Biomedical Engineering

www.bme.jhu.edu

Faculty and students in the Department of Biomedical Engineering have been breaking new ground in biomedical research for over 50 years, and we strive to continue this history of innovation and discovery every day. Some examples of biomedical engineering include instrumentation and systems for use in medical environments, health care delivery systems, therapeutic and prosthetic devices such as artificial organs and orthopedic implants, and the application of quantitative methods and engineering-based modeling to basic research in the biological sciences.

The Department of Biomedical Engineering offers three programs of study to prepare students to work in this area: an undergraduate program leading to a bachelor’s degree with a choice of B.S. or B.A., a master’s degree program, and a doctoral degree program.

Research in the department focuses on several general areas: biomaterials, biomedical imaging systems, biomedical sensors and instrumentation, cardiovascular systems physiology, molecular and cellular engineering physiology, systems neuroscience, theoretical and computational biology, cell and tissue engineering, and nanobiotechnology.

Facilities

The center of gravity for the Department of Biomedical Engineering is the Traylor, Ross, Miller, and Smith research buildings on the campus of the School of Medicine. This location favors a close association with other basic medical science programs and provides access to the clinical environment of one of the nation’s top-ranked hospitals. The Homewood campus houses the Whitaker Biomedical Engineering Institute. The Whitaker Institute was established as a vital link between the School of Medicine and the Whiting School of Engineering. The vision of the institute is of an integrative research and education enterprise that provides leadership in moving biomedical engineering to the forefront of biomedical science and practice.

The general facilities of the Department of Biomedical Engineering include seminar rooms that allow broadcasting throughout the university, physiology teaching laboratories, a microfabrication laboratory, a cell and tissue teaching and research laboratory, a student instrumentation laboratory, and a fully-staffed mechanical shop.

Each faculty member maintains a well-equipped laboratory for research in his or her area of interest. A wide variety of equipment in these laboratories is available to students as their interests draw them into active participation in research.

The profoundly interdivisional nature of biomedical engineering education at Johns Hopkins provides students with a wide range of general university facilities. These include the Human Stem Cell Core facility, the Institute for Basic Biomedical Sciences Microscopy Core facility, the Tissue Microarray Core facility, the Flow Cytometry Core Facility, the Genetics Resources Core Facility, the Transgenic Core Laboratory, the Welch Medical Library at the School of Medicine, the Eisenhower Library at the Homewood campus, and computing laboratories that are available on both campuses.

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.

Thus, the objective of the undergraduate program is to educate students majoring in biomedical engineering who will attain one or both of the following upon or within a few years of graduation:

- entry into graduate (M.S. or Ph.D. degree programs) or professional schools (medical, dental, veterinarian, business, public health, law)
- employment in jobs that utilize biomedical engineering or a related field.

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 human subjects and data for research; 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 specifics 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/archive/2013-14/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 passed or by examination for advanced credit. Engineering, science, and mathematics courses may not be taken satisfactory/unsatisfactory. No more than 6 credits of engineering, science, or mathematics courses in which a grade of D was received may be counted.

**Basic Sciences (22 credits)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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<tbody>
<tr>
<td>AS.171.101 &amp; AS.173.111</td>
<td>General Physics: Physical Science Major I and General Physics Laboratory I</td>
</tr>
<tr>
<td>AS.171.102 &amp; AS.173.112</td>
<td>General Physics: Physical Science Majors II and General Physics Laboratory II</td>
</tr>
<tr>
<td>AS.030.101 &amp; AS.030.105</td>
<td>Introductory Chemistry I and Introductory Chemistry Lab I</td>
</tr>
<tr>
<td>AS.030.102 &amp; AS.030.106</td>
<td>Introductory Chemistry II and Introductory Chemistry Laboratory II</td>
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<tr>
<td>AS.030.205</td>
<td>Organic Chemistry I</td>
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**Mathematics (24 credits)**

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<tbody>
<tr>
<td>AS.110.108 &amp; AS.110.109 &amp; AS.110.202</td>
<td>Calculus I and Calculus II (For Physical Sciences and Engineering) and Calculus III</td>
</tr>
<tr>
<td>AS.110.201</td>
<td>Linear Algebra</td>
</tr>
<tr>
<td>AS.110.302</td>
<td>Diff Equations/Applic</td>
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At least one additional semester of advanced statistics/probability (300 level or above).

**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 are discussed.

At least two semesters of writing intensive course.

**Biomedical Core Knowledge (35 credits)**

What do biomedical engineers do?

- EN.580.111 BME Modeling and Design |
- EN.580.202 BME in the Real World |
- AS.171.102 General Physics: Physical Science Major I |
- AS.173.111 General Physics Laboratory I |
- AS.171.103 General Physics: Physical Science Majors II |
- AS.173.112 General Physics Laboratory II |
- AS.030.101 Introductory Chemistry I |
- AS.030.105 Introductory Chemistry Lab I |
- AS.030.102 Introductory Chemistry II |
- AS.030.106 Introductory Chemistry Laboratory II |
- AS.030.205 Organic Chemistry I |

**Focus Area (21 credits)**

Each student is required to take one of four Biomedical Engineering focus areas.

**Design**

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

**Computer Programming**
Select 3 credits of computer programming 3

**General Electives**

Students may choose at least two courses from any area. *** 6

**Total Credits** 129

* See Writing Requirement (http://e-catalog.jhu.edu/archive/2013-14/undergrad-students/academic-policies/requirements-for-a-bachelors-degree/#Writing_Requirement).

** Building on the foundation of this core curriculum, each student is required to take a cohesive sequence of advanced engineering encompassing one of four Biomedical Engineering focus areas. A student’s choice of focus area is made before the start of the junior year and is based on their experience with the Biomedical Engineering Core and their answers to the questions given below: **

**Systems Biology**—“Do you want to focus on understanding at a fundamental level how biological systems work?”

**Sensors, Micro/Nano Systems, and Instrumentation**—“Do you want to build things that facilitate research or clinical medicine?”

**Cell/Tissue Engineering and Biomaterials**—“Do you want to create replacement cells, tissues, and organs?”

**Computational Bioengineering**—“Do you want to focus on the use of mathematical theory or computers to solve complex biological and medical problems?”

**Imaging**—“Do you want to develop new imaging technology to reveal how biological systems work or diagnose disease?”

Courses in a focus area must be taken for a total of 21 or more credits. Please refer to www.bme.jhu.edu/academics/undergrad.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.

*** Among the technical elective courses offered, 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 www.bme.jhu.edu/academics/undergrad.htm.

## Bachelor of Arts in Biomedical Engineering

(See also General Requirements for Departmental Majors (http://e-catalog.jhu.edu/archive/2013-14/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 (22 credits)

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<tr>
<th>Course</th>
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<tr>
<td>AS.171.101</td>
<td>General Physics:Physical Science Major I</td>
<td>5</td>
</tr>
<tr>
<td>&amp; AS.173.111</td>
<td>and General Physics Laboratory I</td>
<td></td>
</tr>
<tr>
<td>AS.171.102</td>
<td>General Physics: Physical Science Majors II</td>
<td>5</td>
</tr>
<tr>
<td>&amp; AS.173.112</td>
<td>and General Physics Laboratory II</td>
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</table>

### Biomedical Core (35 credits)

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<thead>
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<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>AS.030.101</td>
<td>Introductory Chemistry I</td>
<td>4</td>
</tr>
<tr>
<td>&amp; AS.030.105</td>
<td>and Introductory Chemistry Lab I</td>
<td></td>
</tr>
<tr>
<td>AS.030.102</td>
<td>Introductory Chemistry II</td>
<td>4</td>
</tr>
<tr>
<td>&amp; AS.030.106</td>
<td>and Introductory Chemistry Laboratory II</td>
<td></td>
</tr>
<tr>
<td>AS.030.205</td>
<td>Organic Chemistry I</td>
<td>4</td>
</tr>
</tbody>
</table>

### Mathematics (20 credits)

<table>
<thead>
<tr>
<th>Course</th>
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<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.108</td>
<td>Calculus I</td>
<td>12</td>
</tr>
<tr>
<td>&amp; AS.110.109</td>
<td>and Calculus II (For Physical Sciences and</td>
<td></td>
</tr>
<tr>
<td>&amp; AS.110.202</td>
<td>Engineering)</td>
<td></td>
</tr>
<tr>
<td>AS.110.201</td>
<td>Linear Algebra</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.302</td>
<td>Diff Equations/Applic</td>
<td>4</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 (35 credits)

- Biomedical core consists of 35 credits 35

<table>
<thead>
<tr>
<th>Course</th>
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<tbody>
<tr>
<td>EN.580.111</td>
<td>BME Modeling and Design</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.202</td>
<td>BME in the Real World</td>
<td>1</td>
</tr>
<tr>
<td>EN.580.221</td>
<td>Molecules and Cells</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.222</td>
<td>Systems and Controls</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.223</td>
<td>Models and Simulations</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.321</td>
<td>Statistical Mechanics and Thermodynamics</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.421</td>
<td>Systems Bioengineering I</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.422</td>
<td>Systems Bioengineering II</td>
<td>4</td>
</tr>
<tr>
<td>EN.580.423</td>
<td>Systems Bioengineering Lab I</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.424</td>
<td>Systems Bioengineering Lab</td>
<td>2</td>
</tr>
<tr>
<td>EN.580.429</td>
<td>Systems Bioengineering III</td>
<td>4</td>
</tr>
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### Other Electives

At least 19 additional credits (12 credits for premedical students counting Intermediate Organic Chemistry and lab) are needed to complete the 120 credit requirement for the BA degree. A course in which the use of computers in computer programming is strongly recommended.

**Total Credits** 155

## 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, which is designed to be completed in two years, consists of core courses, elective courses, and a thesis project. The project may be basic research in a laboratory or practical engineering related to patient monitoring or other clinical problems.

### 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.
All students have the potential to receive full tuition support by obtaining a position in a research laboratory. Research assistantships are usually advertised by various laboratories in the institution to carry out specific research and development projects. Students without a research assistantship are expected to pay full tuition independently. Fellowships are also awarded to the top students in the program.

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

For more information and to apply online, go to www.bme.jhu.edu/undergraduate/apply.

Requirements for the M.S.E. Degree

Each student will take a minimum of 24 credits of courses at the 400-level or higher and complete a thesis. Students fulfill the course requirement by taking two courses in the Systems Bioengineering sequence (EN.580.421, EN.580.422 or EN.580.429) and other advanced engineering, math, and science courses. (JHU undergraduates waive the SBE sequence and take 8 credits from advanced engineering, math, or science.) Students will also fulfill a minor teaching requirement by providing support to one of three lab-based undergraduate courses and six core lecture courses each semester. Additionally, all students must complete a thesis based on a research problem requiring application of quantitative or applied engineering principles to biomedical engineering.

B.S./M.S.E. Program

Students enrolled in the B.S. program in biomedical engineering may pursue a combined B.S./M.S.E. degree that can be completed in five years. Students should apply in their junior year and adhere to the published deadlines and application requirements. (The only exception is that biomedical engineering undergraduates do not need to take the GRE.) Course work should be carefully structured so as to fulfill all the requirements for the B.S. as well as the M.S.E. degree in a timely and coordinated manner. Students are advised to make an early start toward their master’s thesis. The M.S.E. program grants partial tuition fellowship awards on the basis of academic merit. Research assistantships are usually advertised by various laboratories in the institution to carry out specific research and development projects. Fellowships are also awarded to the top students in the program.

Master of Science in Engineering in Innovation and Design

The Center for Bioengineering Innovation and Design (CBID), housed in the Department of Biomedical Engineering, focuses on the design aspect of Biomedical Engineering. This exciting program gives students opportunities to design, develop, build, and test devices that solve some of the most pressing problems facing clinicians today.

The mission of CBID is to:
• Improve human health by developing medical devices that solve important clinical problems
• Educate a new generation of medical device engineers and fellows
• Facilitate technology transfer and industry collaboration

In the graduate program CBID students will learn to identify clinical needs and innovate a novel solution to solve that clinical problem. Working in teams, students work closely with engineering faculty and physicians throughout the medical institution to come up with device ideas, build prototypes, research intellectual property, learn about the regulatory process, write business plans, and present their designs to fellow students, faculty, and outside advisors.

Undergraduate students in BME can also become involved in medical device design by joining an undergraduate design team which works on solving clinical problems by designing innovative devices.

Incorporated in all the BME design curriculum is a focus on technology commercialization. All students, graduate and undergraduate, will interact with clinical and corporate sponsors and have experiences that promote the development of leadership, communications, and marketing skills, thus helping to ensure our graduates’ professional success.

The CBID M.S.E. is a one-year program lasting from May through the following May. Please see our website for more information on our programs: http://cbid.bme.jhu.edu.

Ph.D. in Biomedical Engineering through the School of Medicine

Biomedical Engineering has emerged as one of the most exciting interdisciplinary research fields in modern science. Biomedical engineers apply modern approaches from the experimental life sciences in conjunction with theoretical and computational methods from the disciplines of engineering, mathematics, and computer science to the solution of biomedical problems of fundamental importance. The Biomedical Engineering Graduate Program of Johns Hopkins University is designed to train engineers to work at the cutting edge of this exciting discipline.

The cornerstone of the program is our belief in the importance of in-depth training of students in both life sciences and modern engineering. 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 fellowship. 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 also 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
Requirements for Admission

The School of Medicine program accepts applications for the Ph.D. program until December 15 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.

About one third of our incoming students are international students. A short list of these students is formed by committee and the top candidates are interviewed by phone. Like all admitted students, international students receive full financial aid as well as a monthly stipend. They too have the freedom to choose from any lab.

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
410-614-3385 phone
410-614-3386 fax
grad_study@jhmi.edu

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 end of 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.
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 15.

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 panel of three advisors during the first two years. 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 in the first half of the third 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/mdphdadmissions/Howtoapply.html. 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
Elliot McVeigh
Massey Professor and Director: imaging.

Professors
Jennifer H. Elisseeff
Jules Stein Professor: tissue engineering, biomaterials, cartilage regeneration.

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

Michael I. Miller
Herschel and Ruth Seder Chair in Biomedical Engineering: computational anatomy, medical imaging, image understanding.

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

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

Reza Shadmehr
Co-director of the Biomedical Engineering PhD program: human motor control and learning in health and disease, functional imaging of the brain, human neurophysiology, computational and theoretical neuroscience.

Jeffrey H. Siewerdsen
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 prostheses.

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
Director of the Undergraduate program in Biomedical Engineering: Functional electro-physiology of cultured cardiac cell networks, cardiac arrhythmias, analysis of multicellular structure, stem cell-derived cardiac cells.

Xiaqiong 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: computational cell biology, systems biology, cardiac electrophysiology.

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

David T. Yue
Co-director of the Biomedical Engineering PhD program: Ca2+ signaling experiments and modeling, as related to basic mechanisms and neuronal/cardiovascular disease; Ca2+ ion channels; calmodulin/Ca2+ channel decoding of channel nanodomain Ca2+ signaling; Ca2+ channel modulation; genetically encoded Ca2+ sensors; electrophysiology; fluorescence resonance energy transfer (FRET) imaging; confocal multiphoton, and total internal reflectance fluorescence (TIRF) imaging of Ca2+-related signaling; biophysics; molecular biology; biochemistry.

Associate Professors

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

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.

Rene Vidal
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).

Kevin J. Yarema
Director of the Master’s degree program in Biomedical Engineering: metabolic glycoengineering, glycobiology, systems biology of glycosylation, carbohydrate-based cancer drug design and delivery, cellular responses to static magnetic fields.

Assistant Professors

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

Michael A. Beer
Genomics and computational molecular biology.

Harry R. Goldberg
Assistant Dean of the School of Medicine: interactive simulations, virtual classrooms.

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

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

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.

Feilim Mac Gabhann
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
Closed-loop deep brain stimulation, control theory, computational neuroscience and large-scale optimization.

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

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

Kechen Zhang
Theoretical neuroscience, computational neuroscience, neural computation.

Professors Emeriti

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

Murray B. Sachs
University Distinguished Service Professor: Auditory neurophysiology and psychophysics.

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

Adjunct Associate Professor

Yuan Gao
Methylyomics, transcriptomics and bioinformatics big data analytics and visualization.

Research Professor

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

Associate Research Professor

Robert H. Allen
Design, education, biomechanics, birth mechanics.

Soumyadipta Acharya
Director of the Master’s degree program in Bioengineering Innovation and Design: Biomedical instrumentation, medical device innovation, neuroprosthetics, brain machine interfaces, computational neuroscience.

Joseph L. Greenstein
Assistant Research Scientist: cell biology, cardiac electrophysiology and excitation-contraction coupling, ion channels, calcium signaling in microdomains, biophysically detailed mathematical modeling.

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

Research Associate

Xiaofeng Jia
Clinical neuro-engineering—peripheral nerve, cardiac arrest and hypothermia.

Niranjan Pandey
Angiogenesis, cancer, metastasis, peptide drugs, drug discovery.

David Sherman
Quantitative and clinical neurophysiology; EEG; seizure detection; signal processing; instrumentation.

Web Stayman
Imaging physics, 3D image reconstruction, novel imaging systems, image-guided interventions and diagnostic imaging.

Ramana Kumar Vinjamuri
Brain computer interfaces and neuroprostheses.

Lecturers

Lawrence B. Aronhime
Senior Lecturer (Center for Leadership Education): innovation, business, technology commercialization, accounting, entrepreneurship, engineering management, business history.

Paul Fearis
Industrial design, medical device design.

Eileen Haase
Freshmen Modeling and Design, System Bioengineering Laboratory I and II, Cell and Tissue Engineering Laboratory, Molecules and Cells, BME Teaching Practicum.

Joint, Part-Time, and Visiting Appointments

Mohamad E. Allaf
Associate Professor (Urology): laparoscopic and robotic surgery.

Andreas G. Andreou
Professor (Electrical and Computer Engineering): bioelectronics, integrated micro and nano devices for the life sciences, natural and synthetic sensory systems, neural computation.

Isaac N. Bankman
Assistant Professor (Applied Physics Laboratory): biomedical signal and image processing.

Ronald D. Berger
Professor (Department of Medicine, Division of 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.

Jeff W.M. Bulte
Professor (Radiology): stem cells, cell therapy, imaging, nanotechnology, in vivo diagnostics.

Charles C. Della Santina
Associate Professor (Otolaryngology-Head & 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.

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

Peter L. Gehlbach
Associate Professor (Ophthalmology): microsurgical tools, angiogenesis, antiangiogenesis, viral vectors, oxidative injury as they apply to diseases of the retina and vitreous, microsurgical tools, angiogenesis, antiangiogenesis, viral vectors, oxidative injury.

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

John Goutsias
Professor (Electrical and Computer Engineering): complex interaction networks, biochemical reaction system modeling and analysis, computational systems biology.

Edith D. Gurewitsch
Associate Professor (Gynecology and Obstetrics): birth simulation, birth mechanics, mechanical birth injury, shoulder dystocia, obstetric brachial plexus injury, human subjects testing.

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

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

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

Steven S. Hsiao
Professor (Neuroscience): neurophysiology of the central nervous system.

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.

Bruno Jedynak
Associate Research Professor (Applied Mathematics and Statistics): statistical models in image processing, language processing, genomics and neuroscience.

David A. Kass
Professor (Cardiology): molecular pathophysiology of heart failure and hypertrophy, pathobiology of cardiac dyssynchrony 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
Associate 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.

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

Jonathan S. Lewin
Professor (Radiology): interventional MRI, intraoperative MRI, neuroradiology.

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

Robert E. Miller
Associate Professor (Pathology Informatics): clinical laboratory instrumentation, laboratory information systems.

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.

Carey E. Priebe

Jerry L. Prince
Professor (Electrical and Computer Engineering): multi-dimensional signal processing, medical

Assistant Research Professor
Fijoy Vadakkumpadan
Patient-specific whole-heart modeling, ex vivo image-based cardiac modeling, image-based cardiac shape analysis, computational methods for brain surface mapping.

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

Courses
EN.580.106. Discover Hopkins: Nanoparticles for Drug Delivery Applications. 1 Credit.
Humans have used medication to treat diseases for many centuries; however, with the ever growing pharmaceuticals industry and stronger, more effective agents being designed, it has become clear that getting these drugs to their target cells only is a significant issue. Possibly the most striking example is intravenously (IV) administered chemotherapy agents. Patients receiving IV chemotherapy experience severe side-effects throughout their entire body such as hair loss, fatigue, nausea and general pain. This clearly illustrates the need for delivering drugs locally or targeting them to reach only the desired tissues, and this is where the field of nanoparticle drug delivery comes into play. Drug delivery involves encapsulating drugs in a delivery vehicle that can help sustain the release at therapeutic levels over an increased period of time and deliver it to the desired site. This course will focus on current developments as well as the methods used in the field of nanoparticle.
Instructor(s): C. Bishop; K. Maisel
Area: Engineering, Natural Sciences.

EN.580.111. BME Modeling and Design. 2 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.
Instructor(s): E. Haase
Area: Engineering, Natural Sciences.

EN.580.112. BME Design Group. 3 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): R. Allen
Area: Engineering, Natural Sciences.
EN.580.200. Introduction to Scientific Computing in BME using Python, Matlab, and R. 3 Credits.
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): M. Beer
Area: Engineering.

EN.580.202. BME in the Real World. 1 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 Credits.
Sophomore-level version of EN.580.311-312 or Perm. Req’d
Instructor(s): R. Allen
Area: Engineering, Natural Sciences.

EN.580.212. BME Design Group. 3 Credits.
Sophomore-level version of EN.580.111-112. Permission of course directors required.
Instructor(s): R. Allen
Area: Engineering, Natural Sciences.

EN.580.221. Molecules and Cells. 4 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. Advanced quantitative treatment including multi-state kinetics, Monte Carlo simulations of biochemical reactions, and transport phenomena. Recommended Course Background: AS.030.101 and AS.030.104
Instructor(s): E. Haase
Area: Natural Sciences.

EN.580.222. Systems and Controls. 4 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, controlability, and PID controller design. Recommended Course Background: AS.171.102 and AS.110.201, AS.110.302 or EN.550.291
Instructor(s): M. Miller; S. Sarma
Area: Engineering.

EN.580.223. Models and Simulations. 4 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.550.291
Instructor(s): A. Popel; M. Beer
Area: Engineering.

EN.580.302. Careers in Biomedical Engineering. 1 Credit.
See description for EN.580.202. This course is designed for upperclassmen that wish to meet with weekly speakers to discuss careers issues. Junior/Senior Engineers only.
Instructor(s): A. Popel.

EN.580.311. BME Design Group. 3 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): R. Allen
Area: Engineering, Natural Sciences.

EN.580.312. BME Design Group. 3 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): R. Allen
Area: Engineering, Natural Sciences.

EN.580.315. Introduction to Information Processing of Sensory Signals. 3 Credits.
An introductory course to basic concepts of information processing of human communication signals (sounds, images) in living organisms and by machine. Role of sensory signals, introduction (or review) of basic concepts of signals and systems and of information theory, basic psychophysical concepts of auditory and visual perception, physiology of hearing and vision, engineering applications with emphasis on auditory models for speech coding and recognition.
Prerequisites: EN.520.214 OR EN.580.222 or instructor permission
Instructor(s): H. Hermansky.
EN.580.320. How do Cells Compute?. 3 Credits.
Living cells have to make decisions to survive, and they excel at it. In this course, we will study in detail how cells use the static information in their DNA and dynamic information arriving from their environment to compute appropriate responses, how this computation can go terribly wrong in disease and how one can intervene to rectify the decision making. As a part of the course we will review the important concepts related to transcriptional regulation, signal transduction and paracrine cell-cell communication. Recommended Course Background: Introductory college level biology
Area: Engineering.

EN.580.321. Statistical Mechanics and Thermodynamics. 4 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: A5.110.108-A5.110.109, A5.030.101-A5.030.102, A5.171.101-A5.171.102; Freshman/Sophomore Chemistry and Physics
Instructor(s): M. Beer
Area: Engineering, Natural Sciences.

EN.580.404. The Bionic Ear: an odyssey from profound deafness to possible hearing. 1 Credit.
This course aims to examine the growth and success of cochlear implants as a biotechnology tool in aural rehabilitation. A unique perspective will come from Dr. Ratnanather who has been profoundly hearing impaired since birth via his impending CI surgery in mid-semester and subsequent activation. The course will consist of 10-12 seminars. Students will learn among other things the auditory system and clinical aspects of cochlear implantation. Each seminar will involve a discussion of one or two key papers and may include a talk by an otologist. The course will conclude with attendance at a day-long session on rehabilitation and music at CI2012 in downtown Baltimore which reflects Johns Hopkins’ pre-eminent position in pediatric aural rehabilitation. Pass/Fail Only.
Instructor(s): J. Ratnanather
Area: Engineering.

EN.580.410. BME Teaching Practicum. 2 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): M. Beer.

EN.580.411. BME Design Group. 3 Credits.
Perm. Req’d. Senior-level version of EN.580.311-312.
Instructor(s): R. Allen
Area: Engineering.

EN.580.412. BME Design Group. 3 Credits.
Senior-level version of EN.580.311-312. Permission of course directors required
Instructor(s): R. Allen
Area: Engineering.

EN.580.413. Design-Team, Team Leader. 4 Credits.
A two-semester sequence where leaders direct a team of undergraduate biomedical engineering students in a series of design problems. Prior design team experience and permission of course director required.
Perm. Req’d.
Instructor(s): R. Allen
Area: Engineering.

EN.580.414. Design Team/Team Leader. 4 Credits.
A two-semester sequence where leaders direct a team of undergraduate biomedical engineering students in a series of design problems. Prior design team experience and permission of course directors required.
Instructor(s): R. Allen
Area: Engineering.

EN.580.415. Ethics of Biomedical Engineering Innovation. 3 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. Co-listed with 661.425
Instructor(s): F. Macgabhann
Area: Social and Behavioral Sciences Writing Intensive.

EN.580.420. Build-a-Genome. 4 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.
Instructor(s): J. Bader; J. Boeke; K. Zeller
Area: Engineering, Natural Sciences.
EN.580.421. Systems Bioengineering I. 4 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
Area: Engineering, Natural Sciences.

EN.580.422. Systems Bioengineering II. 4 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 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. Priority to Junior BME majors. Recommended Corequisite: EN.580.421.
Instructor(s): E. Haase
Area: Natural Sciences.

EN.580.424. Systems Bioengineering Lab. 2 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
Instructor(s): E. Haase

EN.580.425. Ion Channels in Excitable Membranes. 3 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.580.426. Biofluid Mechanics. 3 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. Co-listed with EN.530.426
Area: Engineering.

EN.580.429. Systems Bioengineering III. 4 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.580.434. Bioelectricity. 3 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.580.439. Models of the Neuron. 4 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.110.301, EN.580.421-EN.580.422 or equivalent. Meets with EN.580.639
Instructor(s): E. Young
Area: Engineering, Natural Sciences.

EN.580.440. Cell & Tissue Engineer. 3 Credits.
Lectures provide an overview of molecular biology fundamentals, an extensive review on extracellular matrix and basics of receptors, followed by topics on cell-cell and cell-matrix interactions at both the theoretical and experimental levels. Subsequent lectures will cover the effects of physical (shear, stress, strain), chemical (cytokins, growth factors), and electrical stimuli on cell function, emphasizing topics on gene regulation and signal transduction processes. Material on cell-cycle, apoptosis, metabolic engineering and gene therapy will also be incorporated into the course. Junior, Senior, Graduate students only. Recommended Course Background: EN.580.421-EN.580.422
Instructor(s): J. Elisseeff; K. Yarema
Area: Engineering, Natural Sciences.
EN.580.441. Cellular Engineering. 3 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 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. Elisseeff; W. Grayson
Area: Engineering.

EN.580.445. Introduction to Speech and Audio Processing. 3 Credits.
Instructor(s): M. Elhilali
Area: Engineering.

EN.580.446. Survey of Synthetic Biology. 1 Credit.
This course surveys basic fundamentals and current topics in synthetic biology including genome synthesis strategies, synthetic genetic systems, the engineering of proteins and genetic circuits, modeling of signaling and genetic circuits, and intellectual property issues. Meets with AS.020.451/EN.540.446.

EN.580.448. Biomechanics of the Cell. 3 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.

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. 2 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.
Instructor(s): E. Haase
Area: Engineering, Natural Sciences.

EN.580.455. Introduction to Orthopaedic Biomechanics. 3 Credits.
This course will cover static and dynamic force in the musculoskeletal systems, joint reactions, soft and hard tissue response to force loads, muscle mechanics, material properties, biomechanical lumped parameter systems, modeling and injury mechanisms. Co-listed with EN.580.655. Recommended Course Background: AS.110.302
Instructor(s): R. Allen
Area: Engineering.

EN.580.456. Introduction to Rehabilitation Engineering. 3 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 the course, students should be able to: • Understand the breadth and scope of physical impairment and disability and its associated pathophysiology • 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 and design new solutions for persons with disabilities
Instructor(s): S. Paul
Area: Engineering.
EN.580.466. Statistical Methods in Imaging. 3 Credits.
Denoising, 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.550.310 or equivalent.
Instructor(s): B. Jedynak
Area: Engineering, Quantitative and Mathematical Sciences.

EN.580.469. Design of Economic Health Care Technologies. 2 Credits.
Permission of instructor. This spring semester course is offered to juniors and seniors in engineering with an interest in developing economic health care technologies for global health care needs. Health care technologies for global use need to be cost effective and serve the needs of the disadvantaged population. In the US as well health care costs are spiraling and economic health care technologies and solutions will be necessary. This laboratory course will focus on identifying the health care needs, coming up with innovative technical solutions, designing and building such instrument prototypes and exploring how such technologies can be disseminated globally. A new laboratory, EcoHealth, will be set up to do rapid prototyping and the students will do independent designs in this lab after doing proper needs identification and will be responsible for finding appropriate target needs. Students will be required to write the problem statement and the need analysis, submit a patent on the design, and a short proposal to seek funding from philanthropic or Government/non Government agencies. The course will focus on hands on design and projects, doing research and writing reports (or patents) pertaining to novel and useful technologies, and will receive 2 design credits and writing credits. This course, along with the 4 credit 580.471 (Principles of Design of Medical Instrumentation) offered in fall, and the 2 credit 580.571 (Honors Instrumentation) offered during the Intersession comprises an 8 credit design sequence that can serve the requirements for a full Capstone Design experience. The enrollment is restricted and subject to approval by the instructor, Prof. Nitish Thakor (nitish@jhu.edu). Selection of the students will depend on commitment and experience with hands on design and instrumentation development and an interest in global health care needs.
Area: Engineering Writing Intensive.

EN.580.470. Biomedical Instrumentation I: Molecular and Cellular. 3 Credits.
This core design course will explore the fundamentals of molecular and cellular measurements, related technologies and their applications in scientific research. Course will include a guided lab. Seniors/Graduate students only, Juniors with permission. Recommended Course Background: EN.520.345
Area: Engineering, Natural Sciences Writing Intensive.

EN.580.471. Principles of Design of BME Instrumentation. 4 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
Instructor(s): N. Thakor
Area: Engineering, Natural Sciences.

EN.580.472. Topics in Medical Imaging Systems. 3 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).
Instructor(s): J. Prince
Area: Engineering.

EN.580.473. Modern Biomedical Imaging Instrumentation and Techniques. 3 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.540.434 Recommended course background: EN.520.432 or EN.580.472
Prerequisites: EN.520.432 OR EN.580.472
Instructor(s): B. Tsui
Area: Engineering, Natural Sciences.

EN.580.474. Molecular and Cellular Imaging. 3 Credits.
Introduction to non-invasive imaging techniques as applied to an early diagnosis of disease, altered gene expression, cellular therapeutics, and fundamental molecular or metabolic changes. Includes magnetic resonance imaging, radionuclide imaging, and optical imaging techniques. Covered will be: principles of specific targeting and non-specific uptake of diagnostic contrast agents; NMR spectroscopy of metabolic changes in cancer; use of cell tracking using exogenous tags; imaging of stem cells, imaging using reporter genes, theranostics (combined therapeutics and diagnostics), imaging cancer, imaging of neurodegenerative disease, and imaging of cardiovascular disease. The emphasis of the overall course is to learn how molecular/ cellular imaging will change the way future diagnostic radiology and drug development will be practiced.
Prerequisites: EN.580.221 or equivalent. Senior Standing or Permission of Instructor required.
Area: Engineering.
EN.580.476. Magnetic Resonance in Medicine. 3 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): P. Bottomley; W. Edelstein
Area: Engineering.

EN.580.477. Advanced Topics in Magnetic Resonance Imaging. 3 Credits.
An advanced imaging course with in-depth quantitative coverage of topics central to magnetic resonance imaging, ranging from techniques currently used in the radiology practice to new developments at the cutting edge of MRI research. Topics include: steady-state imaging and contrast mechanisms, MRI simulations, RF pulse and coil design, flow imaging and angiography, cardiac imaging, diffusion imaging, functional MRI, parallel imaging, and high-field imaging. As part of the course, students will be expected to read and understand classic and current literature. The course is taught by a team of experts in the respective fields and will provide an excellent foundation for students interested in deep understanding of magnetic resonance imaging.
Instructor(s): D. Herzka
Area: Engineering.

EN.580.484. Ultrasound Imaging: Theory and Applications. 3 Credits.
This course is designed to teach students the theory behind ultrasound imaging and provide an opportunity to apply this theory in a final project. The projects will be centered around advanced beamformers, photoacoustic imaging and thermal imaging. Recommended course background: EN.520.432 or EN.580.472 or equivalent.
Instructor(s): E. Boctor; M. Bell
Area: Engineering.

EN.580.488. Foundations of Computational Biology & Bioinformatics II. 3 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.600.226 or equivalent.
Instructor(s): R. Karchin
Area: Engineering, Natural Sciences.

EN.580.491. Learning Theory. 3 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 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.
Instructor(s): J. Bader; J. Boeke; K. Zeller
Area: Engineering, Natural Sciences.

EN.580.495. Microfabrication Lab. 4 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.580.501. Fall BME Research - Freshman/Sophomore. 3 Credits.
Instructor(s): Staff.

EN.580.502. Spring BME Research - Freshman/Sophomore. 0 - 3 Credit.
Practicum in Biomedical Engineering Research projects or engineering design projects under the supervision of any member of the BME faculty.
Instructor(s): Staff.

EN.580.511. Fall BME Independent Study - Freshman/Sophomore. 3 Credits.
Instructor(s): K. Yarema; M. Beer; R. Allen.

EN.580.512. Spring BME Independent Study - Freshman/Sophomore. 0 - 3 Credit.
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 Credits.
Instructor(s): Staff.

EN.580.532. Spring BME Research - Junior/Senior. 3 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 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 - 3 Credit.
Directed readings or other literature research under the direction of any BME faculty member.
Instructor(s): Staff.
EN.580.571. Honors Instrumentation. 2 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.
Prerequisites: EN.580.471 OR EN.580.771
Instructor(s): N. Thakor
Area: Engineering.

EN.580.580. Senior Design Project. 3 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): R. Allen.

EN.580.581. Senior Design Project. 3 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): R. Allen.

EN.580.590. Biomedical Internship. 1 Credit.
Instructor(s): A. Shoukas; J. Bader; L. Tung; S. Sarma; X. Wang.

EN.580.595. BME Senior Design-Summer. 3 Credits.
Instructor(s): J. Green; L. Schramm; R. Allen.

EN.580.597. BME Research - Summer. 3 Credits.
Instructor(s): Staff.

EN.580.598. Design Project. 3 Credits.
Instructor(s): R. Allen.

EN.580.599. Independent Study. 3 Credits.
Instructor(s): A. Shoukas; H. Goldberg; K. Yarema; N. Thakor; S. Kuo.

EN.580.601. Special Topics in Bioengineering Innovation and Design.
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.580.602. Special Topics in Bioengineering Innovation and Design.
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.
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.580.604. The Business of Bioengineering Innovation and Design.
This course comprises two distinct, but related, components. The first is a broad introduction to the terms, concepts, and values of business and management. Particular emphasis will be placed on the economic, financial, and corporate contexts of our business culture, and how they impact the organization, strategy, and decision-making of business firms. The second component is an introduction to the sociological and economic forces that shape the development and diffusion of new technologies. This part is primarily designed to provide a framework for determining the commercial viability of new medical devices and the best path for realizing their value, including how to develop a compelling value proposition, analyze markets and competitors, and protect intellectual property. Throughout, the course utilizes individual exercises, case analyses, and team projects.
Instructor(s): L. Aronhime.

EN.580.605. Business of Bioengineering Innovation and Design.
This course comprises two distinct, but related, components. The first is a broad introduction to the terms, concepts, and values of business and management. Particular emphasis will be placed on the economic, financial, and corporate contexts of our business culture, and how they impact the organization, strategy, and decision-making of business firms. The second component is an introduction to the sociological and economic forces that shape the development and diffusion of new technologies. This part is primarily designed to provide a framework for determining the commercial viability of new medical devices and the best path for realizing their value, including how to develop a compelling value proposition, analyze markets and competitors, and protect intellectual property. Throughout, the course utilizes individual exercises, case analyses, and team projects.
Instructor(s): L. Aronhime.
This course comprises two distinct, but related, components. The first is a broad introduction to the terms, concepts, and values of business and management. Particular emphasis will be placed on the economic, financial, and corporate contexts of our business culture, and how they impact the organization, strategy, and decision-making of business firms. The second component is an introduction to the sociological and economic forces that shape the development and diffusion of new technologies. This part is primarily designed to provide a framework for determining the commercial viability of new medical devices and the best path for realizing their value, including how to develop a compelling value proposition, analyze markets and competitors, and protect intellectual property. Throughout, the course utilizes individual exercises, case analyses, and team projects. CBID MSE students only. Instructor(s): L. Aronhime.

EN.580.607. Regulation of Medical Devices.
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.
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 valid 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.
Instructor(s): E. Haase.

EN.580.610. Comput Funct Genomics.
Instructor(s): J. Goutsias.

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

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

EN.580.613. Global Health Innovation and Design.
Instructor(s): S. Acharya.

EN.580.616. Introduction to Linear Dynamical Systems.
This course examines linear, discrete- and continuous-time, and multi-input-output systems in control and related areas. Least squares and matrix perturbation problems are considered. Topics covered include state-space models, stability, controllability, observability, transfer function matrices, realization theory, feedback compensators, state feedback, optimal regulation, observers, observer-based compensators, measures of control performance, and robustness issues using singular values of transfer functions. BME EN.580.616 can be used to fulfill the requirement of ME EN.530.616 or ECE EN.520.601.
Instructor(s): S. Sarma.

Limited to CBID students only. Registration with instructor’s permission only.
Instructor(s): S. Acharya.

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.
For CBID MSE students only. Instructor’s Permission Required.
Instructor(s): S. Acharya.

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

This course will cover basic mechanisms and functions of the inner ear and brainstem. This is a companion course and alternates with EN.580.626, although these can be taken in either order. The focus is on transmission and transduction of sound and head movements by the auditory and vestibular periphery. Topics include: cellular and molecular mechanisms of mechanotransduction, synaptic signaling and development, primary afferents and the first-order brainstem nuclei, as well as clinical consequences of peripheral damage. Undergraduates with knowledge in Neuroscience welcome. Recommended Course Background: an introduction to neuroscience.
Instructor(s): E. Glowatzki; P. Fuchs.

Brain mechanisms and perception of sound and balance. This course is an accommodation 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.580.422 or equivalent.
EN.580.222 Taught at the School of Medicine.
EN.580.628. Topics in Systems Neuroscience.
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
Instructor(s): K. Zhang; X. Wang.

EN.580.630. Theoretical Neuroscience.
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 trans; 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.550.420 or equivalent, EN.580.222 or equivalent.
Instructor(s): D. Yue.

EN.580.632. Ionic Channels in Excitable Membranes.
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): K. Zhang.

EN.580.633. Horizons in Biological Calcium and Voltage Signaling.
Introductory survey of current and classic discoveries relating to calcium and voltage signaling in biology. Fluctuations of free calcium concentration within cells, and electrical potential differences across cell membranes, turn out to be the currency by which information is communicated in relation to a vast array of vital biological processes. Understanding how these signals are generated, encoded, and decoded is therefore the key to unraveling complex biological signaling networks, and a Rosetta stone for next-generation disease treatments at the molecular and cellular level. Students and faculty will present a mixture of papers and didactic lectures that will give a flavor of this burgeoning area of biophysics, engineering, and systems biology. Appropriate for seniors and graduate students of all levels.
Instructor(s): D. Yue.

EN.580.634. Bioelectricity.
Instructor(s): L. Tung.

EN.580.635. Topics in Bioelectromagnetic Phenomena.
This course reviews theoretical concepts and experimental approaches used to characterize electric, magnetic, and electromagnetic phenomena that arise in biological tissues. Topics include volume conductor models of cells and tissues, complex conductive properties of tissue and cell suspensions, bioelectric and biomagnetic measurements, electric and magnetic stimulation, and impedance plethysmography. Selected topics will be chosen for oral presentations by class participants. Course taught at the School of Medicine.

EN.580.637. Contemporary Topics in the Engineering of Cardiac Tissue.
Cardiac ionic currents, molecular correlates and blockers, calcium clock repolarization reserve, alternans, electrical remodeling, cardiac memory, defective calcium cycling, ion channel mutations, human embryonic stem cells, paracrine signaling, extracellular matrix and cytoskeleton, synthetic tissue scaffolds, in vitro experimental models. Instructor(s): L. Tung
Area: Engineering, Natural Sciences.

EN.580.639. Models of the Neuron.
See description for EN.580.439. Differs in that an advanced modeling project using data from the literature is required. Graduate version of EN.580.439. Recommended Course Background: AS.110.301-AS.110.302, EN.580.421-EN.580.422 or equivalent.
Instructor(s): E. Young.

See 580.440 for full description.
Instructor(s): K. Yarema.

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. Meets with EN.580.441. Recommended Course Background: EN.580.221 or AS.20.305 and AS.020.306 (or equivalent) and AS.030.205
Instructor(s): J. Green; K. Yarema.

EN.580.642. Tissue Engineering.
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
Instructor(s): J. Elisseff; W. Grayson
Area: Engineering.
EN.580.655. Introduction to Orthopedic Biomechanics.
This course will cover static and dynamic force in the musculoskeletal systems, joint reactions, soft and hard tissue response to force loads, muscle mechanics, material properties, biomechanical lumped parameter systems, modeling and injury mechanisms. Co-listed with EN.580.455. Recommended Course Background: AS.110.302
Instructor(s): R. Allen
Area: Engineering.

EN.580.670. Biomedical Instrumentation I: Molecular and Cellular.

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): P. Bottomley; W. Edelstein.

EN.580.677. Advanced Topics in Magnetic Resonance Imaging.
An advanced imaging course with in-depth quantitative coverage of topics central to magnetic resonance imaging, ranging from techniques currently used in the radiology practice to new developments at the cutting edge of MRI research. Topics include: steady-state imaging and contrast mechanisms, MRI simulations, RF pulse and coil design, flow imaging and angiography, cardiac imaging, diffusion imaging, functional MRI, parallel imaging, and high-field imaging. As part of the course, students will be expected to read and understand classic and current literature. The course is taught by a team of experts in the respective fields and will provide an excellent foundation for students interested in deep understanding of magnetic resonance imaging.
Instructor(s): D. Herzka.

EN.580.681. Advanced Topics in Computer Vision.
(Formerly 580.464) State-of-the-art methods in dynamic vision, with an emphasis on segmentation, reconstruction, and recognition of static and dynamic scenes. Topics include reconstruction of static scenes (tracking and correspondence, multiple view geometry, self-calibration), reconstruction of dynamic scenes (2-D and 3-D motion smentation, nonrigid motion analysis), recognition of visual dynamics (dynamic textures, face and hand gestures, human gaits, crowd motion analysis), as well as geometric and statistical methods for clustering and unsupervised learning, such as K-means, Expectation Maximization, and Generalized Principal Component Analysis. Applications in robotics and biomedical imaging are also included.
Prerequisites: Prereq: AS.110.202, EN.600.461 or instructor permission.

EN.580.682. Computational Models of the Cardiac Myocyte.
The cardiac myocyte is one of the most extensively studied cells in biology. As such, it serves as an important example of how to develop quantitative, dynamic, computational models of cell function. "Computational Models of the Cardiac Myocyte" will present a comprehensive review of all aspects of modeling of the cardiac myocyte as an introduction to the discipline of computational cell biology. In this course, students will read and present key papers from the literature, implement and study computer models of the cardiac myocyte, and complete a project. Requirements are knowledge of a programming language (Matlab, C, C++, Java are satisfactory), a course in ordinary differential equations, and an introductory course in molecular and/or systems biology. BME courses Systems Bioengineering I and II meet the biology requirement. This course is taught at the graduate level, and is open to undergraduates (seniors) with permission of the instructors. Students will need a laptop. Recommended Course Background: EN.580.421 and EN.580.422 or equivalent, AS.110.302 or equivalent, and programming language (EN.500.200, EN.600.107, EN.600.120).
Instructor(s): J. Greenstein; R. Winslow.

See description for EN.580.484
Instructor(s): E. Docter; M. Bell.

EN.580.688. Foundations of Computational Biology & Bioinformatics II.
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.600.226 or equivalent.
Instructor(s): R. Karchin.

This course will explore the recent advances in Systems Biology analysis of intracellular processes. Examples of the modeling and experimental studies of metabolic, genetic, signal transduction and cell cycle regulation networks will be studied in detail. The classes will alternate between consideration of network-driven and network element (gene, metabolite or protein)-driven approaches. Recommended Course Background: AS.110.201, AS.110.302 or equivalent, advanced biology.
Instructor(s): A. Levchenko.

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 an 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.
This course will cover machine learning techniques for modeling and segmentation of multivariate mixed data. Topics will include subspace learning (PCA, Probabilistic PCA, Robust PCA, Sparse representation, Rank minimization), manifold learning (Kernel PCA, LLE, Isomap), subspace clustering (K-subspaces, Mixtures of PPCAs, Generalized PCA, Sparse subspace clustering), and manifold clustering (LLMC). These methods will be applied to several problems in computer vision, biomedical imaging, neuroscience, and computational biology. Instructor(s): R. Vidal.

EN.580.701. Sensorimotor Systems.
Instructor(s): R. Shadmehr.

EN.580.718. Advanced Seminars in Integrative and Systems Biology.
The course is designed to introduce the current concepts, methods and modes of analysis being developed in the context of experimental and computational systems biology, with the particular emphasis on the study of signal transduction and cell-cell communication networks. Topics include development and analysis of computational and experimental models of cell interactions with other cells, with extracellular matrix and with micro- and nano-fabricated analysis platforms. The areas of application range from the bacterial signaling to stem cell development and tissue regeneration. Students will be required to read current journal articles, online presentations and actively participate in the in-class discussions. Every student will also be required to be engaged in individual projects and report on their progress. Graduate Level. Seniors by permission. Fall semester only.
Instructor(s): A. Levchenko.

EN.580.719. Advanced Seminars in Integrative and Systems Biology.
The course is designed to introduce the current concepts, methods and modes of analysis being developed in the context of experimental and computational systems biology, with the particular emphasis on the study of signal transduction and cell-cell communication networks. Topics include development and analysis of computational and experimental models of cell interactions with other cells, with extracellular matrix and with micro- and nano-fabricated analysis platforms. The areas of application range from the bacterial signaling to stem cell development and tissue regeneration. Students will be required to read current journal articles, online presentations and actively participate in the in-class discussions. Every student will also be required to be engaged in individual projects and report on their progress. Spring semester only.
Instructor(s): A. Levchenko.

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.

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.

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.
Instructor(s): F. Macgabhann; S. Sarma.

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Instructor(s): S. Sarma.

EN.580.738. Advanced Seminars in Cardiac Electrophysiology and Mechanics.
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.
**EN.580.739. Advanced Seminars in Cardiac Electrophysiology and Mechanics.**

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.

**EN.580.746. Imaging Science Seminar.**

Fall semester only.
Instructor(s): M. Miller; R. Vidal.

**EN.580.747. Imaging Science Seminar.**

Spring semester only.
Instructor(s): M. Miller; R. Vidal.

**EN.580.748. Advanced Seminars in Magnetic Resonance Imaging.**

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.**

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): E. McVeigh.

**EN.580.771. Principles of the Design of Biomedical Instrumentation.**

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.580.774. Molecular and Cellular Imaging.**

Introduction to non-invasive imaging techniques as applied to an early diagnosis of disease, altered gene expression, cellular therapeutics, and fundamental molecular or metabolic changes. Includes magnetic resonance imaging, radiouclide imaging, and optical imaging techniques. Covered will be: principles of specific targeting and non-specific uptake of diagnostic contrast agents; NMR spectroscopy of metabolic changes in cancer; use of cell tracking using exogenous tags; imaging of stem cells, imaging using reporter genes, theranostics (combined therapeutics and diagnostics), imaging cancer, imaging of neurodegenerative disease, and imaging of cardiovascular disease. The emphasis of the overall course is to learn how molecular/ cellular imaging will change the way future diagnostic radiology and drug development will be practiced. Same course as 580.474.

Instructor(s): E. McVeigh.

**EN.580.781. Biomedical Engineering Seminar.**

Instructor(s): J. Bader.

**EN.580.801. Research in Biomedical Engineering.**

Graduate Students only
Instructor(s): K. Yarema.

**EN.580.802. Research in Biomedical Engineering.**

Directed research for MSE and PhD students
Instructor(s): K. Yarema.
Cross Listed Courses

General Engineering
EN.500.745. Seminar in Computational Sensing and Robotics. 3 Credits.
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. Biорobotics and biomechanics, 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): B. Tsui.

Electrical Computer Engineering
EN.520.315. Introduction to Information Processing of Sensory Signals. 3 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 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 equipments in clinical and research settings. Co-listed with EN.580.473
Prerequisites: EN.520.432 OR EN.580.472
Instructor(s): B. Tsui.

EN.520.445. Audio Signal Processing. 3 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.
Instructor(s): M. Elhilali
Area: Engineering.

EN.520.601. Introduction to Linear Systems Theory.
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): D. Tarraf.

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.530.426. Biofluid Mechanics. 3 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 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
Area: Engineering.

EN.530.616. Introduction to Linear Systems.
This course examines linear, discrete- and continuous-time, and multi-input-output systems in control and related areas. Least squares and matrix perturbation problems are considered. Topics covered include state-space models, stability, controllability, observability, transfer function matrices, realization theory, feedback compensators, state feedback, optimal regulation, observers, observer-based compensators, measures of control performance, and robustness issues using singular values of transfer functions. ME EN.530.616 can be used to fulfill the requirement of BME EN.580.616 or ECE EN.520.601.
Instructor(s): N. Cowan.
Applied Mathematics Statistics

EN.550.450. Computational Molecular Medicine. 4 Credits.
Biomedical research has been transformed by the development of new technologies for sequencing genomes and measuring RNA and protein expression levels. Due to the massive number of interacting components, the traditional approach, which is experimental and component-by-component, is no longer adequate. In contrast, statistical learning, modeling and inference have emerged as core methodologies for analyzing these data and uncovering the relationships between molecules, networks and disease, where knowledge extraction is formulated as a problem in high-dimensional pattern recognition. We will cover selected aspects of this methodology (e.g., measuring associations, testing multiple hypotheses, learning predictors and network models, and stochastic simulation) and illustrate how it enhances our ability to discover molecular disease networks, detect disease, predict clinical outcomes, and characterize disease progression. Meets with EN.550.650.
Prerequisites: EN.550.420 and ( EN.550.310 or EN.550.311 or EN.550.430 )
Instructor(s): D. Geman
Area: Engineering, Quantitative and Mathematical Sciences.

EN.550.635. Topics in Bioinformatics.
A "readings" course organized around research articles in the recent bioinformatics and computational biology literatures. In this term, the choice of papers will favor work on inferring phenotype from genotype, and modeling signaling networks, based on gene microarrays bearing the expression levels of thousands of transcripts, and on properties of proteins, such as predicting active sites and detecting harmful mutations. One major objective is to prepare students to comfortably read articles which involve extensive mathematical and statistical modeling as well as techniques from pattern recognition and machine learning. Most papers will be presented by the students. In addition, student expositions will be preceded by “tutorials” by the instructor on various aspects of statistical learning, modeling and prediction, such as properly estimating generalization error in cancer classification and avoiding over-fitting in learning networks of molecular interactions.
Recommended Course Background: course in statistics; previous exposure to machine learning or pattern recognition
Instructor(s): D. Geman
Area: Engineering, Quantitative and Mathematical Sciences.

EN.550.420. Computational Molecular Medicine. 4 Credits.

Computer Science

EN.600.361. Computer Vision. 3 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 (https://cirl.lcsr.jhu.edu/Vision_Syllabus)
Prerequisites: EN.600.226
Instructor(s): R. Vidal
Area: Engineering, Quantitative and Mathematical Sciences.

EN.600.461. Computer Vision. 3 Credits.
Graduate version of EN.600.361. Students may receive credit for EN.600.361 or EN.600.461, but not both. Recommended Course Background: EN.600.226 & linear algebra
Instructor(s): R. Vidal
Area: Engineering, Quantitative and Mathematical Sciences.

EN.600.476. Machine Learning in Complex Domains. 3 Credits.
How can robots locate themselves in an indoor environment when navigating? How do you infer which patients need attention first in the ICU? How can one identify the start of an epidemic using tweets? How does one predict the way a traffic jam will spread through the local streets during an Orioles game? How can you communicate with your TV using only hand gestures? This class will cover the fundamental concepts of Probabilistic Graphical Models as a framework for addressing questions like the ones above. We will study algorithms for model estimation, exact and approximate inference. The class will have 4 interactive sessions during which students will learn through an open discussion format how to think about open-ended real-world problems with the tools learnt in class. Students are also required to tackle a project of their choice within which they will experiment with the ideas learnt in class. 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. 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. Recommended Course Background: EN.550.310, EN.550.311, EN.550.420, or EN.550.430 and EN.550.291 or AS.110.201
Instructor(s): S. Saria
Area: Engineering, Quantitative and Mathematical Sciences.