<td>3</td>
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<td>EN.580.442</td>
<td>Tissue Engineering</td>
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<tr>
<td>EN.580.451</td>
<td>Cell and Tissue Engineering Lab or EN.580.452</td>
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<tr>
<td>EN.580.456</td>
<td>Introduction to Rehabilitation Engineering</td>
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<tr>
<td>EN.580.457</td>
<td>Introduction to Rehabilitation Engineering: Design Lab</td>
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<tr>
<td>EN.580.471</td>
<td>Principles of Design of BME Instrumentation</td>
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<tr>
<td>EN.580.571</td>
<td>Honors Instrumentation (Intersession) will count as an additional 2 credits in the focus area.</td>
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**Neuroengineering Focus Area - 200-Level Engineering Courses**
(maximum of 3 credits from this list may count in focus area)

<table>
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<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>EN.520.213</td>
<td>Circuits</td>
<td>4</td>
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<tr>
<td>EN.520.214</td>
<td>Signals and Systems</td>
<td>4</td>
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<tr>
<td>EN.520.216</td>
<td>Introduction To VLSI</td>
<td>3</td>
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<tr>
<td>EN.520.230</td>
<td>Mastering Electronics</td>
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<td>EN.530.254</td>
<td>Manufacturing Engineering</td>
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**Neuroengineering Focus Area - Non Upper-Level Engineering Courses**
(maximum of 3 credits from this list may count in focus area)

<table>
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<th>Course Title</th>
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<td>EN.580.112</td>
<td>BME Design Group</td>
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<td>BME Design Group</td>
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<td>BME Design Group</td>
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<td>EN.580.580</td>
<td>Senior Design Project</td>
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<td>EN.580.581</td>
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Students may use a maximum of 3 research credits as a non-upper-level engineering course.
### Regenerative and Immune Engineering Focus Area - Upper-Level Engineering Courses

<table>
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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>EN.510.311</td>
<td>Structure Of Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.312</td>
<td>Thermodynamics/Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.313</td>
<td>Mechanical Properties of Materials</td>
<td>3</td>
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<tr>
<td>EN.510.314</td>
<td>Electronic Properties of Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.315</td>
<td>Physical Chemistry of Materials II</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.316</td>
<td>Biomaterials I</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.403</td>
<td>Materials Characterization</td>
<td>3</td>
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<tr>
<td>EN.510.407</td>
<td>Biomaterials II: Host response and biomaterials applications</td>
<td>3</td>
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<td>EN.510.415</td>
<td>The Chemistry of Materials Synthesis</td>
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<td>EN.510.421</td>
<td>Nanoparticles</td>
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<td>EN.510.422</td>
<td>Micro and Nano Structured Materials &amp; Devices</td>
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<td>EN.510.426</td>
<td>Biomolecular Materials I - Soluble Proteins and Amphiphiles</td>
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<td>EN.510.430</td>
<td>Biomaterials Lab</td>
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<td>EN.510.435</td>
<td>Mechanical Properties of Biomaterials</td>
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<td>EN.510.606</td>
<td>Polymer Chemistry &amp; Biology</td>
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<td>EN.530.410</td>
<td>Biomechanics of the Cell</td>
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<td>EN.530.426</td>
<td>Biofluid Mechanics</td>
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<td>EN.530.436</td>
<td>Bioinspired Science and Technology</td>
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<tr>
<td>EN.530.446</td>
<td>Experimental Methods in Biomechanics</td>
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<td>EN.530.448</td>
<td>Biosolid Mechanics</td>
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<td>EN.540.301</td>
<td>Kinetic Processes</td>
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<td>EN.540.303</td>
<td>Transport Phenomena I</td>
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<td>EN.540.304</td>
<td>Transport Phenomena II</td>
<td>4</td>
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<tr>
<td>EN.540.306</td>
<td>Chemical &amp; Biomolecular Separation</td>
<td>3</td>
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<tr>
<td>EN.540.400</td>
<td>Project in Design: Pharmacokinetics</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.402</td>
<td>Metabolic Systems Biotechnology</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.403</td>
<td>Colloids and Nanoparticles</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.405</td>
<td>The Design of Biomolecular Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.414</td>
<td>Computational Protein Structure Prediction and Design</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.421</td>
<td>Project in Design: Pharmacodynamics</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.422</td>
<td>Introduction to Polymeric Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.428</td>
<td>Supramolecular Materials and Nanomedicine</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.437</td>
<td>Application of Molecular Evolution to Biotechnology</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.440</td>
<td>Micro/Nanotechnology: The Science and Engineering of Small Structures</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.465</td>
<td>Engineering Principles of Drug Delivery</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.602</td>
<td>Metabolic Systems Biotechnology</td>
<td>3</td>
</tr>
<tr>
<td>EN.553.391</td>
<td>Dynamical Systems</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.418</td>
<td>Principles of Pulmonary Physiology</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.420</td>
<td>Build-a-Genome</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.430</td>
<td>Systems Pharmacology and Personalized Medicine</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.434</td>
<td>Bioelectricity</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.435</td>
<td>Applied Bioelectrical Engineering I</td>
<td>1.5</td>
</tr>
<tr>
<td>EN.580.436</td>
<td>Applied Bioelectrical Engineering II</td>
<td>1.5</td>
</tr>
<tr>
<td>EN.580.441</td>
<td>Cellular Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.442</td>
<td>Tissue Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.444</td>
<td>Biomedical Applications of Glycoengineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.448</td>
<td>Biomechanics of the Cell</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.451</td>
<td>Cell and Tissue Engineering Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.452</td>
<td>Cell and Tissue Engineering Lab</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.456</td>
<td>Introduction to Rehabilitation Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.492</td>
<td>Build-a-Genome Mentor</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.495</td>
<td>Microfabrication Lab</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.643</td>
<td>Advanced Orthopaedic Tissue Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.646</td>
<td>Molecular Immunoengineering</td>
<td>3</td>
</tr>
<tr>
<td>EN.670.619</td>
<td>Fundamental Physics and Chemistry of Nanomaterials</td>
<td>3</td>
</tr>
</tbody>
</table>

Contact the department advising office for course additions.

### Regenerative and Immune Engineering Focus Area - Non Upper-Level Engineering Courses

(maximum of 3 credits from this list may count in focus area)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.020.303</td>
<td>Genetics</td>
<td>3</td>
</tr>
<tr>
<td>AS.020.337</td>
<td>Stem Cells &amp; the Biology of Aging &amp; Disease</td>
<td>2</td>
</tr>
<tr>
<td>AS.020.363</td>
<td>Developmental Biology</td>
<td>3</td>
</tr>
<tr>
<td>AS.020.373</td>
<td>Develop Biology Lab</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.112</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.211</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.212</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.311</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.312</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.411</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.412</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.580</td>
<td>Senior Design Project</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.581</td>
<td>Senior Design Project</td>
<td>3</td>
</tr>
</tbody>
</table>

Students may use a maximum of 3 research credits as a non-upper-level engineering course.

### Approved Design Courses - 6 credits

This 2-semester sequence must be taken in its entirety.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.510.433</td>
<td>Senior Design Research</td>
<td>3</td>
</tr>
<tr>
<td>EN.510.434</td>
<td>Senior Design/Research II</td>
<td>3</td>
</tr>
</tbody>
</table>

This 1-semester course is augmented by taking 1 semester of 580.581 Independent Design:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.520.498</td>
<td>Senior Design Project</td>
<td>3</td>
</tr>
<tr>
<td>EN.520.499</td>
<td>Senior Design Project</td>
<td>3</td>
</tr>
</tbody>
</table>

This 1-semester course is augmented by taking 1 semester of 580.581 Independent Design:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.540.400</td>
<td>Project in Design: Pharmacokinetics</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.421</td>
<td>Project in Design: Pharmacodynamics</td>
<td>3</td>
</tr>
</tbody>
</table>

This 2-semester sequence must be taken in its entirety.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.580.311</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.312</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
</tbody>
</table>

This 2-semester sequence must be taken in its entirety.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.580.411</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
<tr>
<td>EN.580.412</td>
<td>BME Design Group</td>
<td>3</td>
</tr>
</tbody>
</table>

This 2-semester sequence must be taken in its entirety.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.580.437</td>
<td>Neuro Data Design I</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.438</td>
<td>Neuro Data Design II</td>
<td>4</td>
</tr>
</tbody>
</table>
This 2-semester sequence must be taken in its entirety.
EN.580.456 Introduction to Rehabilitation Engineering 3
EN.580.457 Introduction to Rehabilitation Engineering: Design Lab 3

This 1-semester course must be augmented by taking 1 semester of 580.571 Honors Instrumentation - offered during January Intersession:
EN.580.471 Principles of Design of BME Instrumentation 4

This 1-semester course must be augmented by taking 1 semester of 520.499 Independent Design:
EN.580.580 Senior Design Project 3
EN.580.581 Senior Design Project 3

This 2-semester course must be taken in its entirety:
EN.601.455 Computer Integrated Surgery I 4
EN.601.456 Computer Integrated Surgery II 3

**Bachelor of Arts in Biomedical Engineering**

(See also General Requirements for Departmental Majors [http://catalog.jhu.edu/undergrad-students/academic-policies/requirements-for-a-bachelors-degree])

The B.A. in biomedical engineering requires 120 credits. The courses listed below must either be taken or passed by examination for advanced credit. See the Biomedical Engineering Undergraduate Advising Manual for lists of recommended courses, acceptable course substitutions, and limitations on credits for courses with overlapping material.

**Basic Sciences (18 credits)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.171.101</td>
<td>General Physics/Physical Science Major I</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.107</td>
<td>General Physics for Physical Sciences Majors (AL)</td>
<td>4</td>
</tr>
<tr>
<td>AS.171.102</td>
<td>General Physics: Physical Science Major II</td>
<td>4</td>
</tr>
<tr>
<td>or AS.171.108</td>
<td>General Physics for Physical Science Majors (AL)</td>
<td>4</td>
</tr>
<tr>
<td>AS.173.111</td>
<td>General Physics Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>AS.173.112</td>
<td>General Physics Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>AS.030.101</td>
<td>Introductory Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>AS.030.102</td>
<td>Introductory Chemistry II</td>
<td>3</td>
</tr>
<tr>
<td>AS.030.105</td>
<td>Introductory Chemistry Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>AS.030.106</td>
<td>Introductory Chemistry Laboratory II</td>
<td>1</td>
</tr>
</tbody>
</table>

**Mathematics (16 credits)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.109</td>
<td>Calculus II (For Physical Sciences and Engineering)</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.202</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.211</td>
<td>Honors Multivariable Calculus</td>
<td>4</td>
</tr>
<tr>
<td>EN.553.291</td>
<td>Linear Algebra and Differential Equations</td>
<td>4</td>
</tr>
</tbody>
</table>

**Computer Programming (3 credits)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.500.112</td>
<td>Gateway Computing</td>
<td>3</td>
</tr>
</tbody>
</table>

**Humanities and Social Sciences (24 credits)**

These courses should form a coherent program, with at least 9 credits chosen from one department, including at least one 300-level course.

- At least four semester of writing intensive courses.
- At least two semesters of a modern foreign language.

**Biomedical Core (30 credits)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.580.111</td>
<td>BME Modeling and Design</td>
<td>2</td>
</tr>
</tbody>
</table>

**Graduate Programs**

**Master of Science in Engineering**

The master’s degree program is designed for students who wish to pursue careers in research and development, or as a step toward Ph.D. or M.D./Ph.D. education. The program has two degree options: a course-based plan consisting of 30 credits (equivalent to 10 full courses to be completed in one year) and a thesis-based track that requires 30 credits plus a thesis project which is completed in a second year.

**Admission and Financial Aid**

Students with undergraduate degrees in engineering are eligible to apply. Exceptional students with degrees in basic sciences may also apply, but would normally have to take a number of courses to overcome deficiencies in their curriculum.

Students do not receive departmental financial aid. However, external financial aid is available for qualified students and partial tuition remission may be available for previous Johns Hopkins students. In addition, thesis-track students (once selected for the thesis track) may be provided with additional financial aid to facilitate the research component of their degree (each financial aid package will be negotiated on an individual basis but typically will include either (or a combination of) tuition waivers or a monthly stipend.

Applications for admission are due by the appointed deadline (usually in early January).

For more information and to apply online, go to [http://www.bme.jhu.edu/graduate/mse/apply](http://www.bme.jhu.edu/graduate/mse/apply).

**Requirements for the M.S.E. Degree**

**Course-based Degree Option**

The course-based degree option will require the completion of 30 credits (the equivalent of 10 full courses) that meet the following stipulations:

- A minimum of five graduate-level courses focused in a selected biomedical engineering sub-discipline (e.g., cell and tissue engineering, computational biology, imaging, instrumentation, or systems biology) as approved by the student’s advisor.
- Additional classes that will consist of math, science, medicine, or technology coursework related to biomedical engineering, which
The cornerstone of the program is our belief in the importance of in-depth training of students in life sciences, modern engineering, mathematics, computer science, and in the conduct of original research leading to the doctoral dissertation. In-depth training in life sciences is achieved in one of two ways. Typically, incoming Ph.D. students enroll in the first year basic sciences curriculum of the Johns Hopkins University School of Medicine. That is, they learn human biology with the medical students. This is a unique and intensive curriculum covering a broad range of topics including molecules and cells, human anatomy, immunology, physiology, and neuroscience. Students choosing this option typically devote their entire first academic year to these courses. This curriculum is an excellent way to build a broad and solid foundation in the life sciences. Alternatively, students may elect alternative life sciences curricula. These curricula have been carefully designed to provide training in areas of the life sciences that are appropriate to each of the program’s research areas. This option is of particular value to students who enter the program having a strong background in the life sciences. In-depth training in engineering, mathematics, and computer science is achieved through elective courses that are taken in the second year.

All students are admitted with full financial support. This covers tuition and provides a modest stipend for the duration of their Ph.D. Because the students are fully funded, they can choose to perform their dissertation in essentially any laboratory in the University (subject to the approval of the Program directors). A special program with the National Heart, Lung, and Blood Institute of the National Institute of Health (NIH) allows students to choose from research laboratories at the NIH.

Students typically do research rotations during the summer before start of the first academic semester, during the first year (typically as they are taking medical school courses), and during the following summer year. They are expected to choose a research laboratory before the start of the second academic year.

Emphasis is placed on original research leading to the doctoral dissertation. The research is usually experimental in nature, and students are expected to learn biological experimentation techniques. Nevertheless, experiment or theory can be emphasized in the research as desired by the student.

Requirements for Admission
The School of Medicine program accepts applications for the Ph.D. program until December 1 of each year. We typically recruit students in five areas: Computational Biology, Imaging, Tissue Engineering, Neural engineering, and Molecular, Neural, and Cardiac physiology (MNCP). The program is unique in that it offers the BME student the strengths of one of the best medical schools in the world. If you wish to combine engineering with cutting edge research in medicine, this may be the program for you.

In their first year, our students have the option of taking many of the same courses as the medical students, including human anatomy, molecules and cells, and genes to society. In their second year, our students take advanced engineering courses. Therefore, students that apply to our program need to not only have a strong background in engineering and mathematics, but also sufficient background in chemistry (including organic chemistry) and biology (at least two introductory courses).

The admission process is by committee. The applicant should specify which area they are interested in and write about the kind of research they are considering. The faculty in each area vote and rank the applicants. The final pool of applicants is ranked and voted on by the entire faculty.
Applications should be complete when submitted. In order to be considered a complete application we must have:

- A completed online application form.
- **Official transcripts from each college or university attended**—Sealed, official transcripts or certified records of all university (undergraduate and graduate) study must be submitted. If you have attended more than one institution, transcripts from each must be included with your application.
- **Official Graduate Record Examination**—GRE/MCAT scores will be acceptable and can be arranged through the Office of Graduate Affairs (address provided below). The GRE code for applying to graduate programs at the Johns Hopkins School of Medicine is 5316.
  - The BME Ph.D. program does not rely heavily on the GRE exam in making admissions or financial aid decisions. Research experience, course grades, and recommendations carry more weight. However, because the GRE score is part of the application and does affect admissions decisions in some cases, foreign applicants who took the GRE in its electronic form, in a country where the electronic test is no longer offered, are advised to retake the exam in its paper form. Applications will be considered regardless of which form of the exam was taken.
  - **Three letters of recommendation**—These letters should come from faculty members who are acquainted with you and your academic work. These letters should be sealed and comment on your aptitude and promise for independent research.
  - **Personal Statement**—a typewritten statement (one page maximum) indicating the basis of your interest in graduate study and your career objectives. Included should be a discussion of any research experience you have had.

Applicants for admission must fulfill the following course prerequisites:

- one year of college level biology (may include quantitative biology or physiology)
- one semester of organic chemistry
- differential equations

If you are interested in applying and do not have the prerequisite courses, you may want to submit your application with an explanatory note indicating you have made or will make arrangements to take the prerequisites before you would matriculate, if your application is accepted. In the past, applicants have taken the prerequisites at their present schools, local community colleges, etc. Courses taken at any accredited college or university are acceptable.

Each applicant must have received a B.A. or B.S. degree or its equivalent prior to matriculation. A Masters degree is not required for admission to our program.

All written correspondence and supporting documents should be sent directly to:

The Office of Graduate Affairs
The Johns Hopkins School of Medicine
1830 E. Monument St., Suite 2-107
Baltimore, MD 21205-2196

<table>
<thead>
<tr>
<th>Phone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>410-614-3385</td>
<td>410-614-3386</td>
</tr>
</tbody>
</table>

**Processing**

The Ph.D. Program admissions committee will not consider any application until it is complete. Once an application has been received the applicant will be notified if supporting materials are missing.

**Interview**

The admissions committee will review completed applications and invite applicants to come to Johns Hopkins for a personal interview with faculty. Applicants from North America must come for an interview to be considered for admission. In the case of overseas applicants, for whom such a trip is not possible, a small number of telephone interviews will be conducted. The final admissions decisions will be made from the pool of interviewed applicants. Interviews are generally conducted in March.

**Acceptance**

Applicants will be notified by early March of the outcome of their application. An offer of admission from the program will include a yearly stipend, full tuition, and paid medical and dental insurance. This applies to every accepted applicant, regardless of citizenship or national origin. Those offered admission will be asked to let us know their decision as soon as possible. In any case, we must have the applicant’s decision by April 15. Applications can be found at [www.hopkinsmedicine.org/graduateprograms/application.cfm](http://www.hopkinsmedicine.org/graduateprograms/application.cfm).

**Financial Aid**

Fellowships for tuition and support stipends (regardless of citizenship or national origin) are available from the general funds of the university. U.S. citizens and Permanent Residents are eligible for support from training grants from the NIH. Students are encouraged to apply for individual fellowships from the National Science Foundation and for NRSA awards from the NIH. Only online applications for admission are accepted and must be received by December 1.

**Requirements for the Ph.D. Degree**

The first two years are ordinarily devoted to advanced courses in engineering science and in biomedical science. Engineering, mathematics, and other physical science courses to be taken are arranged between students and their advisors. Each student is assigned a faculty mentor during the first year. This relationship is designed to help students acclimate to the program. Eighteen credit hours of course work in engineering, mathematics, or physical sciences are required. In addition, students must complete eighteen credit hours of course work in the life sciences. Of these 36 credit hours, at least six must be at the graduate level. At least three credit hours in a course with strong engineering or mathematical theory content at the 600-level must be taken.

Summers are spent working in a biomedical laboratory to gain experience and to seek out a suitable thesis research area. By the beginning of the third year, students should start original research leading to the dissertation. Students must fulfill a modest teaching requirement during one year of their program. The remaining time is spent in thesis research. The program typically takes five to six years to complete.

The student must pass a preliminary oral examination which will be a Graduate Board examination. This is taken no later than the end of the second year. The student must then conduct original research, describe it in a dissertation, and pass a final oral examination that is a defense
of the dissertation. There is a minimum residency requirement of two consecutive academic years.

**Integrated M.D./Ph.D. Program**

Candidates for the Ph.D. in biomedical engineering who wish to apply jointly for the M.D. degree must apply directly through the School of Medicine. Although the combined programs would normally require at least seven years to execute sequentially, the combined program can ordinarily be completed in six years, with appropriate planning. Good preparation in biology and chemistry as well as mathematics, engineering, and the physical sciences is essential. Life science graduate requirements are met by the first-year program of the School of Medicine. This program is more arduous than the Ph.D. program alone, but it may have marked advantages for students interested in clinical research and applications in hospital systems and in the delivery of health care. The catalog for the School of Medicine should be consulted for admissions requirements and procedures.

Information about applying to the combined M.D.-Ph.D. program can be found at www.hopkinsmedicine.org/mdphd/admissions (http://www.hopkinsmedicine.org/mdphd/admissions). Applications submitted for consideration of the combined degree will be reviewed by the Medical School admissions committee. If the Medical School admissions committee accepts the application, it is then passed along to the Biomedical Engineering Ph.D. Program admissions committee for review. A student applying to the combined program who wishes to be considered for the straight Ph.D. program must submit a written request to have his or her application forwarded to the Biomedical Engineering Ph.D. Program office for admission consideration if his or her application is not accepted by the Medical School admissions committee.

For current faculty and contact information go to http://www.bme.jhu.edu/people/completefacultylist.php

**Faculty**

**Chair**

Michael I. Miller  
Bessie Massie Professor and Director: computational anatomy, medical imaging, image understanding.

**Professors**

Joel S. Bader  
Bioinformatics, computational biology, systems biology, synthetic biology.

Kathleen E. Cullen  
Multisensory integration for action and perception, neural mechanisms of motor learning, neural prosthetics and rehabilitation, computational neuroscience.

Jennifer H. Elisseeff  
Morton Goldberg Professor: tissue engineering, biomaterials, cartilage regeneration.

Andrew P. Feinberg  
Bloomberg Distinguished Professor: epigenetics of development and disease; stochasticity in development and cancer.

Jordan J. Green  
Cellular engineering, nanobiotechnology, biomaterials, controlled drug delivery and gene delivery.

Taekjip Ha  
Bloomberg Distinguished Professor: single molecular engineering and biophysics, DNA/RNA nanotechnology, cell mechanics, super-resolution microscopy.

Xingde Li  
Endomicroscopy technologies, nanobiophotonics and molecular imaging, early detection (cancer, cardiovascular diseases, wound healing).

Aleksander S. Popel  
Physiological flows and molecular transport, microcirculation, cell mechanics.

Steven L. Salzberg  
Bloomberg Distinguished Professor: bioinformatics and computational biology.

Reza Shadmehr  
Human motor control and learning in health and disease, functional imaging of the brain, human neurophysiology, computational and theoretical neuroscience.

Jeffrey H. Siewerdsen  
John C. Malone Professor; BME Vice Chair Clinical and Industrial Translation: medical imaging, image-guidance, flat-panel imagers, cone-beam CT, volume imaging, MRI, image science, imaging performance, radiation therapy.

Nitish V. Thakor  
Medical instrumentation, medical micro and nanotechnologies, neurological instrumentation, signal processing, and neural prosthesis.

Natalia Trayanova  
Murray B. Sachs Professor: computational cardiac electrophysiology and electro-mechanics, mechanisms of arrhythmogenesis and cardiac anti-arrhythmia therapies, cardiac dyssynchrony and resynchronization, development of cardiac models from imaging modalities.

Leslie Tung  
Functional electrophysiology of cultured cardiac cell networks, cardiac arrhythmias, analysis of multicellular structure, stem cell-derived cardiac cells.

Rene Vidal  
Herschel L. Seder Professor: computer vision (camera sensor networks, recognition of human activities, dynamic scene analysis, structure from motion), biomedical imaging (processing of high angular resolution diffusion imaging, registration and segmentation of diffusion MRI, segmentation and fiber tracking of cardiac MRI, interactive medical image segmentation), machine learning (generalized principal component analysis, manifold learning and clustering, classification of dynamical systems), signal processing (consensus on manifolds, distributed optimization, compressive sensing).

Xiaqin Wang  
Neurophysiology of the auditory cortex, neural mechanisms of speech perception and learning, computational neuroscience.

Raimond L. Winslow  
Raj and Neera Singh Professor of Biomedical Engineering; BME Vice Chair of Academic Programs; Director, BME Masters Program: computational cell biology, systems biology, cardiac electrophysiology.

**Associate Professors**

Michael A. Beer
Genomics and computational molecular biology.

Harry R. Goldberg
Assistant Dean of the School of Medicine: virtual learning systems, student learning, web-based instruction.

Warren L. Grayson
Tissue engineering, stem cells, bioreactors, biomaterials, orthopaedics.

Rachel Karchin
Computational molecular biology, bioinformatics, genetic variation.

Scot C. Kuo
Cell motility and mechanics, nanoscale biophysics, laser-based bioinstrumentation, advanced multiphoton and confocal microscopy.

Feilim Mac Gabhann
BME Director of Graduate Affairs: computational modeling of growth factor-receptor networks, personalized medicine, individualized medicine, experimental studies of interindividual variation, therapeutic cardiovascular remodeling, novel methods for data visualization and automated image analysis, computational models of virus-host interactions.

Sridevi Sarma
Co-Director, Institute for Computational Medicine: closed-loop deep brain stimulation, control theory, computational neuroscience and large-scale optimization.

Kevin J. Yarema
Director of the Biomedical Engineering MSE Program: metabolic glycoengineering, glycomics, systems biology of glycans, carbohydrate-based cancer drug design and delivery, cellular responses to static magnetic fields.

Kechen Zhang
Theoretical neuroscience, computational neuroscience, neural computation.

**Assistant Professors**

Angelo Homayoun All
Spinal cord injury, stem cells, electrophysiology, imaging.

Alexis Battle
Genomics, machine learning, probabilistic methods to analyze genetic data.

Patrick Cahan
Computational biology, stem cell biology, and single cell genomics.

Vikram Chib
Decision-making, motivation, movement, neuroscience, robotics, neuroeconomics.

Nicholas J. Durr
Medical imaging, biomedical optics, endoscopy, ocular diagnostics, biomicroscopy, and medical device design.

Daniel Herzka
Cardiac magnetic resonance imaging, self-navigation, open-ended imaging, fast imaging, high resolution imaging, applications of MRI in cardiac electrophysiology, kinematic imaging, and fetal imaging.

Jamie Spangler
Structural and molecular immunology, protein engineering, therapeutic antibody discovery and design, targeted drug development.

J. Webster Stayman
Imaging physics, 3D image reconstruction, novel imaging systems, image-guided interventions and diagnosis imaging.

Winston Timp
Epigenetics, single cell analysis, single molecule biophysics, nanotechnology, systems biology, computational biology/bioinformatics.

Joshua T. Vogelstein
Big data science, connectomics, statistical neuroscience.

Youseph Yazdi
Medical instrumentation, medical device design, translation and commercialization of medical devices, biophotonics, optical spectroscopy.

Wojciech B. Zbijewski
System modeling for optimization of x-ray CT imaging chain, integration in novel reconstruction algorithms.

**Professors Emeriti**

Richard J. Johns
University Distinguished Service Professor: Industrial liaison.

Lawrence P. Schramm
Spinal cord injury and regeneration, neural regulation of the circulation.

Artin A. Shoukas
Systems analysis of circulatory systems, systems physiology.

Eric D. Young
Auditory neurophysiology, neural modeling, sensory processes.

**Adjunct Professor**

Elliot R. McVeigh
Imaging.

**Adjunct Associate Professors**

Xiaofeng Jia
Novel application of neuro-electrophysiology for detection and restoration of peripheral nerve and spinal cord injury, basic and clinical investigations in neurological injuries and therapeutic hypothermia of brain and spinal cord after asphyxial cardiac arrest.

Scott Paul
Rehabilitation medicine and engineering.

Joseph M. Smith
Healthcare innovations and technologies.

**Adjunct Assistant Professors**

Erhan Bas
Neuronal reconstruction from large scale volumes.

Manu Ben-Johny
Quantitative physiology, molecular biophysics

Ivy Dick
Ca²⁺ signaling mechanisms in neuronal and cardiac systems, Ca²⁺ channels, electrophysiology, channelopathies.

Thomas W. Gilbert
Extracellular matrix scaffold materials for development of regenerative medicine.

**Research Professor**
Kenneth Boheler  
Cardiovascular molecular and cellular biology.

Timothy Harris  
Immunotherapy, radiotherapy and the application of novel technologies and combined therapies in the management of CNS and pediatric malignancies.

Andre Levchenko  
Intracellular signal transduction, cell engineering, cancer research.

Alexander A. Spector  
Biosolid mechanics, cell mechanics and biophysics, membrane mechanics, mechanotransduction, molecular motors, mathematical and computational modeling.

**Associate Research Professor**
J. Tilak Ratnanather  
Computational anatomy, biomedical imaging, numerical analysis, mathematical biology of the cochlea.

Siamak Ardekani  
Image-based (multi-detector CT and MRI) shape and motion analysis of cardiac disease using mathematical models, analysis of brain development and aging process using diffusion MRI and deformation based morphometry.

**Assistant Research Professor**
Soumyadippta Acharya  
Director of the Master's degree program in Bioengineering Innovation and Design: Biomedical instrumentation, medical device innovation, neuroprosthetics, brain machine interfaces, computational neuroscience.

Grace Gang  
Development of mathematical models of image quality for advanced x-ray imaging systems.

Michael Osmanski  
Auditory neuroscience, perception and cortical representation of complex sounds, acoustic communication, comparative and evolutionary biology of hearing.

Niranjan Pandey  
Novel therapeutics for diseases such as age-related macular degeneration, diabetic retinopathy, various types of solid tumors, and immunological diseases.

Kunal Parikh  
Mucus-penetrating particles for tuberculosis.

Alejandro Sisniega-Crespo  
Development of high-performance Monte Carlo simulation methods for 3D imaging, including GPU implementations for high-fidelity, high-speed x-ray scatter simulation, dose calculation, and dual-energy imaging.

Stephany Tzeng  
Biomaterials for gene and drug delivery, cancer therapy, nanomedicine for cellular engineering, controlled drug release.

Qihong Wang  
Mircosurgery.

Scott Wu Yuan  
Endoscopic OCT technologies, high resolution endoscopic imaging, and biomedical applications.

**Senior Lecturers**
Eileen Haase  
Director of the Undergraduate Program in Biomedical Engineering; Chair of Applied Biomedical Engineering, Engineering for Professionals: Freshmen Modeling and Design, System Bioengineering Laboratory I and II, Cell and Tissue Engineering Laboratory, Molecules and Cells, BME Teaching Practicum.

Elizabeth A. Logsdon  
Director, BME Undergraduate Affairs; Director, BME Design Studio: engineering design education, online learning.

Amir Manbachi  
Medical imaging, neurosurgery, spine interventions, and medical device design.

**Visiting Assistant Professor**
Erika Moore  
Biofunctional materials.

**Joint, Secondary, Part-Time, and Visiting Appointments**
Mohamad E. Allaf  
Associate Professor (Urology): laparoscopic and robotic surgery.

William S. Anderson  
Associate Professor (Neurological Surgery): cerebrospinal fluid disorders and movement disorders.

Muynatatu A. Lediju Bell  
Assistant Professor (Electrical and Computer Engineering): ultrasonic imaging, photoacoustic imaging, coherence-based beamforming, image formation, image quality, light delivery systems, medical robotics, image-guided surgery, image-guided interventions, speckle tracking, technology development, medical device design, clinical translation.

Ronald D. Berger  
Professor (Cardiology): mechanisms of sudden cardiac death, new modalities of ablation therapy, device development, signal processing.

Dan E. Berkowitz  
Professor (Anesthesiology and Critical Care Medicine): molecular mechanisms of cardiovascular deconditioning in rodent models of microgravity, vasoregulatory dysfunction associated with obesity, diabetes, the role of leptin in vasoregulatory changes.

Paul A. Bottomley  
Professor (Radiology): magnetic resonance imaging and spectroscopy, medical imaging.

Henry Brem  
Professor (Neurosurgery): clinical treatments for brain tumore, anti-angiogenesis therapies, computer navigation systems used during surgery, brain tumor vaccines.

John A. Carrino  
Associate Professor (Radiology and Radiological Science): spine imaging novel MRI techniques, health services research informatics.

Jiande Chen
Professor (Gastroenterology): electrogastrography.

Charles C. Della Santina
Professor (Otolaryngology-Head and Neck Surgery): electrical stimulation of the inner ear for restoring balance function, neurophysiology, vestibular function testing.

Andrew S. Douglas
Vice Dean for Faculty for the Whiting School of Engineering, Professor (Mechanical Engineering): nonlinear solid mechanics, soft tissue mechanics, mechanics of active materials.

Laura Ensign-Hodges
Associate Professor (Nanoscience): nanomedicine, drug delivery systems.

Andrew Ewald
Professor (Cell Biology and Oncology): cellular mechanisms and molecular regulation of epithelial morphogenesis in development and cancer.

Gene Fridman
Associate Professor (Otolaryngology-Head and Neck Surgery): novel methods and devices for neural interfacing.

Paul A. Fuchs
Professor (Otolaryngology-Head and Neck Surgery): biophysics and sensory physiology of sensory hair cells and neurons on the inner ear.

Israel Gannot
Professor (Electrical and Computer Engineering): optical biopsy-optical diagnostic methods in medicine, laser tissue interaction, fibers and waveguides for medical applications, lasers and optics in medicine.

Donald Geman
Professor (Applied Mathematics and Statistics): statistical learning, visual recognition, computational genomics.

Sharon Gerecht
Professor (Chemical and Biomolecular Engineering): embryonic and adult stem cells, vascular regeneration, micro/nano fabrication, biomaterials, tissue engineering.

John Goutsias
Professor (Electrical and Computer Engineering): signal and image processing, computational systems biology, bioinformatics, modeling and analysis of complex networked systems.

Henry R. Halperin
Professor (Cardiology): cardiovascular medicine, MR compatible devices.

Justin Hanes
Professor (Ophthalmology): drug and gene delivery, biomaterials synthesis, particle transport through biological barriers.

Kalina Hristova
Professor (Materials Science and Engineering): biomolecular materials, biomembranes, biosensor development, signal transduction across biological membranes.

Chao-Wei Hwang
Assistant Professor (Cardiology): optimization of PCI and stent-based drug delivery using computational fluid dynamics, cell-based therapy for the heart and peripheral vasculature, active sensing drug delivery systems.

Pablo A. Iglesias
Professor (Electrical and Computer Engineering): computational biology, models of cellular signal transduction, directed cell motility, cell division, control systems.

Takanari Inoue
Professor (Cell Biology): directed cell migration, tumor metastasis, primary cilia, synthetic chemical biology, technology development.

David A. Kass
Professor (Cardiology): molecular pathophysiology of heart failure and hypertrophy, pathobiology of cardiac dysynchrony and resynchronization, cardiac stress regulation by phosphodiesterase 5, nitric oxide synthase uncoupling, structure-function of sarcomeric proteins to cardiac mechanics, heart failure with preserved ejection fraction.

A. Jay Khanna
Professor (Orthopaedic Surgery): spine surgery, minimally invasive, musculoskeletal imaging, image guidance for surgery, MRI, biomechanics, clinical outcomes.

Konstantinos Konstantopoulos
Professor (Chemical and Biomolecular Engineering): cell adhesion and microfluidics, nanoscale mechanics, receptor biochemistry, quantitative modeling and functional genomics.

Alain Labrique
Associate Professor (International Health and Epidemiology): application of information and communication technologies (ICTs) to strengthen health systems in resource-limited settings.

Albert C. Lardo
Associate Professor (Cardiology): cardiovascular MRI, cardiovascular CT, image guided therapy.

Rong Li
Bloomberg Distinguished Professor (Cell Biology): cellular dynamics in space, time, and adaptation.

Hanzhang Lu
Associate Professor (Radiology): development of novel MRI technologies and applications for the measurement of vital physiological and biophysical parameters.

Hai-Quan Mao
Professor (Materials Science and Engineering): nanomaterials, electrospinning, nanofibers, biomimetic matrix, stem cell expansion and differentiation, nerve regeneration, micellar nanoparticle, therapeutic delivery, biodegradable polymers.

Wayne Mitzner
Professor (Environmental Health Sciences, Program in Respiratory Biology and Lung Disease): modeling lung function, lung structure-function interactions, mechanical aspects of lung disease.

Hien Nguyen
Assistant Professor (Surgery): clinical outcomes in hernia surgery, critical care medicine, bariatric surgery and metabolic syndrome.

Devin O’Brien-Coon
Assistant Professor (Plastic and Reconstructive Surgery): tissue engineering, regenerative medicine, materials science for customized surgical applications, clinical outcomes and novel techniques in gender surgery, analysis of disparities in transgender healthcare.
Arvind P. Pathak  
Associate Professor (Radiology): functional and molecular imaging, systems biology, tumor microenvironment, multiscale imaging, computational and visualization tools.

Martin Pomper  
Professor (Radiology): techniques and agents to study human disease through imaging.

Jerry L. Prince  
Professor (Electrical and Computer Engineering): image processing and computer vision with application to medical imaging.

Lewis H. Romer  
Professor (Anesthesiology and Critical Care Medicine, Cell Biology, and Pediatrics, and the Center for Cell Dynamics): tissue engineering the micro-vasculature, extracellular matrix as an instructive environment, biophysics and biochemistry of matrix assembly, interactions between tyrosine kinases and Rho family GTPases in cell matrix adhesion, mechanochemical coupling in cell-matrix adhesion signaling, harnessing stem and progenitor cells for microvascular restitution.

Lakshmi Santhanam  
Assistant Professor (Anesthesiology and Critical Care Medicine): molecular mechanisms of vascular stiffness.

Akira Sawa  
Professor (Psychiatry and Behavioral Sciences): pathogenesis of mental illnesses, especially schizophrenia and mood disorders, at the molecular level.

Lew Schon  
Associate Professor (Orthopaedic Surgery): surgical delivery systems for stem cells and bioactive molecules.

Ken Katsuyuki Taguchi  
Associate Professor (Radiology): computed tomography (CT) image science, 3-D and 4-D image reconstruction, CT data acquisition, photon counting and spectral CT.

Nicholas Theordore  
Professor (Neurosurgery and Orthopedics): brain and spinal cord injury, minimally invasive spine surgeries, robotics.

Benjamin M.W. Tsui  
Professor (Radiology): molecular imaging including SPECT, PET and CT, anatomical and physiological models of humans and small animals, simulation of imaging systems and processes, quantitative image reconstruction methods, image quality assessment.

Jeff Tza-Huei Wang  
Professor (Mechanical Engineering): bioMEMS and microfluidics, single molecule manipulation and detection, nano/micro scale fabrication, conformational dynamics of biomolecules.

Clifford R. Weiss  
Associate Professor (Radiology and Surgery): Clinical Director of the Johns Hopkins Center for Bioengineering, Innovation and Design (CBID).

Thomas B. Wooff  
Professor (Physiology): molecular dynamics calculations, membrane biophysics, computational neurosciences.

Professor (Applied Mathematics and Statistics): statistical properties of Markov random fields, image analysis, deformation analysis-shape recognition.

Elias Zerhouni  
Professor (Radiology): imaging.

For current course information and registration go to https://sis.jhu.edu/classes/

**Courses**

**EN.530.627. Intermediate Fluid Mechanics (graduate). 3.0 Credits.**  
Instructor(s): G. Tryggvason.

**EN.540.691. Chemical Engineering Modeling and Design for Graduate Students. 3.0 Credits.**  
This course guides student through the open-ended problems in product and process design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the creation of new products to fulfill a societal need. Process design concerns the quantitative description of processes which serve to produce chemically-derived materials and the estimation of process profitability. Students work in small teams to complete a major project demonstrating their understanding of and proficiency in the principles of unit operations and design. Students report weekly both orally and in writing on their accomplishments. Some projects are single semester, but others can be multi-semester. Students can start in any semester and can work on projects for as many semesters as they want.  
Instructor(s): M. Donohue.

**EN.580.105. Basic Intellectual Property Law for Scientists and Engineers: Patents, Copyrights and Trademarks. 3.0 Credits.**  
The course will outline the basics of intellectual property laws with an emphasis on practical aspects of protection of IP for scientists and engineers. Most of the course will cover the basics of patent law, but introductions will also be given to trademarks and copyrights. Specific problems in the areas of biotechnology, computer science and the Internet will also be highlighted. It is hoped that the attendees will obtain a basic understanding of how intellectual property is protected. No prior legal background is required.  
Instructor(s): J. Szilp  
Area: Social and Behavioral Sciences.

**EN.580.111. BME Modeling and Design. 2.0 Credits.**  
Working in teams with upperclassmen this course (1) introduces biomedical engineering freshmen to an orderly method for analyzing and modeling biological systems and (2) introduces engineering principles to solve design problems that are biological, physiological, and/or medical. Freshmen are expected to use the informational content being taught in calculus, physics and chemistry and to apply this knowledge to the solution of practical problems encountered in biomedical engineering. BME Freshmen only.  
**Prerequisites:** Students must have completed Lab Safety training prior to registering for this class.  
Instructor(s): E. Haase; E. Logsdon; P. Boyle  
Area: Engineering, Natural Sciences.
EN.580.112. BME Design Group. 3.0 Credits.
A two-semester course sequence where freshmen work with groups of BME upperclassmen mentors, and learn to use engineering principles to solve design problems that are biological, physiological, and/or medical. Freshmen are expected to use the informational content being taught in calculus, physics, and chemistry and apply this knowledge to the solution of practical problems encountered in biomedical engineering.
Instructor(s): A. Manbachi; E. Logsdon; N. Durr; R. Allen
Area: Engineering, Natural Sciences.

EN.580.117. Introductory Lab Skills. 1.0 Credit.
This course aims to familiarize first-year undergraduates with the basic lab skills necessary to work in a wet-lab. Specific skills covered will include pipetting, microscopy, PCR, gel electrophoresis, basic cell culture, simple microfluidics, and more! This hands-on experience will fully immerse students in the basics of laboratory research and should help prepare students looking for research or internship opportunities in the upcoming spring or summer semester.
Instructor(s): E. Haase
Area: Engineering, Natural Sciences.

This course is an introduction to scientific programming and computing designed for first-year students. The aim is to develop core computer skills required to succeed in research. Programming projects are drawn from current biomedical applications within BME. Emphasis is on algorithm development, large scale data analysis, and effective visualization of results, using MATLAB, Python, and R. Prior programming experience is not required.
Instructor(s): W. Timp
Area: Engineering.

EN.580.202. Bme In The Real World. 1.0 Credit.
Open only to engineering students; A series of weekly lectures to inform students about careers in biomedical engineering and to discuss technological, social, ethical, legal, and economic issues relevant to the profession. Topics include academic careers in biomedical engineering; biomedical engineering in industry (large corporations to sole entrepreneurship); health care delivery; ethical issues; legal issues (patenting, licensing, product liability); standards and government regulations; and economic issues in biomedical engineering industry (start-up companies, global businesses).
Instructor(s): A. Popel.

EN.580.211. BME Design Group. 3.0 Credits.
Sophomore-level version of EN.580.311-312 or Perm. Req’d
Instructor(s): A. Manbachi; E. Logsdon; N. Durr
Area: Engineering, Natural Sciences.

EN.580.212. BME Design Group. 3.0 Credits.
Sophomore-level version of EN.580.111-112. Permission of course directors required.
Instructor(s): A. Manbachi; E. Logsdon; N. Durr; R. Allen
Area: Engineering, Natural Sciences.

EN.580.220. he Science of Medicine: Thinking Critically. 3.0 Credits.
This course investigates some of the most pressing issues in biomedical science with direction from leading clinicians, scientists, policy experts, and industry professionals. The underlying science and ethical implications for topics such as "Rogue Clinics and Designer Babies: How can I decide the genotype of my offspring – and should I?" "Mosquito-borne Diseases: Fighting an enemy that outnumbers us 15,000 to one with genetics," and "HIV: Pushing for a cure versus settling for a treatment: What makes healthcare sufficient" are explored. The class is taught in a flipped method: students will be expected to listen to presentations at home so that class time can be devoted to problem solving activities, experimental design, debates, and discussion. The goal of this course is to teach students how to think critically and to expose students to the great unknowns that remain in science today.
Instructor(s): C. Hanlon; E. Haase; H. Goldberg
Area: Natural Sciences.

EN.580.221. Molecules and Cells. 4.0 Credits.
An introduction to modern molecular and cellular biology in the context of potential biomedical engineering applications. Topics covered: reactions between molecules, including receptor-ligand and antigen-antibody specificity, protein structure, enzyme catalysis, genetic information, protein processing and secretion, cell physiology and cell functions. Along with detailed study of molecular pathways and cellular behavior, we will discuss the quantitative study of molecular and cellular biology.
Recommended Course Background: AS.030.101 and AS.030.104
Instructor(s): E. Haase; F. Macgabhan; K. Yarema
Area: Natural Sciences.

EN.580.222. Systems and Controls. 4.0 Credits.
An introduction to linear systems: analysis, stability and control. Topics include first and second order systems, linear time invariant discrete and continuous systems, convolution, Fourier series, Fourier transforms, Laplace transforms, stability of linear systems, input output and state space representation of linear systems, stability, observability, controllability, and PID controller design. Recommended Course Background: AS.171.102 and AS.110.201, AS.110.302 or EN.553.291
Instructor(s): M. Miller; S. Sarma
Area: Engineering.

EN.580.223. Models and Simulations. 4.0 Credits.
This course introduces students to modeling and analysis of biological systems. The first portion of the course focuses on linear systems. Topics include harmonic oscillators, pharmacokinetics, reaction-diffusion equation, heat transfer, and fluid flow. The second half of the course focuses on non-linear systems. Topics include iterated maps, bifurcations, chaos, stability of autonomous systems, the Hodgkin-Huxley model, bistability, limit cycles, and the Poincare-Bendixson theorem.
The course also introduces students to the Matlab programming language, which allows them to implement the models discussed in class. Recommended Course Background: AS.110.201, AS.110.302, or EN.553.291
Instructor(s): A. Popel; M. Beer
Area: Engineering.

EN.580.230. Introduction to Genomic Data Analysis. 2.0 Credits.
This class will provide an introduction to analysis of genomic data, with a focus on practical applications and research appropriate for students with no experience. It will include directed readings, discussion, and hands-on experience in genomic research projects. Permission of instructor.
Instructor(s): A. Battle
Area: Engineering.
EN.580.237. Neuro Data Design I. 3.0 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. This version of Neuro Data Design is designed for students with less coding experience who wish to develop their writing skills.
Instructor(s): J. Vogelstein
Area: Engineering
Writing Intensive.

EN.580.238. Neuro Data Design II. 3.0 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. This version of Neuro Data Design is designed for students with less coding experience who wish to develop their writing skills.
Instructor(s): J. Vogelstein
Area: Engineering
Writing Intensive.

EN.580.241. Statistical Physics. 2.0 Credits.
Basic principles of statistical physics and thermodynamics of biological systems. Topics included quantitative statistical formulation of entropy and its application in thermodynamic optimization and conversion principles, the Gibbs/Boltzmann distribution, mixing, and phase transitions. Recommended Background: AS.110.108-109, AS.030.101-102, AS.171.101-102 or equivalent.
Instructor(s): M. Beer
Area: Engineering.

EN.580.242. Biological Models and Simulations. 2.0 Credits.
This course introduces students to modeling and analysis of linear biological systems. Topics include viscoelastic materials, pharmacokinetics, reaction-diffusion-convection equation with applications to molecular transport in tissues. The course also introduces students to the Matlab programming language, which allows them to implement the models discussed in the classroom. Recommended course background: AS.110.201 Linear Algebra, AS.110.302 Differential Equations, or EN.553.291 Linear Algebra and Differential Equations.
Area: Engineering.

EN.580.243. Linear Signals and Systems. 2.0 Credits.
An introduction to signals and linear systems. Topics include first and second order systems, linear time variant discrete and continuous systems, convolution, Fourier series, and Fourier transforms. Recommended background: AS.171.102 and AS.110.201, AS.110.302, or 553.291. 110.302 may be taken at the same time.
Instructor(s): M. Miller
Area: Engineering.

EN.580.244. Nonlinear Dynamics of Biological Systems. 2.0 Credits.
Analysis and simulation of nonlinear behavior in biological systems: bifurcations (cell-fate decision), limit cycles (cell-cycle, neuronal excitations), chaos, and maps. Matlab will be used to simulate these systems and motivate nonlinear analytic tools and stability analysis. Recommended course background: Matlab, EN.553.292 Linear Algebra and Differential Equations.
Area: Engineering.

EN.580.246. Systems and Controls. 2.0 Credits.
An introduction to the analysis and synthesis of controllers for linear systems. Topics include LaPlace transforms, input output and state space representations of linear systems, stability, observability, controllability, and PID controller design. Recommended course background: AS.110.201 Linear Algebra, AS.110.302 Differential Equations, or EN.553.291 Linear Algebra and Differential Equations.
Area: Engineering.

EN.580.248. Systems Biology of the Cell. 2.0 Credits.
Cellular systems biology provides a theoretical and quantitative understanding of the interactions between DNA, RNA, and proteins that create the well-regulated system we call life. This course develops first-principles models for the central dogma of molecular biology: information flow through protein signal transduction pathways, gene regulation by protein-DNA physical interactions, transcription of DNA to RNA, translation of RNA to protein, and feedback regulation that closes the cycle. Topics include complex analysis and contour integrals, spectral transforms, linear models for cell signaling, positive and negative feedback, non-linearities introduced by saturation and cooperativity, information content and combinatorial regulation, and instabilities leading to cell fate specification. Recommended Course Background: Linear Algebra, Systems and Controls and programming.
Instructor(s): J. Bader
Area: Engineering, Natural Sciences.

EN.580.256. Rehabilitation Engineering Seminar. 3.0 Credits.
The primary objective of this course is to introduce students to the challenges of engineering solutions for persons functioning with disabilities. In order to achieve this goal, other objectives include: gaining a basic appreciation of the modalities used to treat impairments, the opportunities for application of engineering to improve treatment delivery, understanding the science and engineering applied to helping persons with disabilities function in the everyday world and an basic knowledge of the legal, ethical issues and employment opportunities in rehabilitation engineering. Students must attend at least 70% of lectures to receive a satisfactory (S) grade.
Instructor(s): S. Paul.

EN.580.302. Careers in Biomedical Engineering. 1.0 Credit.
This course is designed for upperclassmen that wish to meet with weekly speakers to discuss careers issues. A series of weekly lectures to inform students about careers in biomedical engineering and to discuss technological, social, ethical, legal, and economic issues relevant to the profession. Topics include academic careers in biomedical engineering; biomedical engineering in industry (large corporations to sole entrepreneurship); health care delivery; ethical issues; legal issues (patenting, licensing, product liability); standards and government regulations; and economic issues in biomedical engineering industry (start-up companies, global businesses). Junior/Senior Engineers only.
Instructor(s): A. Popel.
EN.580.311. BME Design Group. 3.0 Credits.
A two-semester course sequence where juniors and seniors work with a team leader and a group of BME freshmen and sophomores, to solve open-ended problems in biomedical engineering. Upperclassmen are expected to apply their general knowledge and experience, and their knowledge in their concentration area, to teach lower classmen and to generate the solution to practical problems encountered in biomedical engineering. Perm. Req'd.
Instructor(s): A. Manbachi; E. Logsdon; N. Durr; R. Allen
Area: Engineering, Natural Sciences.

EN.580.312. BME Design Group. 3.0 Credits.
A two semester course sequence where juniors and seniors work with a team leader and a group of BME freshmen and sophomores, to solve open-ended problems in biomedical engineering. Upperclassmen are expected to apply their general knowledge and experience, and their knowledge in their concentration area, to teach lower classmen and to generate the solution to practical problems encountered in biomedical engineering.
Instructor(s): E. Logsdon; N. Durr; R. Allen
Area: Engineering, Natural Sciences.

EN.580.321. Statistical Mechanics and Thermodynamics. 4.0 Credits.
Basic principles of statistical physics and thermodynamics with application to biological systems. Topics include fundamental principles of thermodynamics, chemical equilibrium and thermodynamics of reactions in solutions, and elementary statistical mechanics.
Recommended Course Background: AS.110.108-AS.110.109, AS.030.101-AS.030.102, AS.171.101-AS.171.102; Freshman/Sophomore Chemistry and Physics
Instructor(s): M. Beer
Area: Engineering, Natural Sciences.

EN.580.407. Design Team Clinical Immersion. 1.0 Credit.
In this course design team leaders will undergo training in clinical need identification through clinical immersion in the Johns Hopkins Hospital System. Leaders will learn observation techniques, survey methods, mind-mapping and root-cause analysis. Dates: Tues 1/17- Friday 1/20, Monday 1/23 - Friday 1/27. The schedule for this class will change with clinical practice but will generally fall within the hours of 6am - 6pm.
Instructor(s): E. Logsdon; N. Durr.

EN.580.408. Design Team Leader Seminar. 1.0 Credit.
This course prepares undergraduate students to lead teams for the subsequent Design Teams course. This course will teach leadership skills, expose students to project options and clinical sponsors, and prepare them to plan and execute a biomedical design project. Course will meet in the Clark Hall Design Studio and the Carnegie Building (SoM) Design Studio.
Instructor(s): E. Logsdon; N. Durr.

EN.580.410. Effective Teaching and Management of Engineering Teams. 2.0 Credits.
Senior biomedical engineering students will assist the core course instructors and PhD students in managing the sections and recitations and or lab component of a course. Permission required.
Instructor(s): E. Haase.

EN.580.411. BME Design Group. 3.0 Credits.
Perm. Req'd. Senior-level version of EN.580.311-312.
Instructor(s): A. Manbachi; E. Logsdon; N. Durr; R. Allen
Area: Engineering.

EN.580.412. BME Design Group. 3.0 Credits.
Senior-level version of EN.580.311-312. Permission of course directors required
Instructor(s): A. Manbachi; E. Logsdon; N. Durr; R. Allen
Area: Engineering.

EN.580.413. Design Team, Team Leader Seminar. 1.0 Credit.
This course is for Design Team leaders actively leading a team for the academic year. This course focuses on development of leadership, communication and team management skills in the context of biodesign.
Instructor(s): A. Manbachi; E. Logsdon; N. Durr
Area: Engineering.

EN.580.414. Design Team, Team Leader Seminar. 1.0 Credit.
This course is for Design Team leaders actively leading a team for the academic year. This course focuses on development of leadership, communication and team management skills in the context of biodesign.
Instructor(s): A. Manbachi; E. Logsdon; N. Durr; R. Allen
Area: Engineering.

EN.580.415. Ethics of Biomedical Engineering Innovation. 3.0 Credits.
Engineers confront problems and make decisions that hold long term social consequences for individuals, organizations, communities and the profession. For biomedical engineers, these decisions may relate to: inventions such as medical devices and pharmaceuticals; neural prosthetics and synthetic biological organisms; responsible and sustainable design; availability of biotechnology in the developing world. Using a combination of cases, fieldwork and readings, we examine the ethical issues, standards, theory and consequences of recent and emerging engineering interventions as a way to understand the profession and to form a basis for future decisions. In addition students will learn and practice multiple forms of communication, including oral, visual and written rhetoric. A particular focus will be communication targeted to different stakeholders including other professionals and the public. Students will apply good communication principle to the discussion of biomedical engineering ethics, develop their own ethical case studies and participate in group projects to aid ethical decision-making, and to improve communication of complex biomedical ethical issues to others.
Instructor(s): F. Macgabhann
Area: Social and Behavioral Sciences
Writing Intensive.

EN.580.416. BME Advanced Teaching Practicum. 3.0 Credits.
Senior biomedical engineering students will assist the core course instructors in managing the sections, recitations, or lab component of a course. Permission required.
Instructor(s): E. Haase.

EN.580.418. Principles of Pulmonary Physiology. 3.0 Credits.
This course will provide students with an introduction to concepts in the structure and function of the respiratory system. Topics to be covered will include basic anatomy, lung mechanics, gas exchange, tests of pulmonary function and cardiopulmonary exercise, and the effects of disease on aspects of the respiratory system. Class sessions will mix both lecture and hands-on measurement, and will include discussion of instrumentation used in pulmonary measurements and a field trip to a clinical physiology laboratory at JHH. Recommended background: Chemistry, Physics, and Calculus II, and EN.580.222 Systems and Controls or equivalent.
Instructor(s): D. Shade
Area: Engineering, Natural Sciences.
EN.580.420. Build-a-Genome. 4.0 Credits.
Must understand fundamentals of DNA structure, DNA electrophoresis and analysis, Polymerase Chain Reaction (PCR) and must be either a) Experienced with molecular biology lab work or b) Adept at programming with a biological twist. In this combination lecture/laboratory "Synthetic Biology" course students will learn how to make DNA building blocks used in an int’l. project to build the world’s first synthetic eukaryotic genome, Saccharomyces cerevisiae v. 2.0. Please study the wiki www.syntheticyeast.org for more details about the project. Following a biotechnology boot-camp, students will have 24/7 access to computational and wet-lab resources and will be expected to spend 15-20 hours per week on this course. Advanced students will be expected to contribute to the computational and biotech infrastructure. Successful completion of this course provides 3 credit hours toward the supervised research requirement for Molecular and Cellular Biology majors, or 2 credit hours toward the upper level elective requirement for Biology or Molecular and Cellular Biology majors.

Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): J. Bader; K. Zeller
Area: Engineering, Natural Sciences.

EN.580.421. Systems Bioengineering I. 4.0 Credits.
A quantitative, model-oriented investigation of the cardiovascular system. Topics are organized in three segments. (1) Molecular/cellular physiology, including electrical signaling and muscle contraction. (2) Systems cardiovascular physiology, emphasizing circuit-diagram analysis of hemodynamics. (3) Cardio-vascular horizons and challenges for biomedical engineers, including heart failure and its investigation/treatment by computer simulation, by gene-array analysis, by stem-cell technology, and by mechanical devices (left-ventricular assist and total-heart replacement). Recommended Course Background: EN.580.221 and EN.580.222
Instructor(s): N. Trayanova; R. Vidal
Area: Engineering, Natural Sciences.

EN.580.422. Systems Bioengineering II. 4.0 Credits.
A quantitative, model-oriented approach to the study of the nervous system. Topics include functional anatomy of the central and autonomic nervous systems, neurons and networks, learning and memory, structure and function of the auditory and visual systems, motor systems, and neuro-engineering. Recommended Course Background: EN.580.221, EN.580.222, EN.580.223, AS.110.302, EN.580.421; Corequisite: EN.580.424
Instructor(s): E. Haase; X. Wang
Area: Engineering, Natural Sciences.

EN.580.423. Systems Bioengineering Lab I. 2.0 Credits.
A two-semester laboratory course in which various physiological preparations are used as examples of problems of applying technology in biological systems. The emphasis in this course is on the design of experimental measurements and on physical models of biological systems. Recommended Corequisite: EN.580.421
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): B. Bejar Haro; E. Haase
Area: Natural Sciences.

EN.580.424. Systems Bioengineering Lab. 2.0 Credits.
A laboratory course in which various physiological preparations are used as examples of problems of applying technology in biological systems. The emphasis in this course is on the design of experimental measurements and on physical models of biological systems. Recommended Corequisite: EN.580.422
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): E. Haase.

EN.580.425. Ion Channels in Excitable Membranes. 3.0 Credits.
Ion channels are key signaling molecules that support electrical communication throughout the body. As such, these channels are a central focus of biomedical engineering as it relates to neuroscience, computational biology, biophysics, and drug discovery. The course introduces the engineering and molecular strategies used to understand the function of ionic channels. The course also surveys key papers that paint the current picture of how ion channels open and conduct ions. Biological implications of these properties are emphasized throughout. Finally, the course introduces how optical and electrophysiological methods now promise to revolutionize understanding of ionic channels. This course can be seen as a valuable partner of Models of the Neuron (EN.580.439). Recommended Course Background: EN.580.421 and EN.580.422 or equivalent, AS.110.201, AS.110.302
Area: Engineering, Natural Sciences.

EN.580.429. Systems Bioengineering III. 4.0 Credits.
Computational and theoretical systems biology at the cellular and molecular level. Topics include organizational patterns of biological networks; analysis of metabolic networks, gene regulatory networks, and signal transduction networks; inference of pathway structure; and behavior of cellular and molecular circuits. Recommended Course Background: EN.580.221 and EN.580.222 or Permission Required.
Instructor(s): J. Bader
Area: Engineering, Natural Sciences.
EN.580.430. Systems Pharmacology and Personalized Medicine. 3.0 Credits.

We have moved beyond the ‘one-size-fits-all’ era of medicine. Individuals are different, their diseases are different, and their responses to drugs are different too. This variability is not just from person to person; heterogeneity is observed even between tumors within the same person, and between sites within the same tumor. These levels of variability among the human population must be accounted for to improve patient outcomes and the efficiency of clinical trials. Some of the ways in which this is being explored include: drugs are being developed hand-in-hand with the tests needed to determine whether or not they will be effective; tumor fragments excised from patients are being cultured in the lab for high-throughput testing of drugs and drug combinations; data-rich assays such as genomics and proteomics identify thousands of potentially significant differences between individuals; and computational models are being used to predict which therapies will work for which patients. This course will focus on the applications of pharmacokinetics and pharmacodynamics to simulating the effects of various drugs across a heterogeneous population of diseased individuals. Such computational approaches are needed to harness and leverage the vast amounts of data and provide insight into the key differences that determine drug responsiveness. These approaches can also explore the temporal dynamics of disease and treatment, and enable the modification of treatment during recovery. Recommended background: 110.201 Linear Algebra, 110.302 Differential Equations, and 553.311 Probability and Statistics (or equivalent).

Instructor(s): F. Macgabhann
Area: Engineering.

EN.580.431. Introduction to Computational Medicine I. 4.0 Credits.

Computational medicine is an emerging discipline in which computer models of disease are developed, constrained using data measured from individual patients, and then applied to deliver precision health care. Introduction to Computational Medicine I is the first in a sequence of two courses on computational medicine. It covers the core concepts of computational physiological medicine and computational anatomy. The first half of this course will cover computational physiological medicine. Students will learn how to: use biophysical laws and data to formulate computational models of physiological systems in health and disease; analyze the behaviors of these models using analytical and simulation approaches; apply models to understand their use in diagnosing and treating disease. The second half of this course will cover computational anatomy. Students will learn how to: model anatomies using magnetic resonance imaging data; compare anatomies via mappings onto anatomical atlases; discover anatomical biomarkers of disease; analyze changes in the connectivity of anatomies in disease. Class time will emphasize hands-on learning through data analysis, software development, and simulation. All instructional materials will be made available at the beginning of the course. Recommended Course Background: C++, Matlab or Python.

Prerequisites: (AS.110.107 OR AS.110.109 OR AS.110.113) AND (EN.553.310 OR EN.553.311 OR EN.553.420 OR EN.553.430)
Instructor(s): M. Miller; R. Winslow.

EN.580.434. Bioelectricity. 3.0 Credits.

This course has been revised to include numerous examples of bioelectrically active tissues and organs, complemented by relevant engineering principles. Topics include bioelectric currents and potentials, measurements of biological electric fields, wound repair in skin and epithelia, early history of bioelectricity, volume conductor theory, cardiac electrogram and lead theory, electromanipulation of cells, galvanotaxis, stem cell development, bone repair, and neuronal growth. Recommended Prereqs: EN.580.421 and EN.580.422.

Instructor(s): L. Tung
Area: Engineering.

EN.580.435. Applied Bioelectrical Engineering I. 1.5 Credits.

The course is offered in two parts, each a half semester long (1.5 credits each). EN.580.435 explores diverse applications of bioelectrical measurements and manipulation in modern engineering practice. Topics include functional electrical stimulation, deep brain stimulation, cardiac pacing and defibrillation, tissue ablation and cancer treatment. The second part of the course, EN.580.436, is optional and will consist of a lab project involving the physical manipulation of cells, mentored by the instructors and carried out by the entire class. Recommended Course Background: EN.580.421 and EN.580.422.

Instructor(s): D. Hunter; L. Tung
Area: Engineering.

EN.580.436. Applied Bioelectrical Engineering II. 1.5 Credits.

The course is offered in two parts, each a half semester long (1.5 credits each). EN.580.435 explores diverse applications of bioelectrical measurements and manipulation in modern engineering practice. Topics include functional electrical stimulation, deep brain stimulation, cardiac pacing and defibrillation, tissue ablation and cancer treatment. The second part of the course, EN.580.436, is optional and will consist of a lab project involving the physical manipulation of cells, mentored by the instructors and carried out by the entire class. Recommended Course Background: EN.580.421 and EN.580.422.

Instructor(s): D. Hunter; L. Tung
Area: Engineering.

EN.580.437. Neuro Data Design I. 4.0 Credits.

In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. Recommended Course Background: numerical programming.

Instructor(s): J. Vogelstein
Area: Engineering, Natural Sciences.
EN.580.438. Neuro Data Design II. 4.0 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. Recommended background: numerical programming.
Instructor(s): J. Vogelstein
Area: Engineering.

EN.580.439. Models of the Neuron. 4.0 Credits.
Single-neuron modeling, emphasizing the use of computational models as links between the properties of neurons at several levels of detail. Topics include thermodynamics of ion flow in aqueous environments, biology and biophysics of ion channels, gating, nonlinear dynamics as a way of studying the collective properties of channels in a membrane, synaptic transmission, integration of electrical activity in multi-compartment dendritic tree models, and properties of neural networks. Students will study the properties of computational models of neurons; graduate students will develop a neuron model using data from the literature. Recommended Course Background: AS.110.302 or equivalent. Meets with EN.580.639
Instructor(s): R. Winslow; S. Sarma
Area: Engineering, Natural Sciences.

EN.580.441. Cellular Engineering. 3.0 Credits.
This course focuses on principles and applications in cell engineering. Class lectures include an overview of molecular biology fundamentals, protein/ligand binding, receptor/ligand trafficking, cell-cell interactions, cell-matrix interactions, and cell adhesion and migration at both theoretical and experimental levels. Lectures will cover the effects of physical (e.g. shear stress, strain), chemical (e.g. cytokines, growth factors) and electrical stimuli on cell function, emphasizing topics on gene regulation and signal transduction processes. Furthermore, topics in metabolic engineering, enzyme evolution, polymeric biomaterials, and drug and gene delivery will be discussed. This course is intended as Part 1 of a two-semester sequence recommended for students in the Cell and Tissue Engineering focus area. Recommended Course Background: EN.580.221 or AS.020.305 and AS.020.306 or equivalent and AS.030.205 Meets with EN.580.641
Instructor(s): J. Green; K. Yarema
Area: Engineering.

EN.580.442. Tissue Engineering. 3.0 Credits.
This course focuses on the application of engineering fundamentals to designing biological tissue substitutes. Concepts of tissue development, structure and function will be introduced. Students will learn to recognize the majority of histological tissue structures in the body and understand the basic building blocks of the tissue and clinical need for replacement. The engineering components required to develop tissue-engineered grafts will be explored including biomechanics and transport phenomena along with the use of biomaterials and bioreactors to regulate the cellular microenvironment. Emphasis will be placed on different sources of stem cells and their applications to tissue engineering. Clinical and regulatory perspectives will be discussed. Recommended Course Background: EN.580.221 or AS.020.305 and AS.020.306, AS.030.205 Recommended EN.580.441/EN.580.641 Co-listed with EN.580.642
Instructor(s): J. Elisseef; W. Grayson
Area: Engineering.

EN.580.443. Advanced Orthopaedic Tissue Engineering. 3.0 Credits.
This course is intended to provide a comprehensive overview on the current state of the field of Orthopaedic Tissue Engineering. Students will apply engineering fundamentals learned in the Tissue Engineering course (EN.580.442/642) with special emphasis on how they apply to bone, cartilage, and skeletal muscle tissue engineering. The development, structure, mechanics, and function of each of these tissues will be discussed. Key articles from the last three decades that focus on stem cell- and cell-free, biomaterial-based approaches to regenerate functional tissues will be presented and analyzed. Practical (regulatory/commercial) considerations that restrict the translation of therapies to the clinic will be discussed.
Prerequisites: Grade of B or higher in EN.580.442 OR EN.580.642
Instructor(s): W. Grayson
Area: Engineering.

EN.580.444. Biomedical Applications of Glycoengineering. 3.0 Credits.
This course provides an overview of carbohydrate-based technologies in biotechnology and medicine. The course will begin by briefly covering basics of glycobiology and glycochemistry followed by detailed illustrative examples of biomedical applications of glycoengineering. A sample of these applications include the role of sugars in preventative medicine (e.g., for vaccine development and probiotics), tissue engineering (e.g., exploiting natural and engineered polysaccharides for creating tissue or organs de novo in the laboratory), regenerative medicine (e.g., for the treatment of arthritis or degenerative muscle disease), and therapy (e.g., cancer treatment). A major part of the course grade will be based on class participation with each student expected to provide a “journal club” presentation of a relevant paper as well as participate in a team-based project designed to address a current unmet clinical need that could be fulfilled through a glycoengineering approach. Recommended Course Background: EN.580.221 Molecules and Cells
Instructor(s): K. Yarema
Area: Engineering, Natural Sciences.

EN.580.445. Networks. 3.0 Credits.
Networks are ubiquitous in our modern society. The World Wide Web that links us to and enables information flows with the rest of the world is the most visible example. It is, however, only one of many networks within which we are situated. Our social life is organized around networks of friends and colleagues. These networks determine our information, influence our opinions, and shape our political attitudes. They also link us, often through important but weak ties, to everybody else in the United States and in the world. Economic and financial markets also look much more like networks than anonymous marketplaces. Firms interact with the same suppliers and customers and use Web-like supply chains. Financial linkages, both among banks and between consumers, companies and banks, also form a network over which funds flow and risks are shared. Systemic risk in financial markets often results from the counterparty risks created within this financial network. Food chains, interacting biological systems and the spread and containment of epidemics are some of the other natural and social phenomena that exhibit a marked networked structure. This course will introduce the tools for the study of networks. It will show how certain common principles permeate the functioning of these diverse networks and how the same issues related to robustness, fragility, and interlinkages arise in several different types of networks. Biological applications will be highlighted as material is presented. Recommended Course Background: EN.580.222
Instructor(s): S. Sarma
Area: Engineering.
EN.580.446. Physical Epigenetics. 3.0 Credits.
Epigenetics describes information heritable during cell division other than DNA sequence per se. Recent advances show the critical role of epigenetics in controlling gene expression, embryonic development, and common human diseases such as cancer. This course will introduce fundamental epigenetic principles with a focus on mechanisms, modeling, and physical principles, relationship to genetics, and application to understanding human disease mechanisms. Recommended Course Background: EN.580.221 Molecules and Cells or equivalent (molecular and cell biology), college level calculus and calculus-based general physics.
Instructor(s): A. Feinberg; T. Ha
Area: Engineering, Natural Sciences.

EN.580.447. Computational Stem Cell Biology. 3.0 Credits.
This course will provide the student with a mechanistic and systems biology-based understanding of the two defining features of stem cells: multipotency and self-renewal. We will explore these concepts across several contexts and perspectives, emphasizing seminal and new studies in development and stem cell biology, and the critical role that computational approaches have played. The course will start with an introduction to stem cells and a tutorial covering computational basics. The biological contexts that we will cover thereafter include "Cell Identity", "Pluripotency and multipotency", "Stem cells and their niche", "Modeling cell fate decisions", and "Engineering cell fate". This class is heavily weighted by individual computational assignments. The motivation for this strategy is that regularly occurring, moderately-sized computational projects are the most efficient way to impart an understanding of our models of this extraordinary class of cells, and to inspire a sense of excitement and empowerment. Preferred background: familiarity with the UNIX shell. Recommended Background: EN.580.221 - Molecules and Cells or Equivalent.
Prerequisites: Students may take EN.580.447 or EN.580.647, but not both.
Instructor(s): P. Cahan
Area: Engineering, Natural Sciences.

EN.580.448. Biomechanics of the Cell. 3.0 Credits.
Mechanical aspects of the cell are introduced using the concepts in continuum mechanics. We will discuss the role of proteins, membranes and cytoskeleton in cellular function and how to describe them using simple mathematical models. Co-listed with EN.530.410 Recommended course background: AS.171.101-102, AS.110.108-109 and AS.110.202
Instructor(s): A. Spector; S. Sun
Area: Engineering.

EN.580.451. Cell and Tissue Engineering Lab. 3.0 Credits.
Cell and tissue engineering is a field that relies heavily on experimental techniques. This laboratory course will consist of three six experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Students will learn basic cell culture procedures and specialized techniques related to faculty expertise in cell engineering, microfluidics, gene therapy, microfabrication and cell encapsulation. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. Co-listed with EN.530.451. Senior and Graduate students only; others, instructor permission required. Fall semester only. Lab Fee: $100
Instructor(s): E. Haase
Area: Engineering, Natural Sciences.

EN.580.452. Cell and Tissue Engineering Lab. 3.0 Credits.
This laboratory course will consist of three experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. Spring semester only.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): E. Haase
Area: Engineering, Natural Sciences.

EN.580.456. Introduction to Rehabilitation Engineering. 3.0 Credits.
The primary objective of this course is to introduce biomedical engineering students to the challenges of engineering solutions for persons functioning with disabilities and apply that knowledge to the development of a new, improved device to be used for measurement or treatment of an impairment or disability. In order to achieve this goal, the objectives of the fall semester include: gaining a basic appreciation of the modalities used to treat impairments, the opportunities for application of engineering to improve treatment delivery; understanding the science and engineering applied to helping persons with disabilities function in the everyday world and an basic knowledge of the legal, ethical issues and employment opportunities in rehabilitation engineering. By the conclusion of this class, students should be able to: • Understand the breadth and scope of physical impairment and disability, including its associated pathophysiology • Characterize the material and design properties of current evaluation tools for assessment of impairments and adaptations for disability • Characterize the material and design properties of current modalities of treatment of impairments and adaptations for disability • Apply engineering analysis and design principles to critique current solutions for persons with disabilities in order to suggest improvements In the spring semester (in course EN.580.457), students will learn the biomedical engineering design process and its application to persons with disabilities. Working in groups of four to five, teams will work on a project derived from a needs analysis based on their visits to rehabilitation centers in the fall semester. Project will require instructor approval before the beginning of the spring semester. Each project will consist of a proposal for design of a new device or solution to a problem faced by persons with disabilities, preliminary "virtual" (e.g., CAD), and actual proof of concept working prototype.
Prerequisites: EN.580.422
Instructor(s): S. Paul
Area: Engineering.

EN.580.457. Introduction to Rehabilitation Engineering: Design Lab. 3.0 Credits.
Students have the opportunity to apply the knowledge they have gained in the fall semester of EN.580.456 and their prior coursework to the development of a new, improved device to be used for measurement or treatment of an impairment or disability. In doing so, they will learn the biomedical engineering design process and its application to persons with disabilities. Working in groups of four to five, teams will work on a project derived from a needs analysis based on their visits to rehabilitation centers in the fall semester. Project will require instructor approval before the beginning of the spring semester. Each project will consist of a proposal for design of a new device or solution to a problem faced by persons with disabilities, preliminary "virtual" (e.g., CAD), and actual proof of concept working prototype.
Prerequisites: EN.580.456
Instructor(s): S. Paul
Area: Engineering.
EN.580.460. Theory of Cancer. 3.0 Credits.
The course will deal with important problems in cancer and how they can be approached using mathematical and computational modeling. The course will be organized around introductory material describing the biological and clinical problem and the mathematical and computational methodology that will be used for its analysis. This will be followed by analysis of key modeling papers dealing with the problem. An important part of the course will be a computational modeling project (small group or individual) dealing with modeling of cancer in which the students will extend existing models or formulate novel models of cancer, including cancer therapeutics. The students will strive to create models leading to new discoveries.
Instructor(s): A. Popel
Area: Engineering.

EN.580.462. Representations of Choice. 3.0 Credits.
In this course we will examine key computational topics from the nascent fields of decision neuroscience and neuroeconomics. After taking this course students will have an understanding of how the field emerged and will develop a critical appreciation of the advantages and limitations of different analytical approaches. Students will also be able to discuss the current knowledge on processes of valuation, value-learning and decision-making in relation to their computational representations at the behavioral and neural level. Linear Algebra and programming experience (python, matlab, or C) recommended.
Instructor(s): V. Chib
Area: Engineering.

EN.580.466. Statistical Methods in Imaging. 3.0 Credits.
Denosing, segmentation, texture modeling, tracking, object recognition are challenging problems in imaging. We will present a collection of statistical models and methods in order to address these, including the E.M algorithm, Maximum Entropy Modeling, Markov Random Fields, Markov Chain Monte Carlo, Boltzmann Machines and Multilayer Perceptrons. Recommended Course Background: AS.110.202 and EN.553.310 or equivalent.
Instructor(s): B. Jedynak
Area: Engineering, Quantitative and Mathematical Sciences.

EN.580.468. The Art of Data Science. 3.0 Credits.
In this course, we will cover the fundamentals of doing data science research, explaining “best practices” for each step, that collectively comprise an upward spiral. These steps include: (i) asking an interesting question, (ii) determining the degree to which the answer is known, (iii) assessing there currently exists data to likely obtain a satisfactory answer, (iv) exploring the data set, (v) cleaning up the dataset, (vi) formalizing a statistical inquiry, (vii) positing a statistical model which we hope will yield satisfactory answers, (viii) devising a test to assess the answer, (ix) building an estimator to assess the model, (x) checking the model, (xi) reporting the results, (xii) suggesting the next experiment to perform or question to answer to further enhance the model. Note that this course will largely be project based; each student will be expected to complete each of the above steps on some real data of interest to the student. Lectures will be minimal, giving introductory explanations one day, hopefully only part of the time. The rest of the time, we will work independently or in small groups to complete the weekly portion of the overall project. Please come ready to do science! If you don’t have questions that you want answered, you can work in small groups, but each student will need to write the code and reports on their own. Recommended Course Background: No courses are formally required, though students will need to write numerical code (in R, Python, or Julia), and make reports using LaTeX, knitr, or Jupyter notebooks or similar.
Instructor(s): J. Vogelstein
Area: Engineering.

EN.580.471. Principles of Design of BME Instrumentation. 4.0 Credits.
This core design course will cover lectures and hands-on labs. The material covered will include fundamentals of biomedical sensors and instrumentation, FDA regulations, designing with electronics, biopotentials and ECG amplifier design, recording from heart, muscle, brain, etc., diagnostic and therapeutic devices (including pacemakers and defibrillators), applications in prosthetics and rehabilitation, and safety. The course includes extensive laboratory work involving circuits, electronics, sensor design and interface, and building complete biomedical instrumentation. The students will also carry out design challenge projects, individually or in teams (examples include “smart cane for blind,” “computer interface for quadriplegic”). Students satisfying the design requirement must also register for EN.580.571. Lab Fee: $150.
Recommended Course Background: EN.520.345
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): N. Thakor
Area: Engineering, Natural Sciences.

EN.580.472. Medical Imaging Systems. 3.0 Credits.
An introduction to the physics, instrumentation, and signal processing methods used in general radiography, X-ray computed tomography, ultrasound imaging, magnetic resonance imaging, and nuclear medicine. The primary focus is on the methods required to reconstruct images within each modality, with emphasis on the resolution, contrast, and signal-to-noise ratio of the resulting images. Cross-listed with Neuroscience and Electrical and Computer Engineering (EN.520.432).
Prerequisites: EN.580.222 OR EN.520.214
Instructor(s): M. Bell
Area: Engineering.
EN.580.473. Modern Biomedical Imaging Instrumentation and Techniques. 3.0 Credits.

An intermediate biomedical imaging course covering modern biomedical imaging instrumentation and techniques as applied to diagnostic radiology and other biomedical applications. It includes recent advances in various biomedical imaging modalities, multi-modality imaging and molecular imaging. The course is team taught by experts in the respective fields and provides a broad based knowledge of modern biomedical imaging to prepare students for graduate studies and research in biomedical imaging. Also, the course will offer tours and practical experience with modern biomedical imaging equipment in clinical and research settings. Co-listed with EN.520.434 Recommended course background: EN.520.432 or EN.580.472

Prerequisites: Students may not have taken EN.580.773.

Instructor(s): B. Tsui

Area: Engineering, Natural Sciences.

EN.580.476. Magnetic Resonance in Medicine. 3.0 Credits.

This course provides the student with a complete introduction to the physical principles, hardware design, and signal processing used in magnetic resonance imaging and magnetic resonance spectroscopy. The course is designed for students who wish to pursue research in magnetic resonance. Recommended course background: EN.580.222 or EN.520.214. Co-listed with EN.580.673.

Instructor(s): M. Schar; P. Bottomley

Area: Engineering.

EN.580.479. X-ray Imaging and Computed Tomography. 3.0 Credits.

This course provides students with an intermediate-level understanding of the physics, engineering, algorithms, and applications of medical x-ray imaging and computed tomography (CT). It is intended for senior undergraduates (EN.580.479) and/or graduate students (EN.580.679) in Biomedical Engineering, Computer Science, Electrical and Computer Engineering, or related fields in science and engineering. Topics include the physics of x-ray interaction and detection, image quality modeling and assessment, 3D image reconstruction (including analytical and iterative approaches), and applications in diagnostic and image-guided procedures. Recommended Course Background: EN.580.472 and/or EN.580.473 and familiarity with Matlab.

Instructor(s): J. Siewerdsen

Area: Engineering.

EN.580.480. Precision Care Medicine. 3.0 Credits.

Precision Care Medicine is a two-semester project-based learning course. Projects will use methods of machine learning and mechanistic and statistical modeling to develop novel data-driven solutions to important health care problems that arise in anesthesiology and critical care medicine. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 3-4, and will work with their project mentors (clinical faculty in the ACCM Department, Drs. Winslow and Sarma) to develop a project work plan. In the remainder of the course, they will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will also be charged with designing, validating and deploying a web-application that delivers the computational method for solving the underlying healthcare problem to the user. HIPAA regulations, use of human subjects data, and requirements for FDA Class II and Medical Device Data Systems approval will be covered.

Instructor(s): R. Winslow; S. Sarma

Area: Engineering.

EN.580.481. Precision Care Medicine. 3.0 Credits.

Precision Care Medicine is a two-semester project-based learning course. Projects will use methods of machine learning and mechanistic and statistical modeling to develop novel data-driven solutions to important health care problems that arise in anesthesiology and critical care medicine. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 3-4, and will work with their project mentors (clinical faculty in the ACCM Department, Drs. Winslow and Sarma) to develop a project work plan. In the remainder of the course, they will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will also be charged with designing, validating and deploying a web-application that delivers the computational method for solving the underlying healthcare problem to the user. HIPAA regulations, use of human subjects data, and requirements for FDA Class II and Medical Device Data Systems approval will be covered.

Area: Engineering.
EN.580.487. Nuclear Medicine Imaging. 3.0 Credits.
This course provides an intermediate-level introduction to the instrumentation, image processing and reconstruction methods used in planar nuclear medicine imaging, single-photon emission computed tomography (SPECT) and positron emission tomography (PET). Topics include radioactive decay, nuclear medicine instrumentation including radiation detectors and associated electronics, analytic and statistical iterative tomographic reconstruction, imaging physics, and image quality in the context of these three modalities. This course will be taught at the School of Medicine Campus. Recommended Course Background: EN.520.432/EN.580.472 and EN.520.434/EN.580.473
Instructor(s): A. Rahmir, B. Tsui, E. Frey, Y. Du
Area: Engineering.

EN.580.488. Foundations of Computational Biology and Bioinformatics II. 3.0 Credits.
This course will introduce probabilistic modeling and information theory applied to biological sequence analysis, focusing on statistical models of protein families, alignment algorithms, and models of evolution. Topics will include probability theory, score matrices, hidden Markov models, maximum likelihood, expectation maximization and dynamic programming algorithms. Homework assignments will require programming in Python. Foundations of Computational Biology I is not a prerequisite. Recommended Course Background: Math through linear algebra and differential equations, EN.580.221 or equivalent, EN.601.226 or equivalent
Instructor(s): R. Karchin
Area: Engineering, Natural Sciences.

EN.580.491. Learning Theory. 3.0 Credits.
The course introduces the probabilistic foundations of learning theory. We will discuss topics in regression, estimation, optimal control, system identification, Bayesian learning, and classification. Our aim is to first derive some of the important mathematical results in learning theory, and then apply the framework to problems in biology, particularly animal learning and control of action. Recommended Course Background: AS.110.201 and AS.110.302
Instructor(s): R. Shadmehr
Area: Engineering.

EN.580.492. Build-a-Genome Mentor. 4.0 Credits.
In addition to producing and sequencing DNA segments like regular B-a-G students, mentors will help prepare and distribute reagents, and maintain a Moddle site to track student reagent use and productivity. Mentors will also be expected to mentor specific students who are learning new techniques for the first time, contribute to the computational and biotech infrastructure associated with Build-a-Genome, and pursue at least one independent research project. Successful completion of this course provides 3 credit hours toward the supervised research requirement for Molecular and Cellular Biology majors. Co-listed AS.020.451 Permission Required.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): J. Bader; K. Zeller
Area: Engineering, Natural Sciences.

EN.580.493. Imaging Instrumentation. 4.0 Credits.
This course is intended to introduce students to imaging instrumentation. The class will be lab-oriented, giving hands-on experience with data collection and processing using a configurable optical system. Specific topics will include the programming and control of electromechanical elements, imaging data acquisitions, image formation and processing (e.g. 3D reconstruction), and imaging system analysis and optimization. Recommended Course Background: EN.580.222 Systems and Controls or EN.520.214 Signals and Systems. Programming experience highly desirable.
Instructor(s): J. Stayman
Area: Engineering.

EN.580.495. Microfabrication Lab. 4.0 Credits.
This laboratory course introduces the principles used in the construction of microelectronic devices, sensors, and micromechanical structures. Students will work in the laboratory on the fabrication and testing of a device. Accompanying lecture material covers basic processing steps, design and analysis CAD tools, and national foundry services. Co-listed with EN.530.495 and EN.520.495 Seniors only. Permission Required.
Instructor(s): A. Andreou; J. Wang
Area: Engineering, Natural Sciences.

EN.580.497. Advanced Design Projects: Instrumentation. 3.0 Credits.
This course will provide project-specific mentorship and guidance for a team to complete a sophisticated prototype and demonstrate technical feasibility towards impacting a clinical problem. Prototyping and testing tools and procedures will be taught and employed on a per-project basis. Documentation of progress through a design history file and course report is required. Teams will be meet biweekly with course faculty through a Desk Review format. Students are expected to work in teams between desk reviews and present progress updates as well as short- and long-term action plans at each desk review. A final presentation is expected at the end of the semester that will involve course faculty as well as a clinical sponsor (called a committee meeting in Design Teams). Additionally, each team must identify a domain expert from the WSE faculty that agrees to attend the final presentation and at least 2 desk reviews. This faculty will focus on guiding and assessing the team's technical achievements within the context of biomedical instrumentation. Prerequisites: Students must have completed Lab Safety training prior to registering for this class.
Instructor(s): A. Manbachi; N. Durr
Area: Engineering.
EN.580.498. Adv. Design Projects: Instrumentation. 3.0 Credits.
This course will provide project-specific mentorship and guidance for a
team to complete a sophisticated prototype and demonstrate technical
feasibility towards impacting a clinical problem. Prototyping and testing
tools and procedures will be taught and employed on a per-project basis.
Documentation of progress through a design history file and course
report is required. Teams will be meet biweekly with course faculty
through a Desk Review format. Students are expected to work in teams
between desk reviews and present progress updates as well as short-
and long-term action plans at each desk review. A final presentation is
expected at the end of the semester that will involve course faculty as
well as a clinical sponsor (called a committee meeting in Design Teams).
Additionally, each team must identify a domain expert from the WSE
faculty that agrees to attend the final presentation and at least 2 desk
reviews. This faculty will focus on guiding and assessing the team’s
technical achievements within the context of biomedical instrumentation.
Prerequisites: Students must have completed Lab Safety training prior to
registering for this class.
Instructor(s): A. Manbachi; N. Durr
Area: Engineering.
EN.580.501. Fall BME Research - Freshman/Sophomore. 3.0 Credits.
Instructor(s): Staff.
EN.580.502. Spring BME Research - Freshman/Sophomore. 1.0 - 4.0
Credits.
Practicum in Biomedical Engineering Research projects or engineering
design projects under the supervision of any member of the BME faculty.
Instructor(s): Staff.
EN.580.510. Biomedical Engineering Undergraduate Research. 1.0 - 3.0
Credits.
Student participation in ongoing research activities. Research is
conducted under the supervision of a faculty member and often in
conjunction with other members of the research group.
Instructor(s): Staff.
EN.580.511. Biomedical Engineering Undergraduate Research. 1.0 - 3.0
Credits.
Student participation in ongoing research activities. Research is
conducted under the supervision of a faculty member and often in
conjunction with other members of the research group.
Instructor(s): Staff.
EN.580.512. Spring BME Independent Study - Freshman/Sophomore. 0.0 -
4.0 Credits.
Directed readings or other literature research under the direction of any
member of the BME faculty.
Instructor(s): Staff.
EN.580.531. Fall BME Research - Junior/Senior. 3.0 Credits.
Instructor(s): Staff.
EN.580.532. Spring BME Research - Junior/Senior. 3.0 Credits.
Research projects or engineering design projects under the supervision of
any member of the BME faculty.
Instructor(s): Staff.
EN.580.541. Fall BME Independent Study - Junior/Senior. 3.0 Credits.
Directed readings or other literature research under the direction of any
BME faculty member. Junior or Senior standing.
Instructor(s): Staff.
EN.580.542. Spring BME Independent Study - Junior/Senior. 0.0 - 4.0
Credits.
Directed readings or other literature research under the direction of any
BME faculty member.
Instructor(s): Staff.
EN.580.550. Biomedical Engineering Group Undergraduate Research. 1.0
- 3.0 Credits.
Student participation in ongoing research activities. Research is
conducted under the supervision of a faculty member and often in
conjunction with other members of the research group. This section has
a weekly research group meeting that students are expected to attend.
Instructor(s): Staff.
EN.580.551. Biomedical Engineering Group Undergraduate Research. 1.0
- 3.0 Credits.
Student participation in ongoing research activities. Research is
conducted under the supervision of a faculty member and often in
conjunction with other members of the research group. This section has
a weekly research group meeting that students are expected to attend.
Instructor(s): Staff.
EN.580.561. Advanced Focus Area Research: Cell/Tissue/Biomaterials.
3.0 Credits.
This course provides students with the opportunity to consider unsolved
issues within their focus area, delve into the current cutting-edge
research, and provide a synopsis of the next steps required to advance
a particular field. “Advanced Focus Area Research” is a one-semester
course in which students complete a research project, present their work,
and write a publication ready manuscript under the guidance of their
Primary Investigator (PI) and a Focus Area mentor. Priority to Junior
and Senior BME majors. Recommended Course Background: Previous
research experience. Students must complete the online Undergraduate
Lab safety courses available through “MyLearning” including Bloodborne
Pathogens, HIPAA, and any other online training as needed.
Prerequisites: Students must have completed Lab Safety training prior to
registering for this class. To access the tutorial, login to myLearning and
enter 458083 in the Search box to locate the appropriate module.
Instructor(s): E. Haase
Area: Engineering, Quantitative and Mathematical Sciences.
EN.580.563. Advanced Focus Area Research: Computational Biology. 3.0
Credits.
This course provides students with the opportunity to consider unsolved
issues within their focus area, delve into the current cutting-edge
research, and provide a synopsis of the next steps required to advance
a particular field. “Advanced Focus Area Research” is a one-semester
course in which students complete a research project, present their work,
and write a publication ready manuscript under the guidance of their
Primary Investigator (PI) and a Focus Area mentor. Priority to Junior
and Senior BME majors. Recommended Course Background: Previous
research experience. Students must complete the online Undergraduate
Lab safety courses available through “MyLearning” including Bloodborne
Pathogens, HIPAA, and any other online training as needed.
Prerequisites: Students must have completed Lab Safety training prior to
registering for this class. To access the tutorial, login to myLearning and
enter 458083 in the Search box to locate the appropriate module.
Instructor(s): E. Haase
Area: Engineering, Quantitative and Mathematical Sciences.
EN.580.565. Advanced Focus Area Research: Imaging & Sensors/Instrumentation/Micro-Nano Technology. 3.0 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors. Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through "MyLearning" including Bloodborne Pathogens, HIPAA, and any other online training as needed. 
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Instructor(s): E. Haase
Area: Engineering, Quantitative and Mathematical Sciences.

EN.580.567. Advanced Focus Area Research: Systems Biology. 3.0 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors. Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through "MyLearning" including Bloodborne Pathogens, HIPAA, and any other online training as needed. 
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Instructor(s): E. Haase
Area: Engineering, Quantitative and Mathematical Sciences.

EN.580.571. Honors Instrumentation. 2.0 Credits.
Student must have taken 580.471/771. Students will develop a term paper and patent application and carry out a hands-on individual or team project throughout the semester. Previous projects include design of EEG amplifier, voltage clamp and patch clamp, vision aid of blind, pacemaker/defibrillator, sleep detection and alert device, glucose sensor and regulation, temperature controller, eye movement detection and device control, ultrasound ranging and tissue properties, impedance plethysmography, lie detector, blood alcohol detector, pulse oximeter, etc. 
Instructor(s): N. Thakor.

EN.580.580. Senior Design Project. 3.0 Credits.
Per Independent or team design project to design and evaluate a system. The design should demonstrate creative thinking and experimental skills, and must draw upon advanced topics of biomedical and traditional engineering. Permission Required.
Instructor(s): A. Manbachi; Y. Yazdi.

EN.580.581. Senior Design Project. 3.0 Credits.
Independent or team design project to design and evaluate a system. The design should demonstrate creative thinking and experimental skills, and must draw upon advanced topics of biomedical and traditional engineering. Permission Required.
Instructor(s): A. Manbachi.

EN.580.590. Biomedical Internship. 1.0 Credit.
Instructor(s): Staff.

EN.580.591. Advanced Focus Area Research: Cell/Tissue/Biomaterials. 3.0 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors. Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through "MyLearning" including Bloodborne Pathogens, HIPAA, and any other online training as needed. 
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Instructor(s): E. Haase.

EN.580.592. Advanced Focus Area Research: Computational Biology. 3.0 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors. Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through "MyLearning" including Bloodborne Pathogens, HIPAA, and any other online training as needed. 
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Instructor(s): E. Haase.

EN.580.593. Advanced Focus Area Research: Imaging & Sensors/Instrumentation/Micro-Nano Technology. 3.0 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors. Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through "MyLearning" including Bloodborne Pathogens, HIPAA, and any other online training as needed. 
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Instructor(s): E. Haase.
EN.580.594. Advanced Focus Area Research: Systems Biology. 3.0 Credits.
This course provides students with the opportunity to consider unsolved issues within their focus area, delve into the current cutting-edge research, and provide a synopsis of the next steps required to advance a particular field. “Advanced Focus Area Research” is a one-semester course in which students complete a research project, present their work, and write a publication-ready manuscript under the guidance of their Primary Investigator (PI) and a Focus Area mentor. Priority to Junior and Senior BME majors. Recommended Course Background: Previous research experience. Students must complete the online Undergraduate Lab safety courses available through “MyLearning” including Bloodborne Pathogens, HIPAA, and any other online training as needed.
Prerequisites: Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Instructor(s): E. Haase.

EN.580.595. BME Senior Design - Summer. 3.0 Credits.
Instructor(s): J. Green; L. Schramm; R. Allen.

EN.580.597. BME Research - Summer. 3.0 Credits.
Instructor(s): Staff.

EN.580.598. Design Project. 3.0 Credits.
Instructor(s): R. Allen.

EN.580.599. Independent Study. 3.0 Credits.
Instructor(s): A. Shoukas; H. Goldberg; K. Yarema; N. Thakor; S. Kuo.

EN.580.601. Special Topics in Bioengineering Innovation and Design. 1.0 Credit.
This year long seminar series features experts from the medical device industry, venture capital firms, FDA, patent attorneys, entrepreneurs, and many more. They will share their real-world insights into the medical device innovation and commercialization process. Some of the topics covered will include bioethics, regulatory and reimbursement planning, medical device recalls, good design practices, and entrepreneurial success stories. The overarching philosophy of this seminar series is to complement the theoretical and practical aspects of the program curriculum, by learning from the experiences and insights of professionals in the field. For CBID MSE students only.
Instructor(s): S. Acharya.

EN.580.602. Special Topics in Bioengineering Innovation and Design. 1.0 Credit.
This year long seminar series features experts from the medical device industry, venture capital firms, FDA, patent attorneys, entrepreneurs, and many more. They will share their real-world insights into the medical device innovation and commercialization process. Some of the topics covered will include bioethics, regulatory and reimbursement planning, medical device recalls, good design practices, and entrepreneurial success stories. The overarching philosophy of this seminar series is to complement the theoretical and practical aspects of the program curriculum, by learning from the experiences and insights of professionals in the field. For CBID MSE students only. Registration with instructor’s permission only.
Instructor(s): S. Acharya.

EN.580.603. Special Topics in Bioengineering Innovation & Design. 1.0 Credit.
This year long seminar series features experts from the medical device industry, venture capital firms, FDA, patent attorneys, entrepreneurs, and many more. They will share their real-world insights into the medical device innovation and commercialization process. Some of the topics covered will include bioethics, regulatory and reimbursement planning, medical device recalls, good design practices, and entrepreneurial success stories. The overarching philosophy of this seminar series is to complement the theoretical and practical aspects of the program curriculum, by learning from the experiences and insights of professionals in the field. For CBID MSE students only.
Instructor(s): S. Acharya.

EN.580.607. Regulation of Medical Devices. 1.0 Credit.
This course introduces graduate students in Bioengineering Innovation and Design to the medical device regulatory framework, as it pertains to bringing a medical device from concept to market. Topics covered include; FDA Design Controls; Regulatory Approval mechanisms, including the 510k and PMA process; Investigational Device exemption (IDE); planning clinical trials needed for bringing a medical device to market; and postmarket surveillance. Students learn from a series of invited lecturers from the FDA as well as professionals from the medical device industry. This summer course is required for CBID masters students and is not open to any other students.
Instructor(s): S. Acharya.

EN.580.608. Identification and Validation of Medical Device Needs. 6.0 Credits.
This course teaches the art and skill of identifying medical device opportunities by experiencing real world scenarios in an immersive clinical environment. Students rotate through multiple clinical disciplines and become part of the team of senior clinicians, surgeons, residents, fellows, nurses and medical technologists. They learn to identify unmet medical device needs through direct observations in a variety of clinical settings including the hospital ward and operating room, interviews (with patients, doctors, nurses, hospital administration), literature survey, and more. Concurrently, they learn the process of filtering all observations to a few viable medical device opportunities by assessing the market size, intellectual property landscape, regulatory framework, and competitor dynamics in addition to the clinical impact that such a device could have. The ability to identify a relevant medical device need is an important first step in the medical device innovation cycle; this course aims to provide students with practical hands-on training in that process.
Instructor(s): C. Weiss; H. Nguyen; S. Acharya.

EN.580.609. BME Teaching Practicum. 3.0 Credits.
Instructor(s): E. Haase.

EN.580.611. Medical Device Design and Innovation. 4.0 Credits.
For CBID MSE students only. Registration with instructor’s permission only.
Instructor(s): S. Acharya.

EN.580.612. Medical Device Design and Innovation. 4.0 Credits.
For CBID MSE students only.
Instructor(s): S. Acharya.

EN.580.618. Needs Identification and Validation for Global Health Innovation. 4.0 Credits.
Limited to CBID students only
Instructor(s): S. Acharya.
EN.580.619. Bioengineering Innovation and Design - Global Health. 4.0 Credits.
For CBID MSE students only. Registration with instructor’s permission only.
Instructor(s): S. Acharya.

EN.580.620. Principles and Practice of Global Health Innovation and Design. 4.0 Credits.
For CBID MSE students only. Instructor’s Permission Required.
Instructor(s): S. Acharya.

EN.580.621. Insight Informed Innovation I. 3.0 Credits.
For CBID MSE students only. Registration with instructor’s permission only.
Instructor(s): B. Craft; P. Fearis.

EN.580.623. Insight Informed Innovation II. 3.0 Credits.
This course is intended to equip students with a structured process and the tools required to: 1. Identify opportunities for new medical devices through unmet, unarticulated and underserved stakeholder needs. 2. Link these insights to an exhaustive set of potential solutions. 3. Synthesize solutions and features into product concepts. Recommended Course Background: Insight Informed Innovation I (summer)
Instructor(s): B. Craft; P. Fearis.

EN.580.625. Structure and Function of the Auditory and Vestibular Systems. 3.0 Credits.
This course will cover basic functions of the auditory and vestibular pathways responsible for perception of sound and balance. Topics include: hair cell structure and mechanotransduction, hair cell electromotility and cochlear active force production, hair cell synaptic signaling, cochlear development and role of glia in the inner ear, primary auditory and vestibular stimulus encoding, afferents and the first-order brainstem nuclei, as well as clinical consequences of peripheral damage, physiology of hearing loss, vestibular loss, tinnitus, hair cell regeneration and gene therapy. Moving more centrally, synaptic transmission and signal processing in central neurons, and complex sound perception and movement control will be discussed. Aspects such as speech perception, sound localization, vestibular reflexes, vestibular compensation, and self-motion perception are discussed with an integrated perspective covering perceptual, physiological, and mechanistic data. Grades will be based on participation in class, homework, and first-half and second-half exams (both in class, closed book, short answer/essay types). Offered in odd-numbered years. This course will meet in 529 Ross Research Bldg. at the School of Medicine campus. Recommended Background: general introduction to Neuroscience. Undergraduates with knowledge in Neuroscience welcome.
Instructor(s): K. Cullen; P. Fuchs.

EN.580.626. Structure & Function of the Auditory and Vestibular Brain. 3.0 Credits.
Brain mechanisms and perception of sound and balance. This course is an accompaniment for EN.580.625, although the courses can be taken in either order. Topics include representation of sound and balance in neural discharge patterns, anatomy of the central auditory and vestibular systems, synaptic transmission and signal processing in central neurons, and complex sound perception and movement control. Aspects such as speech perception, sound localization, vestibular reflexes and vestibular compensation are discussed with an integrated perspective covering perceptual, physiological, and mechanistic data. Recommended Course Background: EN.580.625 and EN.580.626 or equivalent. Taught at the School of Medicine, Traylor Bldg. 529.
Instructor(s): X. Wang.

EN.580.628. Topics in Systems Neuroscience. 1.0 Credit.
This course consists of weekly discussions of current literature in systems neuroscience. The selected readings will focus on neural mechanisms for perception, attention, motor behavior, learning, and memory, as studied using physiological, psychophysical, computational, and imaging techniques. Students are expected to give presentations and participate in discussions. Recommended Course Background: AS.110.302, EN.520.214, EN.580.421 or equivalent. Students will have to attend the organizational meeting to be able to enroll. The course is run by the Neuroscience department. Enrollment numbers may be limited by the course directors, and priority will be given to Neuroscience graduate students. Please contact the Neuroscience department for more information and the date of the organizational meeting.
Instructor(s): K. Zhang; X. Wang.

EN.580.630. Theoretical Neuroscience. 3.0 Credits.
Theoretical methods for analyzing information encoding and functional representations in neural systems. Models of single and multiple neural spike trains based on stochastic processes and information theory; detection and estimation of behaviorally relevant parameters from spike trains; system theoretic methods for analyzing sensory receptive fields; network models of neural systems. Both theoretical methods and the properties of specific well-studied neural systems will be discussed. Recommended Course Background: EN.580.422 or equivalent, EN.553.420 or equivalent, EN.580.222 or equivalent.
Instructor(s): K. Zhang; X. Wang.

EN.580.631. Introduction to Computational Medicine I. 4.0 Credits.
Computational medicine is an emerging discipline in which computer models of disease are developed, constrained using data measured from individual patients, and then applied to deliver precision health care. Introduction to Computational Medicine I is the first in a sequence of two courses on computational medicine. It covers the core concepts of computational physiological medicine and computational anatomy. The first half of this course will cover computational physiological medicine. Students will learn how to: use biophysical laws and data to formulate computational models of physiological systems in health and disease; analyze the behaviors of these models using analytical and simulation approaches; apply models to understand their use in diagnosing and treating disease. The second half of this course will cover computational anatomy. Students will learn how to: model anatomies using magnetic resonance imaging data; compare anatomies via mappings onto anatomical atlases; discover anatomical biomarkers of disease; analyze changes in the connectivity of anatomies in disease. Class time will emphasize hands-on learning through data analysis, software development, and simulation. All instructional materials will be made available at the beginning of the course. Recommended Course Background: C++, Matlab or Python.
Instructor(s): M. Miller; R. Winslow.
EN.580.632. Ionic Channels in Excitable Membranes. 3.0 Credits.
Ion channels are key signaling molecules that support electrical communication throughout the body. As such, these channels are a central focus of biomedical engineering as it relates to neuroscience, computational biology, biophysics, and drug discovery. The course introduces the engineering and molecular strategies used to understand the function of ionic channels. The course also surveys key papers that paint the current picture of how ion channels open and conduct ions. Biological implications of these properties are emphasized throughout. Finally, the course introduces how optical and electrophysiological methods now promise to revolutionize understanding of ionic channels. This course can be seen as a valuable partner of Models of the Neuron (EN.580.439). Recommended Course Background: EN.580.421 and EN.580.422 or equivalent, AS.110.201, AS.110.302
Instructor(s): D. Yue
Area: Engineering, Natural Sciences.

EN.580.638. Neuro Data Design II. 4.0 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. Recommended background: numerical programming.
Instructor(s): J. Vogelstein.

EN.580.639. Models of the Neuron. 4.0 Credits.
Single-neuron modeling, emphasizing the use of computational models as links between the properties of neurons at several levels of detail. Topics include thermodynamics of ion flow in aqueous environments, biology and biophysics of ion channels, gating, nonlinear dynamics as a way of studying the collective properties of channels in a membrane, synaptic transmission, integration of electrical activity in multi-compartment dendritic tree models, and properties of neural networks. Students will study the properties of computational models of neurons; graduate students will develop a neuron model using data from the literature. Differs in that an advanced modeling project using data from the literature is required. Graduate version of EN.580.439. Recommended Course Background: AS.110.302 or equivalent.
Instructor(s): R. Winslow; S. Sarma.

EN.580.640. Systems Pharmacology and Personalized Medicine. 3.0 Credits.
We have moved beyond the 'one-size-fits-all' era of medicine. Individuals are different, their diseases are different, and their responses to drugs are different too. This variability is not just from person to person; heterogeneity is observed even between tumors within the same person, and between sites within the same tumor. These levels of variability among the human population must be accounted for to improve patient outcomes and the efficiency of clinical trials. Some of the ways in which this is being explored include: drugs are being developed hand-in-hand with the tests needed to determine whether or not they will be effective; tumor fragments excised from patients are being cultured in the lab for high-throughput testing of drugs and drug combinations; data-rich assays such as genomics and proteomics identify thousands of potentially significant differences between individuals; and computational models are being used to predict which therapies will work for which patients. This course will focus on the applications of pharmacokinetics and pharmacodynamics to simulating the effects of various drugs across a heterogeneous population of diseased individuals. Such computational approaches are needed to harness and leverage the vast amounts of data and provide insight into the key differences that determine drug responsiveness. These approaches can also explore the temporal dynamics of disease and treatment, and enable the modification of treatment during recovery. Recommended background: 110.201 Linear Algebra, 110.302 Differential Equations, and 553.311 Probability and Statistics (or equivalent).
Instructor(s): F. Macgabhann.

EN.580.641. Cellular Engineering. 4.0 Credits.
This course focuses on principles and applications in cell engineering. Class lectures include an overview of molecular biology fundamentals, protein/ligand binding, receptor/ligand trafficking, cell-cell interactions, cell-matrix interactions, and cell adhesion and migration at both theoretical and experimental levels. Lectures will cover the effects of physical (e.g. shear stress, strain), chemical (e.g. cytokines, growth factors) and electrical stimuli on cell function, emphasizing topics on gene regulation and signal transduction processes. Furthermore, topics in metabolic engineering, enzyme evolution, polymeric biomaterials, and drug and gene delivery will be discussed. This course meets with EN.580.441 but includes additional requirements designed for the core curriculum of the RIE (Regenerative and Immune Engineering) track of the BME masters program. The course is also appropriate for Cell & Tissue Engineering Ph.D. students and may be taken by advanced undergraduate students upon permission of the instructor. Prerequisites: Graduate standing with background in cell biology and biochemistry or EN.580.221 or AS20.305 and AS.020.306 (or equivalent) and AS.030.205 or permission of the instructor.
Instructor(s): J. Green; K. Yarema.
EN.580.642. Tissue Engineering. 3.0 Credits.
This course focuses on the application of engineering fundamentals to designing biological tissue substitutes. Concepts of tissue development, structure, and function will be introduced. Students will learn to recognize the majority of histological tissue structures in the body and understand the basic building blocks of the tissue and clinical need for replacement. The engineering components required to develop tissue-engineered grafts will be explored including biomechanics and transport phenomena along with the use of biomaterials and bioreactors to regulate the cellular microenvironment. Emphasis will be placed on different sources of stem cells and their applications to tissue engineering. Clinical and regulatory perspectives will be discussed. Co-listed with EN.580.442. Recommended Course Background: EN.580.221 or AS.020.305 and AS.020.306, AS.030.205, EN.580.441/EN.580.641
Area: Engineering.

EN.580.643. Advanced Orthopaedic Tissue Engineering. 3.0 Credits.
This course is intended to provide a comprehensive overview on the current state of the field of Orthopaedic Tissue Engineering. Students will apply engineering fundamentals learned in the Tissue Engineering course (580.442/580.642) with special emphasis on how they apply to bone, cartilage, and skeletal muscle tissue engineering. The development, structure, mechanics, and function of each of these tissues will be discussed. Key articles from the last three decades that focus on stem cell- and cell-free, biomaterial-based approaches to regenerate functional tissues will be presented and analyzed. Practical (regulatory/commercial) considerations that restrict the translation of therapies to the clinic will be discussed. Undergraduate by permission only. Recommended Course Background: EN.580.442 or EN.580.642.
Instructor(s): W. Grayson.

EN.580.644. Biomedical Applications of Glycoengineering. 3.0 Credits.
This course provides an overview of carbohydrate-based technologies in biotechnology and medicine. The course will begin by briefly covering basics of glycobiology and glycochemistry followed by detailed illustrative examples of biomedical applications of glycoengineering. A sample of these applications include the role of sugars in preventative medicine (e.g., for vaccine development and probiotics), tissue engineering (e.g., exploiting natural and engineered polysaccharides for creating tissue or organs de novo in the laboratory), regenerative medicine (e.g., for the treatment of arthritis or degenerative muscle disease), and therapy (e.g., cancer treatment). A major part of the course grade will be based on class participation with each student expected to provide a "journal club" presentation of a relevant paper as well as participate in a team-based project designed to address a current unmet clinical need that could be fulfilled through a glycoengineering approach. Emphasis will be placed on different sources of stem cells and their applications to tissue engineering. Clinical and regulatory perspectives will be discussed. Co-listed with EN.580.442. Recommended Course Background: EN.580.221 Molecules and Cells or equivalent (molecular and cell biology), college level calculus and calculus-based general physics.
Instructor(s): K. Yarema
Area: Engineering, Natural Sciences.

EN.580.646. Molecular Immunoengineering. 3.0 Credits.
An in-depth study of the use of biomolecular engineering tools and techniques to manipulate immune function for clinical translation. The course will begin with a brief overview of the immune system, placing a particular emphasis on the molecular-level interactions that determine phenotypic outcomes. The remainder of the curriculum will address ways in which integrative approaches incorporating biochemistry, structural biophysics, molecular biology, and engineering have been used either to stimulate the immune response for applications in cancer and infectious disease, or to repress immune activation for autoimmune disease therapy. Recommended background: Biochemistry and Cell Biology or the BME Molecules and Cells. Those without recommended background should contact the instructor prior to enrolling.
Instructor(s): J. Spangler
Area: Engineering, Natural Sciences.

EN.580.647. Computational Stem Cell Biology. 3.0 Credits.
This course will provide the student with a mechanistic and systems biology-based understanding of the two defining features of stem cells: multipotency and self-renewal. We will explore these concepts across several contexts and perspectives, emphasizing seminal and new studies in development and stem cell biology, and the critical role that computational approaches have played. The course will start with an introduction to stem cells and a tutorial covering computational basics. The biological contexts that we will cover thereafter include "Cell Identity", "Pluripotency and multipotency", "Stem cells and their niche", "Modeling cell fate decisions", and "Engineering cell fate". This class is heavily weighted by individual computational assignments. The motivation for this strategy is that regularly occurring, moderately-sized computational projects are the most efficient way to impart an understanding of our models of this extraordinary class of cells, and to inspire a sense of excitement and empowerment. Preferred background: 580.221 Molecules and Cells or equivalent and familiarity with the UNIX shell.
Prerequisites: Students may earn credit for EN.580.447 or EN.580.647, but not both.
Instructor(s): P. Cahan
Area: Engineering, Natural Sciences.

EN.580.656. Introduction to Rehabilitation Engineering. 3.0 Credits.
The primary objective of this course is to introduce biomedical engineering students to the challenges of engineering solutions for persons functioning with disabilities. In order to achieve this goal, other objectives include: gaining a basic appreciation of the modalities used to treat impairments, the opportunities for application of engineering to improve treatment delivery, understanding the science and engineering applied to helping persons with disabilities function in the everyday world and an basic knowledge of the legal, ethical issues and employment opportunities in rehabilitation engineering. By the conclusion of this class, students should be able to: understand the breadth and scope of physical impairment and disability, including its associated pathophysiology; characterize the material and design properties of current evaluation tools for assessment of impairments and adaptations for disability; characterize the material and design properties of current modalities of treatment of impairments and adaptations for disability; apply engineering analysis and design principles to critique current solutions for persons with disabilities in order to suggest improvements.
Instructor(s): S. Paul
Area: Engineering.
EN.580.668. The Art of Data Science. 3.0 Credits.
In this course, we will cover the fundamentals of doing data science research, explaining "best practices" for each step, that collectively comprise an upward spiral. These steps include: (i) asking an interesting question, (ii) determining the degree to which the answer is known, (iii) assessing there currently exists data to likely obtain a satisfactory answer, (iv) exploring the data set, (v) cleaning up the dataset, (vi) formulating a statistical inquiry, (vii) positing a statistical model which we hope will yield satisfactory answers, (viii) devising a test to assess the answer, (ix) building an estimator to assess the model, (x) checking the model, (xi) reporting the results, (xii) suggesting the next experiment to perform or question to answer to further enhance the model. Note that this course will largely be project based; each student will be expected to complete each of the above steps on some real data of interest to the student. Lectures will be minimal, giving introductory explanations one day, hopefully only part of the time. The rest of the time, we will work independently or in small groups to complete the weekly portion of the overall project. Please come ready to do science! If you don't have questions that you want answered, you can work in small groups, but each student will need to write the code and reports on their own. Recommended background: No courses are formally required, though students will need to write numerical code (in R, Python, or Julia), and make reports using LaTeX, knitr, or Jupyter notebooks or similar.
Instructor(s): J. Vogelstein
Area: Engineering.

EN.580.673. Magnetic Resonance in Medicine. 3.0 Credits.
This course provides the student with a complete introduction to the physical principles, hardware design, and signal processing used in magnetic resonance imaging and magnetic resonance spectroscopy. The course is designed for students who wish to pursue research in magnetic resonance. Recommended course background: EN.580.222 or EN.520.214. Co-listed with EN.580.476.
Instructor(s): M. Schar; P. Bottomley.

EN.580.674. Introduction to Neuro-Image Processing. 3.0 Credits.
Developments in medical image acquisition systems such as magnetic resonance imaging (MRI) and computed tomography (CT) have resulted in large number of clinical images with rich information regarding structure and function of nervous system. A challenging task is to extract clinically relevant information from the raw images that can be used to characterize structural alteration of brain in disease state. This course introduces the underlying physical foundation of different image modalities that are used to study neurological disorders followed by presentation of concepts and techniques that are used to process and extract information from medical images, in particular MRI. Topics that are covered include medical image formats, enhancement, segmentation, registration, and visualization. Suggest Course Background: Mathematical Methods For Engineers or equivalent course, Signals and Systems, and Probability
Instructor(s): S. Ardekani.

EN.580.678. Biomedical Photonics. 4.0 Credits.
This course will cover the basic optics principles including geometric, beam and wave description of light. The course will also cover the basic generation and detection techniques of light and the principles of optical imaging and spectroscopy. After the basis is established, we will focus on some commonly employed optical techniques and tools for biomedical research including various optical microscopy technologies, fiber optics, Raman spectroscopy, Fluorescence (lifetime), FRAT, FRET and FCS. The recent development in tissue optics, biomedical optical imaging/ spectroscopy techniques (such as OCT, multiphoton fluorescence and harmonics microscopy, Structured Illumination, light scattering, diffuse light imaging and spectroscopy, optical molecular imaging, photo-acoustic imaging) will also be discussed. Representative biomedical applications of translational biomedical photonics technologies will be integrated into the corresponding chapters.
Instructor(s): X. Li
Area: Engineering.

EN.580.679. X-ray Imaging and Computed Tomography. 3.0 Credits.
This course provides students with an intermediate-level understanding of the physics, engineering, algorithms, and applications of medical x-ray imaging and computed tomography (CT). It is intended for senior undergraduates (EN.580.479) and/or graduate students (EN.580.679) in Biomedical Engineering, Computer Science, Electrical and Computer Engineering, or related fields in science and engineering. Topics include the physics of x-ray interaction and detection, image quality modeling and assessment, 3D image reconstruction (including analytical and iterative approaches), and applications in diagnostic and image-guided procedures. Recommended Course Background: EN.580.472 and/or EN.580.473 and familiarity with Matlab.
Instructor(s): W. Zbijewski
Area: Engineering.

EN.580.680. Precision Care Medicine. 4.0 Credits.
Precision Care Medicine is a two-semester project-based learning course. Projects will use methods of machine learning and mechanistic and statistical modeling to develop novel data-driven solutions to important health care problems that arise in anesthesiology and critical care medicine. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 3-4, and will work with their project mentors (clinical faculty in the ACCM Department; Drs. Winslow and Sarma) to develop a project work plan. In the remainder of the course, they will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will also be charged with designing, validating and deploying a web-application that delivers the computational method for solving the underlying healthcare problem to the user. HIPAA regulations, use of human subjects data, and requirements for FDA Class II and Medical Device Data Systems approval will be covered.
Instructor(s): R. Winslow; S. Sarma.
EN.580.681. Precision Care Medicine. 3.0 Credits.
Precision Care Medicine is a two-semester project-based learning course. Projects will use methods of machine learning and mechanistic and statistical modeling to develop novel data-driven solutions to important health care problems that arise in anesthesiology and critical care medicine. The scope of such problems is vast, and few have been approached before. Examples include data- and modeling-driven approaches to: optimal selection of patients to be admitted to ICUs; optimal determination of when it is safe to discharge a patient from an ICU; early prediction of pending changes in the clinical state of patients in an ICU; data-driven optimal selection of patient therapy; and others. In the first semester, students will assemble into teams of 3-4, and will work with their project mentors (clinical faculty in the ACCM Department; Drs. Winslow and Sarma) to develop a project work plan. In the remainder of the course, they will apply engineering approaches to solve the important health care problems in their projects. Class time will include: lectures and tutorials covering the physiology, medicine, and engineering principles relevant to each project; project work in a setting where faculty are available to assist students with challenges. Each team will present project updates to the entire class at regular intervals so that every student becomes familiar with each project. Teams will also be charged with designing, validating and deploying a web-application that delivers the computational method for solving the underlying healthcare problem to the user. HIPAA regulations, use of human subjects data, and requirements for FDA Class II and Medical Device Data Systems approval will be covered.

EN.580.683. Nuclear Medicine Imaging. 3.0 Credits.
This course provides an intermediate-level introduction to the instrumentation, image processing and reconstruction methods used in planar nuclear medicine imaging, single-photon emission computed tomography (SPECT) and positron emission tomography (PET). Topics include radioactive decay, nuclear medicine instrumentation including radiation detectors and associated electronics, analytic and statistical iterative tomographic reconstruction, imaging physics, and image quality in the context of these three modalities. This course will be taught at the School of Medicine Campus. Recommended Course Background: EN.520.432/EN.580.472 and EN.520.434/EN.580.473
Instructor(s): A. Rahmim; B. Tsui; E. Frey; Y. Du
Area: Engineering.

EN.580.688. Foundations of Computational Biology & Bioinformatics II. 3.0 Credits.
This course will introduce probabilistic modeling and information theory applied to biological sequence analysis, focusing on statistical models of protein families, alignment algorithms, and models of evolution. Topics will include probability theory, score matrices, hidden Markov models, maximum likelihood, expectation maximization and dynamic programming algorithms. Homework assignments will require programming in Python. Recommended Course Background: Math through linear algebra and differential equations, EN.580.221 or equivalent, EN.601.226 or equivalent.
Instructor(s): R. Karchin.

EN.580.689. Computational Personal Genomics. 3.0 Credits.
What can we learn from the genome sequence of an individual? Genomic technology now makes it possible to generate huge amounts of DNA sequence data for a single individual at a relatively low cost. To make sense of this data, we need to employ sophisticated computational methods to identify genetic variations that influence an individual's health. In this course, we will first review the state of the art in sequencing technology, and discuss how this technology is being applied to study human biology and disease. We will then explore the computational methods used to turn raw sequence data into knowledge. Topics will include genetic variant detection; discovery of chromosomal rearrangements and fusions; methods to measure gene expression from RNA; and measurements of the microbiome living inside our bodies. Recommended Course Background: EN.601.447/639, EN.600.363/463, EN.600.688, EN.580.688 (any one is sufficient), or permission of the instructor. Course is also open to undergraduate students.
Instructor(s): S. Salzberg
Area: Engineering.

EN.580.691. Learning Theory. 3.0 Credits.
This course introduces the probabilistic foundations of learning theory. We will discuss topics in regression, estimation, Kalman filters, Bayesian learning, classification, reinforcement learning, and active learning. Our focus is on iterative rather than batch methods for parameter estimation. Our aim is to use the mathematical results to model learning processes in the biological system. Recommended Course Background: Probability and Linear Algebra.
Instructor(s): R. Shadmehr.

EN.580.693. Imaging Instrumentation. 4.0 Credits.
This course is intended to introduce students to imaging instrumentation. The class will be lab-oriented, giving hands-on experience with data collection and processing using a configurable optical system. Specific topics will include the programming and control of electromechanical elements, imaging data acquisitions, image formation and processing (e.g. 3D reconstruction), and imaging system analysis and optimization. Recommended Course Background: EN.580.222 Systems and Controls or EN.520.214 Signals and Systems. Programming experience highly desirable.
Instructor(s): J. Stayman.

EN.580.694. Statistical Connectomics. 3.0 Credits.
This course will cover the basics of an exciting emerging field of statistical connectomics (aka, brain-graphs). It is so new, that we are going to make some of it up in this class! The first week will be introductory lectures that I give. The rest of the semester will be run like a seminar; each week will focus on a different topic. On Tuesdays we will hear about a statistical method that operates on graphs, and on Thursdays we will read about some neuroscience data upon which one could apply these techniques. The final project will consist of implementing a statistical method devised for graphs on a brain-graph problem. Recommended background: coursework in probability, linear algebra, and numerical programming (eg, R, Python, Matlab).
Instructor(s): J. Vogelstein
Area: Engineering.
EN.580.697. Neuro Data Design I. 4.0 Credits.
In this year long course, students will work together in small teams to design, develop, and deploy a functioning tool for practicing brain scientists, either for accelerating research or augmenting the clinic. The first semester will focus on scoping the tool, including determining feasibility (for us in a year) and significance (for the targeted brain science community), as well as a statement of work specifying deliverables and milestones. The second semester will focus on developing the tool, getting regular feedback, and iterating, using the agile/lean development process. Recommended Course Background: numerical programming.
Instructor(s): J. Vogelstein.

EN.580.701. CBID Masters Advanced Project. 3.0 - 10.0 Credits.
For second year CBID students.
Instructor(s): S. Acharya.

EN.580.702. CBID Masters Advanced Project. 3.0 - 10.0 Credits.
Instructor(s): S. Acharya.

The course introduces modern techniques in mathematical analysis of biomedical data. Techniques include maximum likelihood, estimation theory via Kalman equation, state-space models, Bayesian estimation, classification of labeled data, support vector machine, dimensionality reduction via principal component analysis, clustering, expectation maximization, and dynamic programming via the Bellman equation.
Instructor(s): R. Shadmehr.

EN.580.706. Introduction to Biomedical Rodent Surgery Laboratory and Grantsmanship. 3.0 Credits.
This course has been specifically designed for students interested in understanding the translational aspects of biomedical research and pursuing research as a career. The course aims to introduce diverse yet interlinked research concepts that will equip students with the necessary knowledge and expertise to independently carry out research endeavors in the future. A part of the course includes supervised hands-on in vivo workshops, in which students will learn basic rodent anatomy, physiology and some general experimental procedures. A second component will introduce research methodology, which will enable students to develop their scientific thought process and enhance their critical thinking skills by formulating hypothesis, developing aims, searching PubMed for related literature, understanding ethical guidelines and other regulatory issues. In today’s scenario, scientists also need to have a strong communication ability to ensure that their research is accessible at a global platform. This requires skill and knowledge of scientifically drafting manuscripts, writing grants and articulating business plans as well as effectively presenting their research results (presentation, poster, etc.). We will allocate necessary time to develop this science-art as well. Students’ attendance and active participation will enrich this exciting and interactive course, which is entirely based on in-class learning.
Instructor(s): A. All.

EN.580.721. Systems Bioengineering I. 4.0 Credits.
A quantitative, model-oriented investigation of the cardiovascular system. Topics are organized in three segments. (1) Molecular/cellular physiology, including electrical signaling and muscle contraction. (2) Systems cardiovascular physiology, emphasizing circuit-diagram analysis of hemodynamics. (3) Cardio-vascular horizons and challenges for biomedical engineers, including heart failure and its investigation/treatment by computer simulation, by gene-array analysis, by stem-cell technology, and by mechanical devices (left-ventricular assist and total-heart replacement). Recommended Course Background: EN.580.221 and EN.580.222
Instructor(s): N. Trayanova; R. Vidal.

EN.580.722. Systems Bioengineering II. 4.0 Credits.
A quantitative, model-oriented approach to the study of the nervous system. Topics include functional anatomy of the central and autonomic nervous systems, neurons and networks, learning and memory, structure and function of the auditory and visual systems, motor systems, and neuro-engineering. Recommended Course Background: EN.580.221, EN.580.222, EN.580.223, AS.110.302, EN.580.421; Corequisite: EN.580.424
Instructor(s): E. Haase; X. Wang.

EN.580.727. Cell Engineering and Regenerative Medicine Seminar Series. 1.0 Credit.
Top researchers from around the world will present the latest research on stem cell science and clinical application followed by discussion. School of Medicine campus: PCTB, Mountcastle Auditorium
Instructor(s): J. Elisseff.

EN.580.728. Advanced Seminar in Chemical Glycobiology & Carbohydrate Drug Design. 1.0 Credit.
This course uses the current literature to teach advanced topics in carbohydrate engineering. Students will be required to read current papers, selected textbook chapters and online content to prepare for interactive teaching sessions with faculty and other students. Potential topics will include: sugars as information storage entities and signaling molecules; methods to manipulate and characterize complex carbohydrates in vivo, through chemoenzymatic methods, and emerging high-throughput methodology; carbohydrate-based drug development; and the role of sugars in stem cell biology and tissue engineering.
Evaluation will be both by faculty and fellow students. Graduate Level.
Seniors by permission. Fall semester only.
Instructor(s): K. Yarema.

EN.580.729. Advanced Seminar in Chemical Glycobiology & Carbohydrate Drug Design. 1.0 Credit.
This course uses the current literature to teach advanced topics in carbohydrate engineering. Students will be required to read current papers, selected textbook chapters and online content to prepare for interactive teaching sessions with faculty and other students. Potential topics will include: sugars as information storage entities and signaling molecules; methods to manipulate and characterize complex carbohydrates in vivo, through chemoenzymatic methods, and emerging high-throughput methodology; carbohydrate-based drug development; and the role of sugars in stem cell biology and tissue engineering.
Evaluation will be both by faculty and fellow students. Spring semester only.
Instructor(s): K. Yarema.
EN.580.735. Advanced Seminars in Computational Medicine. 1.0 Credit.
In this course, students will review current literature on the most salient and interesting topics in the emerging field of Computational Medicine, which is focused on the development of quantitative approaches for understanding the mechanisms, diagnosis and treatment of human disease through applications of mathematics, engineering, and computational science. Whenever possible, the publications considered will be directly relevant to the lectures delivered by visiting scholars in the Institute for Computational Medicine’s seminar series. Students will be required to search for the most relevant papers in the current literature; read and critically interpret these papers; conduct interactive teaching sessions with the course instructor, other students, and trainees/faculty from the Institute. Potential topics will include: computational anatomy; computational molecular medicine; computational physiological medicine; and computational healthcare. Evaluation will be by the course instructor (pass/fail). Graduate level. Seniors by permission. All registrants must be approved by the course instructor.
Instructor(s): F. Macgabhann; S. Sarma.

EN.580.736. Distinguished Seminar Series in Computational Medicine. 1.0 Credit.
We live in a new era in the understanding, diagnosis and treatment of human disease. Over the past ten years, extraordinary advances in modeling and computing technologies have opened the door to an array of possibilities that were previously beyond the reach of biomedical researchers. Today's powerful computational platforms are allowing us to begin to identify, analyze, and compare the fundamental biological components and processes that regulate human diseases and their impact on the body. The next step, then, is to harness the potential of these theoretical and computational tools and theory in a meaningful way—that is, to apply this "new medicine" to the exploration and treatment of many of our current diseases. This lecture series will feature world experts in computational medicine as well as laboratories at JHU's institute for Computational Medicine (ICM). Fall semester only. S/U grading only.
Instructor(s): F. Macgabhann; S. Sarma.

EN.580.737. Distinguished Seminar Series in Computational Medicine. 1.0 Credit.
We live in a new era in the understanding, diagnosis and treatment of human disease. Over the past ten years, extraordinary advances in modeling and computing technologies have opened the door to an array of possibilities that were previously beyond the reach of biomedical researchers. Today's powerful computational platforms are allowing us to begin to identify, analyze, and compare the fundamental biological components and processes that regulate human diseases and their impact on the body. The next step, then, is to harness the potential of these theoretical and computational tools and theory in a meaningful way—that is, to apply this "new medicine" to the exploration and treatment of many of our current diseases. This lecture series will feature world experts in computational medicine as well as laboratories at JHU's institute for Computational Medicine (ICM). Spring semester only.
Instructor(s): F. Macgabhann; S. Sarma.

EN.580.738. Advanced Seminars in Cardiac Electrophysiology and Mechanics. 1.0 Credit.
This course uses the current literature to teach advanced topics in cardiac electrophysiology and mechanics. Students will be required to read current articles and then conduct interactive teaching sessions with faculty and other students. Potential topics will include: ion channels, cardiac excitation-contraction coupling, myofilament regulation, cardiac arrhythmias, heart failure, therapies for arrhythmias and pump dysfunction. Evaluation will be both by faculty and fellow students. Graduate Level. Seniors by permission. Fall semester only.
Instructor(s): N. Trayanova; P. Boyle.

EN.580.739. Advanced Seminars in Cardiac Electrophysiology and Mechanics. 1.0 Credit.
This course uses the current literature to teach advanced topics in cardiac electrophysiology and mechanics. Students will be required to read current articles and then conduct interactive teaching sessions with faculty and other students. Potential topics will include: ion channels, cardiac excitation-contraction coupling, myofilament regulation, cardiac arrhythmias, heart failure, therapies for arrhythmias and pump dysfunction. Evaluation will be both by faculty and fellow students. Graduate Level. Seniors by permission only (signed add/drop form). Spring semester only.
Instructor(s): N. Trayanova; P. Boyle.

EN.580.740. Surgery For Engineering. 3.0 Credits.
This course provides an introduction to basic principles and emerging techniques in surgery, interventional radiology, and radiation therapy for engineering students. Basic principles include introduction to fundamental surgical approaches and tools as well as sub-specialties, including neurosurgery, orthopaedic surgery, ENT surgery, thoracic surgery, and laparoscopic surgery as well as minimally invasive (body and neurovascular) interventional radiology as well as radiotherapy (external beam and brachytherapy). Introduction to cutting edge and emerging technologies include intraoperative imaging (all modalities), surgical navigation, and robotics. Requisite background for engineering students includes analytic geometry, linear algebra, computing (Matlab, Python, or C++), and basic familiarity with the physics of medical imaging. Safety Training: certificate in Bloodborne Pathogens and HIPAA & Research. Recommended course background: 580.472, 601.455
Instructor(s): J. Siewersdson.

EN.580.741. Models of Cardiac Electrophysiology and Arrhythmia. 1.0 Credit.
This course will cover the fundamentals of different experimental and computational models of cardiac electrophysiology and when particular models are appropriate for use. Students will be required to read review articles and engage in interactive discussion with faculty and other students. With some projects and presentations to reinforce important concepts. Topics will include measurement of cardiac electrical signals, stimulation of cardiac tissue, single cell and tissue level electrical properties, excitation-contraction coupling, and mechanisms of arrhythmia. Seniors by permission.
Instructor(s): L. Tung.
EN.580.742. Neural Implants and Interfaces. 3.0 Credits.
This course will focus on invasive neural implants that electrically interface with the peripheral or central nervous system. We will investigate the different types of recording and stimulating neural interface technologies currently in use in patients as well as coverage of the biophysics, neural coding, and hardware. We will also cover computational modeling of neurophysiology in the context of implantable devices and their neural interfaces. A final group project will be required for simulating a neural interface system. Recommended course background includes cell biology, physics with electromagnetics (or electrical circuits), chemistry, differential equations, and computer programming.
Instructor(s): G. Fridman.

EN.580.745. Mathematics of Deep Learning. 1.5 Credits.
The past few years have seen a dramatic increase in the performance of recognition systems thanks to the introduction of deep networks for representation learning. However, the mathematical reasons for this success remain elusive. For example, a key issue is that the training problem is nonconvex, hence optimization algorithms are not guaranteed to return a global minima. Another key issue is that the size of deep networks is very large relative to the number of training examples, deep networks appear to generalize very well to unseen examples and new tasks. This course will overview recent work on the theory of deep learning that aims to understand the interplay between architecture design, regularization, generalization, and optimality properties of deep networks.
Instructor(s): R. Vidal.

EN.580.746. Imaging Science Seminar. 1.0 Credit.
Fall semester only.
Instructor(s): M. Miller; R. Vidal.

EN.580.747. Imaging Science Seminar. 1.0 Credit.
Spring semester only.
Instructor(s): M. Miller; R. Vidal.

EN.580.748. Advanced Seminars in Magnetic Resonance Imaging. 3.0 Credits.
This course uses the current literature to teach advanced topics in magnetic resonance imaging. Students will be required to read current papers, selected textbook chapters and online content to prepare for interactive teaching sessions with faculty and other students. Potential topics will include: image artifacts, effect of motion, resolution and SNR, realtime imaging, clinical applications. Evaluation will be both by faculty and fellow students. Graduate Level. Seniors by permission. Fall semester only.
Instructor(s): E. McVeigh.

EN.580.749. Advanced Seminars in Magnetic Resonance Imaging. 3.0 Credits.
This course uses the current literature to teach advanced topics in magnetic resonance imaging. Students will be required to read current papers, selected textbook chapters and online content to prepare for interactive teaching sessions with faculty and other students. Potential topics will include: image artifacts, effect of motion, resolution and SNR, realtime imaging, clinical applications. Evaluation will be both by faculty and fellow students. Spring semester only.
Instructor(s): D. Herzka.

EN.580.751. Cell & Tissue Engineering Lab. 4.0 Credits.
Cell and tissue engineering is a field that relies heavily on experimental techniques. This laboratory course will consist of three six experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Students will learn specialized techniques related to faculty expertise in cell engineering, microfluidics, gene therapy, microfabrication and cell encapsulation. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. This course includes an ‘advanced topics’ component designed to fulfill toe core curriculum requirements of the RIE (Regenerative and Immune Engineering) track of the BME masters program. Offered the first half of fall semester only.
Instructor(s): E. Haase; K. Yarema.

EN.580.771. Principles of the Design of Biomedical Instrumentation. 4.0 Credits.
This course is designed for graduate students interested in learning basic biomedical instrumentation design concepts and translating these into advanced projects based on their research on current state-of-the-art. They will first gain the basic knowledge of instrumentation design, explore various applications, and critically gain hands-on experience through laboratory and projects. At the end of the course, students would get an excellent awareness of biological or clinical measurement techniques, design of sensors and electronics (or electromechanical/chemical, microprocessor system and their use). They will systematically learn to design instrumentation with a focus on the use of sensors, electronics to design a core instrumentation system such as an ECG amplifier. Armed with that knowledge and lab skills, students will be encouraged to discuss various advanced instrumentation applications, such as brain monitor, pacemaker/defibrillator, or prosthetics. Further, they will be “challenged” to come up with some novel design ideas and implement them in a semester-long design project. Students will take part in reading the literature, learning about the state-of-the-art through journal papers and patents, and discussing, critiquing, and improving on these ideas. Finally, they will be implementing a selected idea into a semester-long advanced group project. Meets with 580.471 Graduate students only.
Instructor(s): N. Thakor.

EN.580.773. Modern Biomedical Imaging Instrumentation and Techniques. 3.0 Credits.
An intermediate biomedical imaging course covering modern biomedical imaging instrumentation and techniques as applied to diagnostic radiology and other biomedical applications. It includes recent advances in various biomedical imaging modalities, multi-modality imaging and molecular imaging. The course is team taught by experts in the respective fields and provides a broad based knowledge of modern biomedical imaging to prepare students for graduate studies and research in biomedical imaging. Also, the course will offer tours and practical experience with modern biomedical imaging equipment in clinical and research settings. Recommended course background: EN.520.432 or EN.580.472
Prerequisites: Students may not have taken EN.580.473.
Instructor(s): B. Tsui
Area: Engineering.
EN.580.779. Systems Bioengineering III. 4.0 Credits.
Computational and theoretical systems biology at the cellular and molecular level. Topics include organizational patterns of biological networks; analysis of metabolic networks, gene regulatory networks, and signal transduction networks; inference of pathway structure; and behavior of cellular and molecular circuits. Recommended Course Background: EN.580.221 and EN.580.222 or Permission Required.
Instructor(s): J. Bader.

EN.580.781. Biomedical Engineering Seminar. 1.0 Credit.
Instructor(s): W. Grayson.

EN.580.782. Biomedical Engineering Seminar. 1.0 Credit.
Instructor(s): W. Grayson.

EN.580.788. Biomedical Photonics II. 4.0 Credits.
This course serves as the continuation of 580.678 (520.678), Biomedical Photonics I. It will cover the advanced topics on biomedical photonics, including, but not limited to, light scattering (Rayleigh and Mie scattering), photon diffusion, polarization (birefringence), fluorescence, lifetime measurements, confocal microscopy, optical coherence tomography, nonlinear microscopy, and super-resolution microscopy. Representative biomedical applications of some of these technologies will be integrated into the relevant chapters. A hands-on lab section (optional) for students to design and build an imaging instrument, space permitting.
Instructor(s): X. Li.

EN.580.791. Biomedical Engineering Project Design and Proposal Development I. 2.0 Credits.
The goal of this class is to provide students with experience in designing and implementing a biomedical engineering research project. Students will select a laboratory to host their research rotation within the first two weeks (ideally, before the start of the term) and will participate in lab-related activities for a minimum of 6 hours a week that involve “in person” interaction between the PI or other members of the sponsoring lab and the student. Activities will include attendance at lab meetings, preparation of a research proposal, and “hands on” experimental, computational, or modeling tasks: in addition, attendance at department research seminars and class meetings is required. Periodic reports on your research proposal/project and progress, as well providing feedback on your colleagues’ projects and proposals will also be expected. A final research proposal (to be presented in the format of a NIH F31-type grant application) will provide evidence that a student is capable of carrying out advanced research by identifying a significant biomedical problem, developing innovative approaches to solve it, and then designing a relevant and implementable research plan.
Instructor(s): K. Yarema.

EN.580.821. Applied Research and Grant Methodology I. 3.0 Credits.
Students will select a laboratory to host their research rotation within the first two weeks (ideally, before the start of the term) and will participate in lab-related activities for a minimum of 12 hours a week; at least 6 hours a week is expected to involve “in person” interaction between the PI or other members of the sponsoring lab and the student. Activities will include attendance at lab meetings, preparation of a research proposal, and “hands on” experimental, computational, or modeling tasks: in addition, attendance at department research seminars and class meetings is required. Periodic reports on your research proposal/project and progress, as well providing feedback on your colleagues’ projects and proposals will also be expected. A final research proposal (to be presented in the format of a NIH R21-type grant application) will provide evidence that a student is capable of carrying out advanced research by identifying a significant biomedical problem, developing innovative approaches to solve it, and then designing a relevant and implementable research plan.
Instructor(s): K. Yarema.

EN.580.822. Applied Research and Grant Methodology II. 3.0 Credits.
Students will participate in lab related activities for at least 12 hours a week. These activities will include attendance at lab meetings, preparation of a research proposal, and “hands on” experimental, computational, or modeling tasks. In addition, attendance at research seminars and class meetings is expected. Finally, periodic reports on your research project and progress, as well providing feedback on your colleagues’ projects and proposals, will be required. Finally a research proposal essay (to be presented in the format of a NIH F31 (or NSF equivalent) grant application will be required (it is expected that the application will be submitted to the funding agency for students interested in continuing their research career); it is anticipated that this proposal will include data generated by the student over the Fall, Intersession, or Spring term(s).
Prerequisites: EN.580.821 OR EN.580.706
Instructor(s): K. Yarema.

EN.580.850. BME MSE Research Practicum. 6.0 Credits.
BME MSE Research Practicum For Thesis-Track Students
Instructor(s): K. Yarema.

Cross Listed Courses

General Engineering
EN.500.112. Gateway Computing. 3.0 Credits.
This course introduces fundamental programming concepts and techniques, and is intended for all who plan to develop computational artifacts or intelligently deploy computational tools in their studies and careers. Topics covered include the design and implementation of algorithms using variables, control structures, arrays, functions, files, testing, debugging, and structured program design. Elements of object-oriented programming, algorithmic efficiency and data visualization are also introduced. Students develop programming to develop working solutions that address problems in engineering, science and other areas of contemporary interest that vary from section to section. Course work involves significant programming. Attendance and participation in class sessions are expected.
Instructor(s): I. Sekyonda; J. Selinski; M. Darvish Darab
Area: Engineering, Natural Sciences.
EN.500.745. Seminar in Computational Sensing and Robotics. 1.0 Credit.
Seminar series in robotics. Topics include: Medical robotics, including computer-integrated surgical systems and image-guided intervention. Sensor based robotics, including computer vision and biomedical image analysis. Algorithmic robotics, robot control and machine learning. Autonomous robotics for monitoring, exploration and manipulation with applications in home, environmental (land, sea, space), and defense areas. Birobotics and neuromechanics, including devices, algorithms and approaches to robotics inspired by principles in biomechanics and neuroscience. Human-machine systems, including haptic and visual feedback, human perception, cognition and decision making, and human-machine collaborative systems. Cross-listed Mechanical Engineering, Computer Science, Electrical and Computer Engineering, and Biomedical Engineering.
Instructor(s): L. Whitcomb; P. Kazanzides.

Electrical Computer Engineering
EN.520.315. Intro. to Bio-Inspired Processing of Audio-Visual Signals. 3.0 Credits.
An introductory course to basic concepts of information processing of human communication signals (sounds, images) in living organisms and by machine. Recommended Course Background: EN.520.214 (or EN.580.222) or consent of the instructor.
Instructor(s): H. Hermansky
Area: Engineering.

EN.520.434. Modern Biomedical Imaging Instrumentation and Techniques. 3.0 Credits.
An intermediate biomedical imaging course covering modern biomedical imaging instrumentation and techniques as applied to diagnostic radiology and other biomedical applications. It includes recent advances in various biomedical imaging modalities, multi-modality imaging and molecular imaging. The course is taught by experts in the respective fields and provides a broad based knowledge of modern biomedical imaging to prepare students for graduate studies and research in biomedical imaging. Also, the course will offer tours and practical experience with modern biomedical imaging equipment in clinical and research settings. Co-listed with EN.580.473
Prerequisites: Students may not have taken EN.520.634
Instructor(s): B. Tsui

EN.520.445. Audio Signal Processing. 3.0 Credits.
This course gives a foundation in current audio and speech technologies, and covers techniques for sound processing by processing and pattern recognition, acoustics, auditory perception, speech production and synthesis, speech estimation. The course will explore applications of speech and audio processing in human computer interfaces such as speech recognition, speaker identification, coding schemes (e.g., MP3), music analysis, noise reduction. Students should have knowledge of Fourier analysis and signal processing.
Prerequisites: Students make take EN.520.445 or EN.520.645, but not both.
Instructor(s): M. Elhilali
Area: Engineering.

EN.520.601. Introduction to Linear Systems Theory. 3.0 Credits.
A beginning graduate course in multi-input multi-output, linear, time-invariant systems. Topics include state-space and input-output representations; solutions and their properties; multivariable poles and zeros; reachability, observability and minimal realizations; stability; system norms and their computation; linearization techniques. Recommended Course Background: Undergraduate courses in control systems and linear algebra.
Instructor(s): P. Iglesias.

EN.520.622. Principles of Complex Networked Systems. 3.0 Credits.
By employing fundamental concepts from diverse areas of research, such as statistics, signal processing, biophysics, biochemistry, cell biology, and epidemiology, this course introduces a multidisciplinary and rigorous approach to the modeling and computational analysis of complex interaction networks. Topics to be covered include: overview of complex nonlinear interaction networks and their applications, graph-theoretic representations of network topology and stoichiometry, stochastic modeling of dynamic processes on complex networks and master equations, Langevin, Poisson, Fokker-Plank, and moment closure approximations, exact and approximate Monte Carlo simulation techniques, time-scale separation approaches, deterministic and stochastic sensitivity analysis techniques, network thermodynamics, and reverse engineering approaches for inferring network models from data.
Instructor(s): J. Goutsias.

Mechanical Engineering
EN.530.410. Biomechanics of the Cell. 3.0 Credits.
Mechanical aspects of the cell are introduced using the concepts in continuum mechanics. Discussion of the role of proteins, membranes and cytoskeleton in cellular function and how to describe them using simple mathematical models.
Instructor(s): S. Sun
Area: Engineering, Natural Sciences.

EN.530.426. Biofluid Mechanics. 3.0 Credits.
Course will cover selected topics from physiological fluid dynamics, including respiratory flow patterns, blood flow and pulse propagation, aerodynamics of phonation and speech, rheology of blood flow in the microcirculation, aquatic animal propulsion, and animal flight.
Instructor(s): R. Mittal
Area: Engineering.

EN.530.448. Biosolid Mechanics. 3.0 Credits.
This class will introduce fundamental concepts of statics and solid mechanics and apply them to study the mechanical behavior bones, blood vessels, and connective tissues such as tendon and skin. Topics to be covered include concepts of small and large deformation, stress, constitutive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity, and experimental methods. Recommended Course Background: AS.110.201 and AS.110.302, as well as a class in statics and mechanics
Instructor(s): T. Nguyen
Area: Engineering.
Applied Mathematics Statistics
EN.553.450. Computational Molecular Medicine. 4.0 Credits.
Computational systems biology has emerged as the dominant framework for analyzing high-dimensional "omics" data in order to uncover the relationships among molecules, networks and disease. In particular, many of the core methodologies are based on statistical modeling, including machine learning, stochastic processes and statistical inference. We will cover the key aspects of this methodology, including measuring associations, testing multiple hypotheses, and learning predictors, Markov chains and graphical models. In addition, by studying recent important articles in cancer systems biology, we will illustrate how this approach enhances our ability to annotate genomes, discover molecular disease networks, detect disease, predict clinical outcomes, and characterize disease progression. Whereas a good foundation in probability and statistics is necessary, no prior exposure to molecular biology is required (although helpful).
Prerequisites: (EN.553.420 OR EN.553.620) AND (EN.553.430 OR EN.553.630) OR equivalent courses in probability and statistics.; Students may receive credit for EN.550.450/EN.553.450 or EN.553.650, but not both.
Instructor(s): D. Geman; J. Bader
Area: Engineering, Quantitative and Mathematical Sciences.

EN.553.650. Computational Molecular Medicine. 4.0 Credits.
Computational systems biology has emerged as the dominant framework for analyzing high-dimensional "omics" data in order to uncover the relationships among molecules, networks and disease. In particular, many of the core methodologies are based on statistical modeling, including machine learning, stochastic processes and statistical inference. We will cover the key aspects of this methodology, including measuring associations, testing multiple hypotheses, and learning predictors, Markov chains and graphical models. In addition, by studying recent important articles in cancer systems biology, we will illustrate how this approach enhances our ability to annotate genomes, discover molecular disease networks, detect disease, predict clinical outcomes, and characterize disease progression. Whereas a good foundation in probability and statistics is necessary, no prior exposure to molecular biology is required (although helpful). Recommended Course Background: EN.553.620 AND EN.553.630.
Prerequisites: Students may receive credit for EN.550.450/EN.553.450 or EN.553.650, but not both.
Instructor(s): D. Geman
Area: Engineering, Quantitative and Mathematical Sciences.

Computer Science
EN.601.350. Introduction to Genomic Research. 3.0 Credits.
This course will use a project-based approach to introduce undergraduates to research in computational biology and genomics. During the semester, students will take a series of large data sets, all derived from recent research, and learn all the computational steps required to convert raw data into a polished analysis. Data challenges might include the DNA sequences from a bacterial genome project, the RNA sequences from an experiment to measure gene expression, the DNA from a human microbiome sequencing experiment, and others. Topics may vary from year to year. In addition to computational data analysis, students will learn to do critical reading of the scientific literature by reading high-profile research papers that generated groundbreaking or controversial results. [Applications] Recommended Course Background: Knowledge of the Unix operating system and programming expertise in a language such as Perl or Python.
Instructor(s): S. Salzberg
Area: Engineering.

EN.601.448. Computational Genomics: Data Analysis. 3.0 Credits.
Genomic data has the potential to reveal causes of disease, novel drug targets, and relationships among genes and pathways in our cells. However, identifying meaningful patterns from high-dimensional genomic data has required development of new computational tools. This course will cover current approaches in computational analysis of genomic data with a focus on statistical methods and machine learning. Topics will include disease association, prediction tasks, clustering and dimensionality reduction, data integration, and network reconstruction. There will be some programming and a project component. [Applications] Prerequisites: EN.601.226 or other programming experience, probability and statistics, linear algebra or calculus.
Prerequisites: Students may receive credit for EN.600.438 or EN.600.638, but not both.
Instructor(s): A. Battle
Area: Engineering.

EN.601.461. Computer Vision. 3.0 Credits.
This course gives an overview of fundamental methods in computer vision from a computational perspective. Methods studied include: camera systems and their modeling, computation of 3-D geometry from binocular stereo, motion, and photometric stereo; and object recognition. Edge detection and color perception are covered as well. Elements of machine vision and biological vision are also included. [Applications] Prerequisites: intro programming, linear algebra, and prob/stat.
Prerequisites: Students may receive credit for only one of EN.600.361, EN.600.461, EN.600.661, EN.601.461, EN.601.661.
Instructor(s): H. Ali
Area: Engineering, Quantitative and Mathematical Sciences.

EN.601.476. Machine Learning: Data to Models. 3.0 Credits.
How can robots localize themselves in an environment when navigating? Can we predict which patients are at greatest-risk for complications in the hospital? Which movie should I recommend to this user given his history of likes? Many such big data questions can be answered using the paradigm of probabilistic models in machine learning. These are especially useful when common off-the-shelf algorithms such as support vector machines and k-means fail. You will learn methods for clustering, classification, structured prediction, recommendation and inference. We will use Murphy's book, Machine Learning: a Probabilistic Perspective, as the text for this course. Assignments are solved in groups of size 1-3 students. The class will have 4 interactive sessions during which we brainstorm how to solve example open-ended real-world problems with the tools learnt in class. Students are also required to do a project of their choice within which they experiment with the ideas learnt in class. [Analysis or Applications] Prerequisites include Intro Prob/Stat, Linear Algebra and Intro Machine Learning as well as strong background in s.
Instructor(s): S. Saria
Area: Engineering, Quantitative and Mathematical Sciences.

EN.601.748. Computational Genomics: Data Analysis. 3.0 Credits.
Graduate level version of EN.601.448. [Applications] Recommended Course Background: EN.601.226 or other programming experience, probability and statistics, linear algebra or calculus. Students may receive credit for EN.601.448 or EN.601.748 but not both.
Prerequisites: Students may receive credit for EN.600.438 or EN.600.638, but not both.
Instructor(s): A. Battle
Area: Engineering.
EN.601.776. Machine Learning: Data to Models. 3.0 Credits.
Students in the class will be asked to do assignments in Matlab. Matlab is typically easy to pick up if one is already familiar with a different programming language. Students are expected to be mathematically mature. One should have taken at least an introductory course in probability theory and linear algebra. Though not required, exposure to optimization or machine learning is recommended. Proficiency in at least one programming language is expected. When in doubt, send the instructor a copy of your transcript to see if the class is appropriate for you. Also, sit through the first few sessions and first homework to get a sense of fit. Requisites include Intro Prob/Stat, Linear Algebra and Intro Machine Learning as well as strong background in s.
Instructor(s): S. Saria.