PITT | SWANSON ENGINEERING

BIOENGINEERING

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HAND BOOK

BIOE

Quick Guide

Few pointers to help with searching for content within the document:

- The following convention has been adopted to present courses within this document: **COURSE_DESIGNATOR ####** (with a space between the designator and following 4 digits) e.g., **BIOENG 1002**, **MATH 0220**, etc.
- If **Preview** (Mac specific software) is being used to view and search for courses, then note that the course must be enclosed within quotation marks, e.g., "**BIOENG 1002**", etc.
- **Adobe Acrobat** (Pro or Reader) does not require the extra quotation marks. Also, when viewing and searching the handbook in a **web browser** there is no need to use the quotation marks.
- Users can take advantage of bookmark links (**Bookmarks**) in **Adobe Acrobat** (Pro and Reader) to access specific points of interest in the document.
- **Preview** user can use the **Table of Contents** feature to access specific points of interest in the document. Note that **web browsers** do not have these features.

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Undergraduate Program Description

Undergraduate Program Rationale

In keeping with the two-fold mission of the Department of Bioengineering to: *provide a high-quality engineering education to both undergraduate and graduate students*, and *be a leader in research in specific areas encompassed by Bioengineering*, the Bioengineering undergraduate curriculum has the objective to prepare students to achieve their post-baccalaureate goal of (a) an industrial career in bioengineering or related field; (b) graduate school (M.S. and Ph.D. programs related to bioengineering); or (c) professional school (Medical, Dental, Health-Related, Business, and Law).

To achieve their particular goal(s), students are: (a) provided with a broad knowledge of the technical and social principles of bioengineering as well as a focused education in one track area within bioengineering; and (b) prepared through educational experiences beyond the classroom that deepen their understanding of the technical and non-technical issues in bioengineering process and design.

Bioengineering Undergraduate Curriculum

The Bioengineering undergraduate curriculum has seven pedagogical components (Figure 1) with options for dual degrees, minors, and certificates.

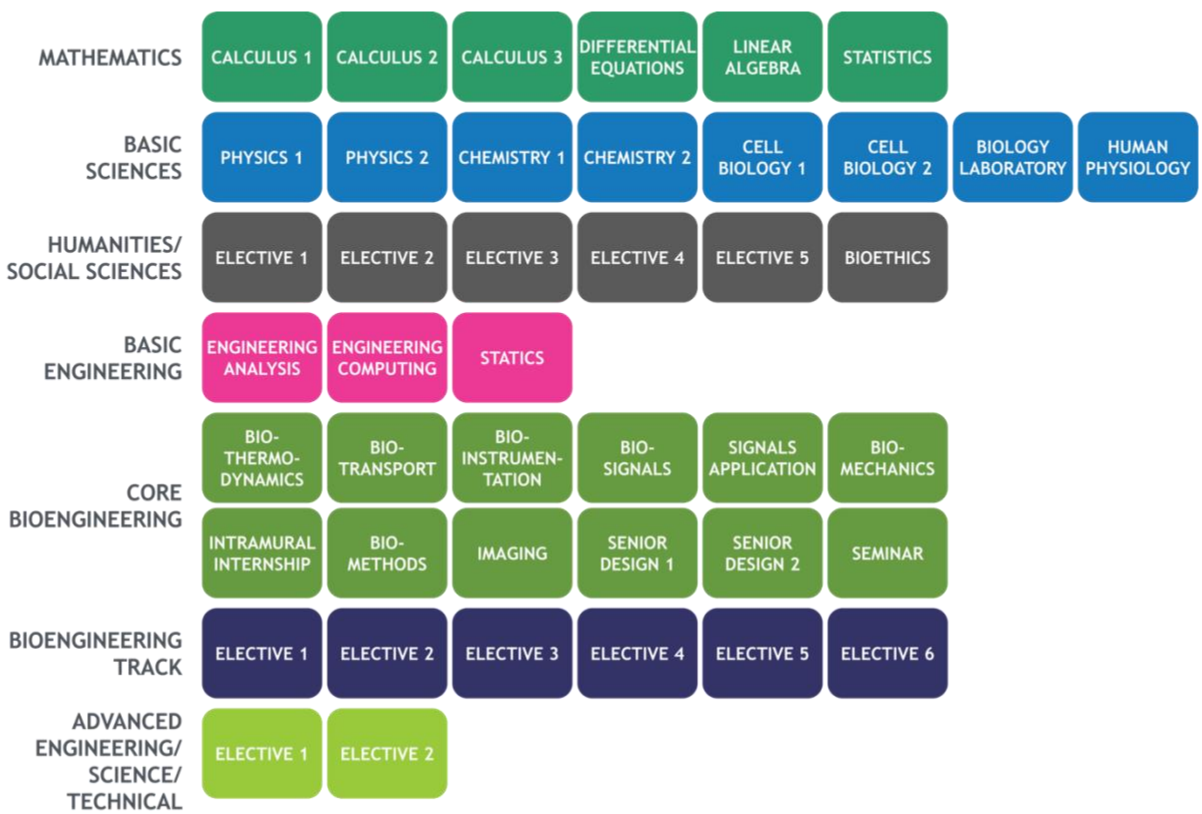

Figure 1. Bioengineering Undergraduate Program curriculum (reflecting course titles) at a glance.

Refer to **Appendix A** to **see one possible, 4-year, semester-by-semester sequence through the curriculum, both for non-pre-med and pre-med paths**. Bioengineering students can monitor their own progression through the curriculum using the **Degree Progress Worksheet** (DPW).

Dual Degrees, Minors, and Certificates. We encourage our students to take full advantage of University of Pittsburgh resources and educational opportunities. Many of our students seek a Dual Degree that augments the bioengineering experience – sometimes another engineering degree, sometimes a degree in Arts & Sciences. Almost all obtain minors and certificates that add value to their education and distinguish them as they move forward in their careers. Planning for minors and certificates is a part of developing the **Comprehensive Electives Plan** (CEP) and needs to start as early as the sophomore year; perhaps, even, the freshman year!

Required Mathematics Courses (6 Courses)

We require that students master basic mathematical skills in analytical geometry, calculus, linear algebra, differential equations, and statistics as preparation for mastery of bioengineering applications. The basic math courses include:

- **MATH 0220** (4 credits): Analytical Geometry and Calculus 1
- **MATH 0230** (4 credits): Analytical Geometry and Calculus 2
- **MATH 0240** (4 credits): Analytical Geometry and Calculus 3
- Differential Equations. Either:
  - **MATH 0290** (3 credits): Differential Equations, or
  - **MATH 1270** (3 credits): Ordinary Differential Equations 1
- Linear Algebra. Either:
  - **MATH 0280** (3 credits): Introduction to Matrices & Linear Algebra, or
  - **MATH 1180** (3 credits): Linear Algebra 1, or
  - **MATH 1185** (3 credits): Honors Linear Algebra
- **BIOENG 1000** (4 credits): Statistics for Bioengineering

Note. Students interested in a **MATH Minor** should consider taking **MATH 1270** instead of **MATH 0290** and either **MATH 1180** or **MATH 1185** instead of **MATH 0280**. See **Chapter 4** > **Minors and Certificates** for more information.

Required Basic Sciences (7 Courses, 1 Lab)

Engineering practice is frequently described as *applied science*. In addition to knowledge of and ability to use basic physics and chemistry, bioengineers need to be conversant with and able to use concepts of biology and physiology. Because of the importance of cellular processes in bioengineering applications, we have developed our own (required) 2-course sequence in cell and molecular biology.

Note. We **do not** accept general biology (**BIOSC 0150** and **BIOSC 0160**) as meeting the cell biology requirement or as advanced engineering/science/technical electives.

- Two semesters of calculus-based physics
  - First semester:
    - **PHYS 0174** (4 credits): Basic Physics for Science and Engineering 1, or
    - **PHYS 0475** (4 credits): Honors Physics 1
  - Second semester:
    - **PHYS 0175** (4 credits): Basic Physics for Science and Engineering 2, or
    - **PHYS 0476** (4 credits): Honors Physics 2
- Two semesters of introductory chemistry
  - First semester:
    - **CHEM 0110** (4 credits): General Chemistry 1, or
    - **CHEM 0410** (3 credits): General Chemistry 1, or
    - **CHEM 0710** (4 credits): Honors General Chemistry 1, or
    - **CHEM 0760** (3 credits): Honors General Chemistry for Engineers 1, or
    - **CHEM 0960** (3 credits): General Chemistry for Engineers 1
  - Second semester:
    - **CHEM 0120** (4 credits): General Chemistry 2, or
    - **CHEM 0420** (3 credits): General Chemistry 2, or
    - **CHEM 0720** (4 credits): Honors General Chemistry 2, or
    - **CHEM 0780** (3 credits): Honors General Chemistry for Engineers 2, or
    - **CHEM 0970** (3 credits): General Chemistry for Engineers 2

Note. CHEM 0410/CHEM 0420 sequence also requires **CHEM 0430** (1 credit): General Chemistry 1 Laboratory.

- Two semesters of cell and molecular biology
  - First semester:
    - **BIOENG 1070** (3 credits): Introductory Cell Biology 1
  - Second semester:
    - **BIOENG 1071** (3 credits): Introductory Cell Biology 2, or
    - **BIOENG 1072** (3 credits): Honors Introductory Cell Biology 2

- Biology laboratory
  - **BIOSC 0050** (1 credit): Foundations of Biology Laboratory 1 (last offered Summer 2019; please see **BIOSC 0057** instead), or
  - **BIOSC 0057** (1 credit): Foundations of Biology Research Laboratory 1, or
  - **BIOSC 0058** (1 credit): Foundations of Biology SEA-PHAGES Laboratory 1, or
  - **BIOSC 0060** (1 credit): Foundations of Biology Laboratory 2 (last offered Summer 2017; see **BIOSC 0067** instead), or
  - **BIOSC 0067** (1 credit): Foundations of Biology Research Laboratory 2
  - **BIOSC 0068** (1 credit): Foundations of Biology SEA-PHAGES Laboratory 2

Note. We accept Advanced Placement (AP) or International Baccalaureate (IB) credits for **BIOSC 0050**. See **Advanced Standing** for more information.

Note. BIOSC 0058/**BIOSC 0068** is a specialized two term sequence, in which students isolate and characterize a phage in **BIOSC 0058** and continue to use this phage in **BIOSC 0068** to perform additional experiments. The Department of Biological Sciences hopes that students in **BIOSC 0058** will continue to **BIOSC 0068**, although there is no mandatory participation in the latter course. As such, it is recommended that you take **BIOSC 0057** if you are only considering 1 credit of biology laboratory experience.

- Human Physiology
  - **BIOSC 1250** (3 credits): Human Physiology, or
  - **NROSCI 1250** (3 credits): Human Physiology, or
  - **BIOSC 1070** (4 credits): Honors Human Physiology, or
  - **NROSCI 1070** (4 credits): Honors Human Physiology

Note. The 2-semester sequence **NUR 0012** (3 credits): Human Anatomy and Physiology 1/**NUR 0002** (1 credit): Nursing Anatomy and Physiology Laboratory 1 and **NUR 0013** (3 credits): Human Anatomy and Physiology 2/**NUR 0003** (1 credit): Nursing Anatomy and Physiology Laboratory 2 can be used to satisfy the Human Physiology requirement plus an advanced engineering/science/technical elective – but both semesters are required to satisfy the Human Physiology requirement.

Current PHYS, CHEM, BIOSC and NROSCI course descriptions can be found at **PeopleSoft Mobile**.

Required Humanities and Social Sciences (6 Courses)

The Swanson School of Engineering (SSoE) requires all undergraduates to complete **at least six** humanities and social science (HUM/SS) elective courses that adhere to the **SSoE Guidelines and Requirements** in order to satisfy SSoE and ABET accreditation requirements for breadth and depth. Complete rules for breadth and depth can be found at the [Approved Electives](#) webpage.

While only approved humanities and social science courses can be used to satisfy the HUM/SS requirements for the Bioengineering degree, **the approved list is not static**. New courses are added frequently. If you wish to take a course not on the approved list, you need to make a request to the Bioengineering Associate Chair for Undergraduate Education **before** taking the course. Please fill out the **HUM/SS Approval Request Form** and e-mail it to the Bioengineering Associate Chair for Undergraduate Education, who will seek approval from Engineering Administration and let you know whether the course has been approved. Please do not request a class from a department which is not on the approved list (e.g., Administration of Justice, Business, etc.).

The Department of Bioengineering feels that ethics is such an integral part of societal practice of bioengineering that we have developed our own bioethics course: **BIOENG 1241** (3 credits): Societal, Political and Ethical Issues in Bioengineering, that emphasizes the fact that we practice bioengineering in the real world and that we need to be aware of the broad societal impact of doing so. **BIOENG 1241 is a required course for all bioengineering undergraduate students**. Because of the strong humanities and social science basis, **BIOENG 1241** is acceptable as one of the required six HUM/SS electives. Thus, bioengineering undergraduates need at least five additional HUM/SS elective courses drawn from the School's list of approved courses.

The SSoE breadth and depth rules for HUM/SS electives, for the purposes of the Bioengineering program, are interpreted as: students must have at least two courses from the same department to satisfy the depth requirement (students may also satisfy the depth requirement by completing two or more courses with a related theme – **in this case, students must submit their intended courses to the Bioengineering Associate Chair for Undergraduate Education for approval**); and, students must have courses from at least three different departments (in addition to **BIOENG 1241**) to satisfy the breadth requirement.

The **University Course Descriptions** website has current information about HUM/SS course offerings. Please note that Dietrich School of Arts & Sciences (DSAS) courses cross-listed with College of General Studies (CGS) that are designated as self-paced (self), online (www), or hybrid online (hybrid) **are not** acceptable for fulfilling the humanities/social science requirement.

Note: Students may use an ENGR study abroad experience, such as the Plus3 program, either as an advanced engineering/science/technical elective or as a HUM/SS elective. **If students are planning on using an ENGR study abroad experience as a HUM/SS elective, they must inform the Bioengineering Associate Chair for Undergraduate Education before partaking in the course.**

W Requirement: All students must have a **W**riting course, designated as such in their academic record, in order to satisfy graduation requirements.

- **Matriculating sophomores coming through SSoE first-year program (AY21 onward)**: This cohort will satisfy the **W** requirement by completing **ENGCMP 0412** (3 credits): Engineering Communication in a Professional Context during their second semester of freshman year. Note that all first-year students are also required to take **ENGCMP 0210** (3 credits): Seminar in Composition: Engineering or **ENGCMP 0200** (3 credits): Seminar in Composition during their first semester as a general composition requirement. Both **ENGCMP 0210** and **ENGCMP 0412** can be used to satisfy the HUM/SS requirements for the Bioengineering degree. However, **ENGCMP 0200** is **not** an acceptable HUM/SS elective.
- **Other cases**: The **W** can be satisfied by a course in any department. However, most students choose to take a 3-credit course in the humanities/social sciences. A one-credit **W** addition to a 3-credit course is also acceptable. A 2-credit **W** course satisfies the **W** requirement but cannot be used to satisfy a course requirement. Listings of **W** courses can be found at the **University Course Descriptions** website.
    - Students should refer to **Peoplesoft** (in the **Class Search** screen, choose **Writing Option** from the **Requirement Designation** field) each term to determine whether a course is being offered as a **W**-designated course (i.e., courses with the **Writing Requirement Course** attribute). Note that there are courses that may have a writing option but not for all their offered sections. Make sure that you check all sections of a course to enroll in the one that does have the **Writing Requirement Course** attribute.

Required Basic Engineering (3 Courses)

The basic engineering courses include:

- Freshman Engineering, first semester:
    - **ENGR 0011** (3 credits): Introduction to Engineering Analysis, or
    - **ENGR 0015** (3 credits): Introduction to Engineering Analysis, or
    - **ENGR 0711** (3 credits): Honors Engineering Analysis and Computing

Note. Transfer students can substitute any engineering course for the **ENGR 0011**/**ENGR 0015**/**ENGR 0711** requirement.

- Freshman Engineering, second semester:
    - **ENGR 0012** (3 credits): Introduction to Engineering Computing, or
    - **ENGR 0016** (3 credits): Introduction to Engineering Computing, or
    - **ENGR 0712** (3 credits): Advanced Engineering Applications for Freshman (Honors)
    - **ENGR 0716** (3 credits): Art of Hands-On System Design and Engineering (Art of Making)

Note. Students who take **ENGR 0016** must also take **ENGCMP 0200** (3 credits): Seminar in Composition.

- **ENGR 0135** (3 credits): Statics and Mechanics of Materials 1

The common Freshman courses, **ENGR 0011/ENGR 0015/ENGR 0711** and **ENGR 0012/ENGR 0016/ENGR 0712/ENGR 0716** are integrated with the Freshman math, physics, and chemistry courses with the specific goals of: (1) introducing students to fundamentals of engineering common to all engineering disciplines, (2) providing an overview of how engineers integrate math, physics, chemistry, and communications into solving practical problems of interest to society, and (3) providing a rigorous foundation in design of computer programs to solve engineering problems.

ENGR 0135 is a basic course in statics and mechanics of materials that applies concepts from physics in understanding the effect of external forces acting on particles and deformable bodies with emphasis on how material responses to external forces impact engineering choices of appropriate materials to use to meet design specifications.

Required Core Bioengineering (11 Courses, 6 Seminars)

In keeping with the Department of Bioengineering philosophy that bioengineers draw from all engineering disciplines in the practice of bioengineering and that, therefore, bioengineers should be conversant with and able to employ the basic skills of the various engineering disciplines, the Bioengineering Core consists of:

- **BIOENG 1210** (3 credits): Biothermodynamics or **BIOENG 1211** (3 credits): Honors Biothermodynamics
- **BIOENG 1220** (3 credits): Biotransport Phenomena
- **BIOENG 1310** (3 credits): Bioinstrumentation
- **BIOENG 1320** (3 credits): Biosignals and Systems
- Choice of a Biosignals application course selected from:
  - **BIOENG 1255** (4 credits): Dynamic Systems: A Physiological Perspective
  - **BIOENG 1580** (4 credits): Biomedical Applications of Signal Processing
  - **BIOENG 1680** (4 credits): Biomedical Applications of Control
- **BIOENG 1630** (3 credits): Biomechanics 1
- **BIOENG 1002** (3 credits): Intramural Internship
- **BIOENG 1150** (3 credits): Biomethods
- Imaging course selected from:
  - **BIOENG 1005** (3 credits): RF Medical Devices
  - **BIOENG 1330** (3 credits): Biomedical Imaging
  - **BIOENG 1340** (3 credits): Introduction to Medical Imaging and Image Analysis

  - **BIOENG 1383** (3 credits): Biomedical Optical Microscopy
  - **BIOENG 2385** (3 credits): Engineering Medical Devices for Quantitative Image Analysis & Visualization
  - **BIOENG 2505** (3 credits): Multi-Modal Biomedical Imaging Technologies
  - **ECE 1390** (3 credits): Introduction to Image Processing/Computer Vision
  - **PSY 1471** (3 credits): Mapping Brain Connectivity
  - Carnegie Mellon University (CMU) courses (kindly refer to **CMU Schedule of Classes webpage for details):**
    - **CMU RI 16-725** (12 units): (Bio)Medical Image Analysis
    - **CMU BioSc 03-315** (9 units): Magnetic Resonance Imaging in Neuroscience
    - **CMU BioSc 03-534** (9 units): Biological Imaging and Fluorescence Spectroscopy
    - **CMU Biomed 42-431** (9 units): Introduction to Biomedical Imaging and Image Analysis
    - **CMU Biomed 42-640** (9 units): Computational Bio-Modeling and Visualization
    - **CMU Biomed 42-474** (9 units): Introduction to Biophotonics
    - **CMU Biomed 42-689** (9 units): Introduction to Bioimaging
    - **CMU Psych 85-429** (9 units): Cognitive Brain Imaging
- **BIOENG 1160** (3 credits): Senior Design 1
- **BIOENG 1161** (3 credits): Senior Design 2
- **BIOENG 1085** (0 credits/6 required): Introduction to Bioengineering Seminar

The Bioengineering Core has been designed to provide students with exposure to the basic engineering disciplines that bioengineers use in preparation for being a functional member of a multidisciplinary team working to creatively solve biomedical problems.

BIOENG 1210 and **BIOENG 1220** provide knowledge and applications in thermal/fluid engineering which are important in design and operation of cellular engineering and tissue culture applications and artificial organs technology.

BIOENG 1310 and **BIOENG 1320** provide fundamental knowledge and applications in electrical engineering that are required for data acquisition, signal processing, imaging, and systems control. **BIOENG 1255** (biological insights through mathematical modeling), **BIOENG 1580** (biological insights through signal processing in general), and **BIOENG 1680** (applications in biological control systems) are more in-depth application of concepts presented in **BIOENG 1310** and **BIOENG 1320**.

BIOENG 1630, coupled with **ENGR 0135**, provides knowledge and applications that are required to model and design solutions in such diverse areas as motion and balance, prosthetics design, and soft tissue mechanics.

Both **BIOENG 1002** and **BIOENG 1150** are laboratory, research-based courses that focus on communications skills: **BIOENG 1002** on preparation and public presentation of research; **BIOENG 1150** on analysis and written communication.

Imaging is an integral skill in bioengineering. Several choices are offered to help meet individual needs of students in designing a curriculum relevant to their interests and course of study. While any of the listed courses satisfy the imaging requirement, students are encouraged to seek advisor input with respect to which course might be best for their particular interests. Students can petition the Bioengineering Associate Chair for Undergraduate Education to have a new imaging course placed on the list of acceptable courses.

Senior Design (**BIOENG 1160** & **BIOENG 1161**) is a unique two-semester capstone sequence that challenges teams of students to develop and implement practical solutions to real problems.

Finally, **BIOENG 1085** is used both as a vehicle for communication between the department and students and to provide diverse perspectives on the professional practice of bioengineering.

Bioengineering Tracks (6 Courses)

While the Bioengineering Core was designed to provide students with exposure to the basic engineering disciplines that bioengineers use in preparation for being a functional member of a multidisciplinary team working to creatively solve biomedical problems, the Bioengineering Tracks offer students an opportunity to focus in greater depth on an area of bioengineering practice relevant to their interests. Students are encouraged to design their own curriculum, within the constraints of the track, to prepare them for their post-graduate goals. The department offers four tracks: **Bioimaging and Signals** | **Biomechanics** | **Cellular Engineering** | **Medical Product Engineering**.

Each track consists of six courses split between track requirements and track electives (for track specific details refer to the **Bioengineering Tracks** section). Track requirements are courses that the Track Coordinator and associated track faculty deem essential knowledge for professional practice in the track. Track electives (drawn from a restricted list of courses) offer an opportunity either to explore the track broadly or to focus more narrowly in an area of interest to the student.

As part of planning for post-graduate goals and the advising process, all students are required to develop a comprehensive electives plan (CEP) that details how their choices of track electives and advanced engineering/science/technical electives will help them achieve their individual goals.

Note. Because of the large number of bioengineering students interested in careers in the health sciences (medical doctor, osteopathic doctor, nurse practitioner, physical therapist) post-graduation, **CHEM 0310** (3 credits): Organic Chemistry 1 and **CHEM 0320** (3 credits): Organic Chemistry 2 are accepted track electives in all tracks.

Note. CHEM 0320 (3 credits): Organic Chemistry 2 is a prerequisite for **BIOENG 1620** (3 credits): Introduction to Tissue Engineering and **BIOENG 1810** (3 credits): Biomaterials and Biocompatibility. Students who want to take those courses need to take the **CHEM 0310/CHEM 0320** sequence prior to doing so.

Note. Particular minors (see **Chapter 4** > **Minors and Certificates**) are easier to obtain through specific tracks. The key to obtaining a minor that will aid the student in fulfilling post-graduate goals is to start planning early.

Required Advanced Engineering/Science/Technical (2 Courses)

Students are required to take two advanced engineering/science/technical elective courses, as developed in their comprehensive electives plan (CEP), that complement their Bioengineering Track electives and will help them meet their post-graduate goals.

Advanced engineering/science/technical elective means that if the student has already taken a course in a discipline, the advanced engineering/science/technical elective must be at a more advanced level (depth), i.e., not a course that is a prerequisite for a course already taken or cover a different aspect of the discipline (breadth).

Note. Other departments offer courses that substantially duplicate content in some BIOENG courses (which focus on engineering applications in biology, physiology, and medicine). Known courses under this prohibition that students cannot use for an advanced engineering/science/technical elective include:

- **ECE/COE 0031** & **MEMS 0031** (duplicates **BIOENG 1310**)
- **ENGR 0145** (duplicates **BIOENG 1630**)
- **ENGR 1010** (duplicates **BIOENG 1002** & **BIOENG 1150**)
- **MEMS 0051** (duplicates **BIOENG 1210**)
- **MEMS 1014** (duplicates **BIOENG 1255**)
- **ECE/COE 1552** (duplicates **BIOENG 1320**)

Note. Students **may not** use any natural science course (ASTRON, BIOSC, CHEM, GEOL, NROSCI, PHYS) with a course number less than 0100 or described as “for students not majoring in the physical sciences” to satisfy an advanced engineering/science/technical requirement.

Note. Students may use an ENGR study abroad experience, such as the Plus3 program, either as an advanced engineering/science/technical elective or as a HUM/SS elective. **If students are planning on using an ENGR study abroad experience as a HUM/SS elective, they must inform the Bioengineering Associate Chair for Undergraduate Education before partaking in the course.**

Note. Students who successfully complete **three** co-op rotations can also apply that experience to satisfy one of the advanced engineering/science/technical electives; students in the Medical Product Engineering (MPE) track can use **three** co-op rotations to satisfy a track elective. Refer to **Chapter 5** > **Cooperative Education** for details.

Note. Duplicate courses, such as **MEMS 0051** or **ENGR 0145**, **cannot** be used in lieu of their BIOENG equivalent to satisfy Bioengineering degree requirements. **All Bioengineering Majors are required to complete Bioengineering Core courses as reflected in the curriculum**. The course equivalency only applies to: (1) fulfilling pre-requisite requirements for non-Bioengineering courses (e.g., for obtaining minors – **ENGR 0145** duplicates **BIOENG 1630** as such Bioengineering Majors are not required to take **ENGR 0145** in order to enroll in **MEMS 1028** which requires **ENGR 0145** as a prerequisite) or (2): in the case of dual-majors (dual-degrees), students may take either the BIOENG version or its equivalent in the other department to fulfill their dual-degree requirements.

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Bioengineering Tracks

The Undergraduate Bioengineering Program offers four tracks that provide a depth component in bioengineering complementary to the breadth of the core curriculum: **Bioimaging and Signals | Biomechanics | Cellular Engineering | Medical Product Engineering**.

Each track consists of 6 courses, required or drawn from a list of suggested courses, that provide a *cohesive, focused,* and *in-depth* area of study within the track. In conjunction with their 2 advanced engineering/science/technical electives, students develop a **Comprehensive Electives Plan** that describes how their choice of track, track courses, and advanced engineering/science/technical electives will help meet their post-graduation goals. Students are strongly encouraged to structure their CEP to obtain a minor or certificate (see **Chapter 4** > **Minors and Certificates** for details) that complements and augments their in-depth study. A minor or certificate distinguishes **students** as individuals who have gone beyond the minimum requirements to get their degree.

All bioengineering students must have a **minimum of 4 engineering courses** (any department) out of the 8 elective courses (6 track courses and 2 advanced engineering/science/technical electives).

Note. Because of the large number of bioengineering students interested in careers in the health sciences (medical doctor, osteopathic doctor, nurse practitioner, physical therapist) post-graduation, **CHEM 0310** (3 credits): Organic Chemistry 1 and **CHEM 0320** (3 credits): Organic Chemistry 2 are accepted track courses in all tracks.

Note. To access a list of Bioengineering Faculty and their respective tracks, please refer to the **Faculty Research Interests** page.

Bioimaging and Signals Track

Track Coordinator. Prof. **Arash Mahboobin**
The Bioimaging and Signals Track is designed for flexibility so that students are able to tailor their degree within the broad fields of biological signal acquisition and processing. Track students pursue coursework in focus areas such as:

- Bioimaging, including sensing, rendering, interpreting biological images, and imaging devices;
- Biological signal processing, modeling, measurement, and analysis;
- Control and dynamic systems; and
- Neural engineering.

The Bioimaging and Signals Track is particularly suitable for students who wish to double major or minor in a related field such as Electrical Engineering, Neuroscience, or Computer Science. With proper planning, students can use their 6 track courses plus 2 advanced engineering/science/technical electives to obtain the minor. **Students must justify in their CEP how selected courses contribute to in-depth study in an area related to Bioimaging and Signals**. Please consult **Chapter 4** > **Minors and Certificates** for further details about getting a minor. Students should talk with the Bioengineering Associate Chair for Undergraduate Education about the possibility of a double major **after** talking with their advisor.

Bioimaging and Signals Track Requirements

All Bioimaging and Signals Track students are **required** to take 6 track courses beyond the core Bioengineering requirements, with **at least one** of them being a **Bioimaging** course and **one** being a **Biological Signal Processing** or **Control and Dynamic Systems** course. Note that these two courses are **in addition** to the required biosignals application and imaging courses that students are required to take as part of their core bioengineering course work. Students are free to choose the remaining 4 track courses from any of the preapproved lists provided below.

Consistent with their CEP, students can choose courses from bioimaging, biological signal processing, control and dynamic systems, neural engineering, etc. Students should identify their Bioimaging and Signals focus area in the CEP and state why selected courses are important for realizing their post-graduation goals.

No prior approval is necessary for a track course chosen from the list of preapproved track courses (see below). Please note that this list is compiled based on track courses taken by students who have previously pursued the Bioimaging and Signals Track. **If students are interested in taking a course that is relevant to Bioimaging and Signals as a part of their CEP that is not listed here, they should seek approval from the Track Coordinator prior to enrolling in the course.**

Note. For courses offered at Carnegie Mellon University (CMU), kindly refer to **CMU Schedule of Classes** webpage.

Bioimaging

Engineering Courses

- **BIOENG 1005** (3 credits): RF (Radiofrequency) Medical Devices
- **BIOENG 1330** (3 credits): Biomedical Imaging
- **BIOENG 1340** (3 credits): Introduction to Medical Imaging and Image Analysis
- **BIOENG 1383** (3 credits): Biomedical Optical Microscopy
- **BIOENG 2505** (3 credits): Multi-Modal Biomedical Imaging Technologies
- **ECE 1390** (3 credits): Introduction to Image Processing/Computer Vision
- Introduction to Biomedical Imaging and Image Analysis (**CMU**)
- (Bio)Medical Image Analysis (**CMU**)

- Bioimage Informatics (**CMU**)
- Optical Image and Radar Processing (**CMU**)
- Image, Video, and Multimedia (**CMU**)
- Introduction to Bioimaging (**CMU**)
- Computer Vision (**CMU**)

Science Courses

- Introduction to Magnetic Resonance Imaging (**CMU**)
- Biological Imaging and Fluorescence Spectroscopy (**CMU**)
- Techniques in Electron Microscopy (**CMU**)
- Magnetic Resonance Imaging in Neuroscience (**CMU**)
- Computer Graphics I (**CMU**)
- Computational Photography (**CMU**)

Biological Signal Processing

Engineering Courses

- **BIOENG 1351** (3 credits): Biosignal Acquisition and Analysis
- **BIOENG 1580** (4 credits): Biomedical Applications of Signal Processing
- **ECE 1472** (3 credits): Analog Communication Systems
- **ECE 1473** (3 credits): Digital Communication Systems
- **ECE 1562** (3 credits): Digital and Analog Filters
- **ECE 1563** (3 credits): Signal Processing Laboratory
- Vision Sensors (**CMU**)

Control and Dynamic Systems

Engineering Courses

- **BIOENG 1255** (4 credits): Dynamic Systems: A Physiological Perspective
- **BIOENG 1680** (4 credits): Biomedical Applications of Control
- **BIOENG 2035** (3 credits): Biomechanical Modeling of Movement
- **BIOENG 2045** (3 credits): Computational Case Studies in Biomedical Engineering
- **MEMS 1045** (3 credits): Automatic Controls
- Gadgetry (**CMU**)

- Introduction to Feedback Control Systems (**CMU**)
- Kinematics, Dynamic Systems and Control (**CMU**)

Neural Engineering

Engineering Courses

- **BIOENG 1586** (3 credits): Quantitative Systems Neuroscience
- **BIOENG 1615** (3 credits): Introduction to Neural Engineering
- **BIOENG 2650** (3 credits): Learning & Control of Movement

Science Courses

- **MATH 1800** (3 credits): Advanced Topics in Mathematics
- **MATH 3370** (3 credits): Mathematical Neuroscience
- **MATH 3375** (3 credits): Computational Neuroscience Methods
- **NROSCI 1000** (3 credits): Introduction to Neuroscience
- **NROSCI 1012** (3 credits): Neurophysiology
- Neural Computation (**CMU**)
- Computational Models of Neural Systems (**CMU**)

Biomechanics Track

Track Coordinator. Prof. Katrina Knight
Biomechanics is the application of mechanical principles to biological systems. The Biomechanics Track curriculum was designed for flexibility so that students are able to tailor their degree into a focus area that is of interest to them. Examples of such areas include cell biomechanics, tissue/organ biomechanics, orthopaedic biomechanics, design, biomaterials, whole-body biomechanics, human factors, rehabilitation biomechanics, motor control and robotics. The Biomechanics Track curriculum is also designed to ensure that the fundamentals of contemporary biomechanics are covered. The goal is to cover the fundamentals in Biomechanics while still allowing flexibility in individual focus.

Students pursuing the Biomechanics Track are encouraged to obtain a minor in Mechanical Engineering, which is a particularly attractive option for students interested in industrial positions post-graduation. With proper planning, Biomechanics students can use their 6 track courses plus 2 advanced engineering/science/technical electives to obtain the minor. Please consult **Chapter 4** > **Minors and Certificates** for further details.

Biomechanics Track Requirements

All Biomechanics Track students are **required** to take:

- **BIOENG 1631** (3 credits): Biomechanics 2 – Introduction to Biodynamics and Biosolid Mechanics;

and at least one of:

- **BIOENG 1632** (3 credits): Biomechanics 3 – Biodynamics of Movement or
- **BIOENG 1633** (3 credits): Biomechanics 4 – Biomechanics of Organs, Tissues, and Cells.

  Note. Both courses, that is, **BIOENG 1632** & **BIOENG 1633**, can be used as track courses. Only one is required.

Students are free to choose the remaining 4 track courses from the preapproved list provided below. Consistent with their CEP, students can choose courses from bioengineering, industrial engineering, mechanical engineering, robotics, math, biomaterials, cell/molecular biology, nursing, etc. Students should identify their Biomechanics focus area in the CEP and state why selected courses are important to helping realize their post-graduate goals.

Preapproved track courses are listed below. Please note that the list is only a sample of courses compiled based on track courses taken by students who have previously pursued the Biomechanics Track. **Students may petition the Track Coordinator to have new courses placed on the list**. Additionally, **if students are interested in taking a course that is relevant to Biomechanics as a part of their CEP that is not listed here, they should seek approval from the Track Coordinator prior to enrolling in the course.**

Preapproved Track Courses

Engineering Courses

- **BIOENG 1351** (3 credits): Biosignal Acquisition and Analysis
- **BIOENG 1810** (3 credits): Biomaterials and Biocompatibility
- **BIOENG 1370** (3 credits): Computational Simulation in Medical Device Design
- **BIOENG 2635** (3 credits): Tribology: Adhesion, Friction, Lubrication, and Wear
- **BIOENG 2650** (3 credits): Learning & Control of Movement
- **ENGR 0022** (3 credits): Materials Structure and Properties
- **IE 1061** (3 credits): Human Factors Engineering
- **MEMS 1015** (3 credits): Rigid-Body Dynamics
- **MEMS 1028** (3 credits): Mechanical Design 1
- **MEMS 1047** (3 credits): Finite Element Analysis
- **ME 2003** (3 credits): Introduction to Continuum Mechanics
- **ME 2045** (3 credits): Linear Control Systems

- **RT 1101** (3 credits): Fundamentals of Rehabilitation & Assistive Technology Applications

Science Courses

- **CHEM 0310** (3 credits): Organic Chemistry 1
- **CHEM 0320** (3 credits): Organic Chemistry 2
- **MATH 1080** (3 credits): Numerical Linear Algebra
- **MATH 1360** (3 credits): Modeling in Applied Math 1
- **NUR 0013** (3 credits): Human Anatomy and Physiology 2
- **REHSCI 1200** (3 credits): Human Anatomy

  Note. REHSCI 1201 (1 credit): Human Anatomy Lab can also be taken concurrently with **REHSCI 1200** as it is a co-requisite for **REHSCI 1200**
- **REHSCI 1220** (2 credits): Kinesiology and Biomechanics **and REHSCI 1221** (1 credit): Kinesiology and Biomechanics Lab
- **HHD 1011** (3 credits): Applied Human Anatomy
- **HRS 1787** (3 credits): Introduction to Orthotics and Prosthetics

  Note. Prior to Fall 2022 semester, **HRS 1787** was offered as **HRS 1701** (2 credits): Introduction to Orthotics and Prosthetics. Students who have completed **HRS 1701** should adhere to the following: **HRS 1701** is a 2-credit course. Since students are required to take 18 credits (6 track courses) to fulfill their track requirements, they should consider registering for an additional course (perhaps another 1, 2, or 3-credit course with prior approval from the Track Coordinator) to cover the deficit. Alternatively, students interested in **HRS 1701** could consider enrolling in the 2-semester sequence **NUR 0012** (3 credits): Human Anatomy and Physiology 1/**NUR 0002** (1 credit): Nursing Anatomy and Physiology Laboratory 1 and **NUR 0013** (3 credits): Human Anatomy and Physiology 2/**NUR 0003** (1 credit): Nursing Anatomy and Physiology Laboratory 2 to meet the track requirements as well as to satisfy the Human Physiology requirement plus an advanced engineering/science/technical elective.

Cellular Engineering Track

Track Coordinator. Prof. Lance Davidson

The Cellular Engineering Track provides students with the opportunity to focus in areas related to cellular, tissue, and organ engineering. The track is designed for students interested in a quantitative understanding of the native biological structure/function at various levels of organization (molecules-cells-tissues-organs) and in leveraging that understanding to manipulate processes and/or engineer artifacts for biomedical applications. Students receive a solid grounding in cell and molecular biology, organic chemistry, biochemistry, tissue engineering, synthetic biology, biomaterials, and biocompatibility with diversification in allied bioscience fields such as immunology, genetics, and microbiology.

Students pursuing the Cellular Engineering Track are encouraged to obtain a minor in Chemistry, which requires only the 2-credit Organic Chemistry laboratory (i.e., CHEM 0345) in addition to the required track courses. Please consult **Chapter 4** > **Minors and Certificates** for further details.

Cellular Engineering Track Requirements

All Cellular Engineering Track students are **required** to take:

- **CHEM 0310** (3 credits): Organic Chemistry 1;
- **CHEM 0320** (3 credits): Organic Chemistry 2;

and a choice of:

- **CHEM 1810** (3 credits): Chemical Biology, or
- **CHEM 1880** (3 credits): Chemical Biology for Engineers, or
- **BIOSC 1000** (3 credits): Introduction to Biochemistry, or
- **BIOSC 1810** (3 credits): Macromolecular Structure and Function.

Students are free to choose the remaining 3 track courses from the preapproved list provided below. Consistent with their CEP, students can choose courses from a list of acceptable electives. Students should state why selected courses are important to helping realize their post-graduate goals.

Preapproved track courses are listed below. **Students may petition the Track Coordinator to have new courses placed on the list**. Additionally, **if students are interested in taking a course that is relevant to Cellular Engineering as a part of their CEP that is not listed here, they should seek approval from the Track Coordinator prior to enrolling in the course.**

Preapproved Track Courses

Engineering Courses

- **BIOENG 1050** (3 credits): Artificial Organs (Lung and Vascular)
- **BIOENG 1051** (3 credits): Artificial Organs 2 (Blood and Heart)
- **BIOENG 1052** (3 credits): Artificial Organs 3 (Kidney and Liver)

  Note. Only one Artificial Organ (AO) course can be used to satisfy a track course. Students in the Cellular Engineering Track are welcome to enroll in more than one AO course, however, the second (or third) AO course can only be used to satisfy an advanced engineering/science/technical elective.
- **BIOENG 1075** (3 credits): Introduction to Cell and Molecular Biology Laboratory Techniques
- **BIOENG 1218** (3 credits): Emerging Biomedical Technologies (Honors)

- **BIOENG 1351** (3 credits): Biosignal Acquisition and Analysis
- **BIOENG 1533** (3 credits): Controlled Drug Delivery
- **BIOENG 1615** (3 credits): Introduction to Neural Engineering
- **BIOENG 1620** (3 credits): Introduction to Tissue Engineering
- **BIOENG 1633** (3 credits): Biomechanics 4 – Biomechanics of Organs, Tissues, and Cells
- **BIOENG 1810** (3 credits): Biomaterials and Biocompatibility
- **BIOENG 2820** (3 credits): Synthetic Biology – Engineering Living Systems

Science Courses

- **BIOENG 2520** (6 credits): Molecular Cell Biology and Biophysics
  Note. This course counts as two electives
- **BIOSC 0350** (3 credits): Genetics
- **BIOSC 0355** (3 credits): Genetics (Honors)
- **BIOSC 1760** (3 credits): Immunology
- **BIOSC 1850** (3 credits): Microbiology
- **NROSCI 1000** (3 credits): Introduction to Neuroscience
- **NROSCI 1012** (3 credits): Neurophysiology
- **NROSCI 1013** (4 credits): Functional Neuroanatomy (UHC)
- **NROSCI 1017** (3 credits): Synaptic Transmission

Medical Product Engineering Track

Track Coordinator. Prof. **Mark Gartner**
Students choosing the Medical Product Engineering (MPE) Track leverage the medical product design process to identify unmet clinical needs and develop products that contribute to human health and welfare. This process is based on key elements of the FDA Quality System Regulation with particular focus on the Design Controls. Facets of this process include ethnography and customer discovery, design conceptualization, hazard and risk analysis, prototyping and fabrication, identification of appropriate regulatory and reimbursement pathways, and formulation of appropriate qualification testing. In addition, the MPE Track requires student exposure to other elements unique to the medical product design process including clinician, patient, and caregiver interaction, economic considerations, and use of computer-aided design and simulation tools. The MPE Track provides students an option to pursue a *technical* or *business focus* via customization of an individual student curriculum that aligns with their post-graduation plans. For example, the MPE *business focus* provides expanded exposure to business model discovery techniques, facets of business management unique to the development of medical products, and an understanding of the marketing and management of medical products.

With proper planning, MPE Track students can structure their CEP to earn a minor in Mechanical Engineering, a minor in Industrial Engineering, a Certificate in Product Realization, or a Certificate in Engineering for Humanity. Please consult **Chapter 4** > **Minors and Certificates** for further details.

Medical Product Engineering Track Requirements

All MPE Track students are **required** to take:

- **MEMS 0024** (3 credits): Introduction to Mechanical Engineering Design; or
- **IE 1051** (3 credits): Engineering Product Design; or
- **BIOENG 1024** (3 credits): Medical Product Design

  Note. The combination of **BIOENG 1024 and BIOENG 0050** (1 credit): Introduction to SolidWorks is a possible alternative to **MEMS 0024** for Bioengineering students that wish to obtain a Mechanical Engineering Minor.

and a choice of:

- **BUSERV 1985** (3 credits): Small Business Management, or
- **BUSMKT 1431** (3 credits): Product Development and Management, or
- **BUSSPP 1750** (3 credits): Commercializing New Technologies.

Students are free to choose the remaining 4 track courses from the preapproved list provided below. Consistent with their CEP, students can choose courses from a list of acceptable electives that provide options to achieve an MPE technical or business focus. Students should state why selected courses are important to helping realize their post-graduate goals.

Preapproved track courses are listed below. **Students may petition the Track Coordinator to have new courses placed on the list**. Additionally, **if students are interested in taking a course that is relevant to Medical Product Design as a part of their CEP that is not listed here, they should seek approval from the Track Coordinator prior to enrolling in the course.**

Preapproved Track Courses

MPE Business Focus Courses

- **BUSENV 1785** (3 credits): Social Entrepreneurship
- **BIOENG 2150** (3 credits): Medical Product Ideation
- **BIOENG 2165** (3 credits): Medical Product Entrepreneurship
- **BIOENG 2166** (3 credits): Managing Medical Product R&D
- **IE 1040** (3 credits): Engineering Economic Analysis

- **IE 1080** (3 credits): Supply chain analysis
- **ENGR 1060** (3 credits): Social Entrepreneurship – Engineering for Humanity
- **ENGR 1080** (3 credits): Lean Launchpad: Evidence-Based Entrepreneurship
- **ENGR 1090P**: Engineering Cooperative Education (see **Chapter 5** > **Cooperative Education** for details)

MPE Technical Focus Courses

- **BIOENG 1351** (3 credits): Biosignal Acquisition and Analysis
- **BIOENG 1355** (3 credits): Medical Product Regulation and Reimbursement
- **BIOENG 1370** (3 credits): Computational Simulation in Medical Device Design
- **BIOENG 1810** (3 credits): Biomaterials and Biocompatibility
- **BIOENG 2150** (3 credits): Medical Product Ideation
- **BIOENG 2151** (3 credits): Medical Product Development
- **CEE 1618** (3 credits): Design for the Environment
- **ENGR 0022** (3 credits): Materials Structure and Properties
- **ENGR 1050** (3 credits): Product Realization
- **ENGR 1610** (3 credits): Product Realization for Global Opportunities
- **ENGR 1716** (3 credits): The Art of Making – Hands-On System Design and Engineering
- **ENGR 1090P**: Engineering Cooperative Education (see **Chapter 5** > **Cooperative Education** for details)
- **IE 1061** (3 credits): Human Factors Engineering
- **IE 1201** (3 credits): Biomaterials and Biomanufacturing
- **IE 1052** (3 credits): Manufacturing Processes and Analysis
- **IE 1089** (3 credits): Rapid Prototyping Additive Manufacturing
- **MEMS 1028** (3 credits): Mechanical Design 1
- **MEMS 1049** (3 credits): Mechatronics

3

Undergraduate Bioengineering Course Descriptions

BIOENG 0050: Workshop in Bioengineering Design (Fundamentals of SolidWorks)

Credits. 1 (Letter Grade Only).

Semesters Offered. Fall, Spring.

Description. This course provides an opportunity for students to learn computer aided design and engineering techniques and is based on the SolidWorks software suite. SolidWorks is one of several computer aided engineering software packages that is widely used in industry and academia. Though this is a SolidWorks class, the skills students learn are directly transferrable to other computer aided engineering packages. This course has been designed to prepare students for the Certified SolidWorks Associate (CSWA) exam, which is free as part of this class. Taking the CSWA exam is a requirement of this course and represents the final exam.

Prerequisites. Bioengineering students only.

Course Objectives. Upon completing the course, the student should be able to use SolidWorks to develop professional quality engineering drawings and simulations.

Topics Covered

- Sketching and basic modeling skills
- Drawing assembly basics
- Tolerancing
- Engineering drawings
- Modeling and simulation
- Best practices

Schedule. Class meets once a week for 50 minutes.

BIOENG 0051: Workshop in Medical Devices – The Basics

Credits. 1 (Satisfactory/No Credit).

Semesters Offered. Please note that this course is not offered on a regular basis. Please check with the Bioengineering Undergraduate Academic Administrator and/or Associate Chair for Undergraduate Education to inquire about course offering.

Description. *Reverse engineering* of medical devices is used to introduce students to basic terminology in the medical device field, the coupling of design with function, and the processes involved in moving from device conception to product. The course (1) emphasizes the significance of curiosity and information seeking in device development, 2) will help with Bioengineering design projects, and (3) will expand knowledge of devices in general, along with needs assessment. Multiple medical specialties will be covered, along with basic function of devices (diagnostics, treatment, monitoring, etc.). The workshop will use *hands on* learning experiences, focusing on devices that can be taken apart. After discussion of device purpose and function, students will be challenged to identify potential design improvements. Students are expected to be active participants in the seminar.

Prerequisites. Bioengineering students only. Instructor permission required.

Course Objectives. Upon completing the course, the student should be conversant with medical device terminology, be able to state the basic elements involved in needs assessment and be able to identify hurdles in medical device development.

Topics Covered

- Medical device terminology
- Reverse engineering: device function/purpose
- Importance of needs assessment
- Design controls
- Hurdles to medical device development
- Impact of deployment site on medical device development

Schedule. Class meets once a week for 75 minutes. 1-2 visits (field trips) to local medical device companies are expected to be offered (attendance optional), along with guest lectures from company representatives and possible physicians on specific devices and procedures.

BIOENG 0052: Workshop in OpenSim

Credits. 1 (Satisfactory/No Credit).

Semesters Offered. Please note that this course is not offered on a regular basis. Please check with the Bioengineering Undergraduate Academic Administrator and/or Associate Chair for Undergraduate Education to inquire about course offering.

Description. Computational models and simulations are tremendously useful tools for understanding human movement control. It is not always straightforward to identify cause-and-effect relationships through experiments alone and computational modeling and simulation techniques can complement experimental approaches – e.g., models can provide estimates of important variables such as muscle forces that are difficult to measure experimentally.

OpenSim is an open-source software package that enables users to build, exchange, and analyze computer models of the musculoskeletal system and dynamic simulations of movement (Delp et al., 2007). The purpose of this course is to introduce students to OpenSim by demonstrating the utility of graphics-based modeling and simulation. Specifically, students will learn how to use OpenSim tools, through both the graphical user interface (GUI) and Application Programming Interface (API) that uses MATLAB scripting, to analyze and simulate models and motions.

The course consists of weekly practice assignments that must be completed to receive a satisfactory (S) grade.

Prerequisites. Bioengineering students only. Instructor permission required.

Course Objectives. Upon completing the course, the student should be able to use OpenSim to analyze and develop forward dynamic simulations of movement.

Topics Covered

- Data preparation for use in OpenSim
- Model scaling
- Inverse kinematics
- Inverse dynamics
- Static optimization (an extension to inverse dynamics)
- Computed muscle control (muscle-driven forward simulations of motion)

Schedule. Class meets once a week for 50 to 75 minutes.

BIOENG 0053: Workshop in Statistical Design of Experiments

Credits. 1 (Satisfactory/No Credit).

Semesters Offered. Please note that this course is not offered on a regular basis. Please check with the Bioengineering Undergraduate Academic Administrator and/or Associate Chair for Undergraduate Education to inquire about course offering.

Description. Engineers use experiments for a variety of reasons, some of which are: determine whether one treatment is better than an alternative; determine parameters in a descriptive model; and determine accurate physical properties of a material. Simply put, experiments take time and can be expensive. Statistical design of experiments (DOE) is a tool to maximize the amount of relevant information gained while minimizing the amount of experimentation required to obtain that information. After discussion of general experimental design principles, Design-Ease® software is used to introduce students to DOE through a series of workshops that highlight the importance of DOE in engineering practice. The course consists of weekly practice assignments that must be completed to receive a satisfactory (S) grade.

Prerequisites. BIOENG 1000 or **ENGR 0020** or **ENGR 0021**. Bioengineering students only. Instructor permission required.

Course Objectives. Upon completing the course, the student should be able to design an experiment using statistical design of experiment principles to maximize knowledge gained from the experiment.

Topics Covered

- Randomization / completely randomized designs
- Data display
- Analysis of variance
- Factorial design
- Hurdles to medical device development
- Power analysis / sample size
- Response surface design

Schedule. Class meets once a week for 75 minutes.

BIOENG 0054: Workshop in Design for Manufacturability

Credits. 1 (Satisfactory/No Credit).

Semesters Offered. Please note that this course is not offered on a regular basis. Please check with the Bioengineering Undergraduate Academic Administrator and/or Associate Chair for Undergraduate Education to inquire about course offering.

Description. Design for Manufacturability (DFM) provides a systematic methodology that can be used to analyze product design for improvements in assembly and manufacturing. Students will use DFM to redesign current products for changes in manufacture that lead to reduction in production cost and improved operability/customer satisfaction. Students will employ modern software tools that accurately model parts for specific manufacturing operations, model part costs, simplify products, find specific avenues to reduce manufacturing and assembly costs, benchmark products, and quantify improvements.

Prerequisites. (**BIOENG 0050** and **BIOENG 1024**) or **MEMS 0024**. Bioengineering students only. Instructor permission required.

Course Objectives. Students will gain hands-on experience incorporating the DFM concepts in a project. Upon completing the course, the students should be able to describe the utility of DFM in product development and early manufacturing design, be able to quantitatively evaluate the impact of design choices on manufacturing cost and be able to use modern quality control concepts and approaches.

Topics Covered

- Steps for applying DFM during product design
- DFM guidelines for assembly
- Strategies in component(s) design
- Designing for automation
- Designing in quality/reliability
- Standardization
- Designing in teams
- Early resolution of issues
- Optimizing vendor participation
- Off-the-shelf parts
- Modular design
- Product definition
- Creativity
- Brainstorming

- Total cost
- Modern philosophies and practices
    - Lean Manufacturing
    - Quality control in Manufacturing Systems
    - Use of Software Tools for Analysis of Manufacturing Cost and Time
- Evaluation of alternatives

Schedule. Class meets once a week for 60 minutes.

BIOENG 1000: Statistics for Bioengineering

Credits. 4 (Letter Grade Only).

Semesters Offered. Fall, Spring.

Description. Bioengineering statistics presents the basic statistical methods relevant to engineering and clinical applications. Specifically, assumptions inherent in statistical analyses, calculation of statistical parameters, automated statistical methods using software, interpretation of the meaning of statistical parameters, and design of experiments conducive to proper statistics are explored through use of biological and medical examples that reinforce concepts of the course.

Prerequisites. **MATH 0230** or **MATH 0235** (or equivalent). Bioengineering students only.

Course Objectives. Upon completing the course, the student will be able to design an experiment using statistical design of experiments principles to maximize knowledge gained from the experiment and interpret results from statistical analysis of the design.

Topics Covered

- Randomization/completely randomized designs
- Analysis of variance
- Probability and the binomial distribution
- Statistical tests based on the normal distribution
- Non-parametric tests
- Power analysis/sample size

Schedule. Class meets twice a week for 75 minutes, laboratory once a week for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (6).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics.

BIOENG 1002: Intramural Internship

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall, Spring.

Description. Students employ practical experience, gained from mentored research in an academic environment, that includes project planning, design of experiments, and analysis of results to develop professional quality oral presentation and abstract writing skills. Emphasis is placed on critical analysis of research projects, development of technical abstract writing skills, and development of professional quality visual aids that accompany oral presentations. The course culminates with an oral presentation at a technical symposium.

Prerequisites. **BIOENG 1000** or **ENGR 0020** or **ENGR 0021**. Bioengineering students only. Instructor permission required.

Course Objectives. Upon completing the course, the student should be able to prepare a professional quality abstract documenting background, methodology, and results from a research project and make a professional quality oral presentation describing the research.

Topics Covered

- Library Skills
- Project planning
- Oral project overview
- Literature report
- Preliminary project presentation
- Oral interview presentation
- Formal oral presentation
- Technical report (abstract)

Schedule. Class meets twice a week for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (3) and (6).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics.

Important Information

- Students must file a **BIOENG 1002 Application** to receive instructor permission for enrollment
- Students must have **junior** or **senior** standing in Bioengineering
- Mentored research can be with any faculty member listed on the Bioengineering website, any faculty member in the Pittsburgh area (e.g., CMU, Duquesne, Allegheny General) performing bioengineering research, or programs outside of Pittsburgh sponsored by the Department of Bioengineering
- Students are encouraged to contact (e-mail) faculty mentors about volunteering in their laboratory, **but** let the mentor know the research would be for BIOENG 1002
- BIOENG 1002 credit is given for mastering the skills associated with oral presentation of research and abstract writing of research, not for the research itself. As such, students can either volunteer or be paid (at the mentor's discretion) for research performed in order to take the course
- Students **must start in the laboratory the semester prior** to taking the class. Preferably, the project should also start the semester before taking the class

BIOENG 1005: RF (Radiofrequency) Medical Devices and Applications of Electromagnetics in Medicine

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. The course will cover topics related to the applications of electromagnetics and RF in medicine and in other devices that can cause thermal safety hazards. Topics such as Maxwell Equations, Wave Equations, Transmission Lines, Electromagnetic Theorems, Introduction to Antennas, and Introduction to Computational Electromagnetics will be presented. The class will include analyses of several RF devices used in medical applications and/or have electromagnetic safety implications such as magnetic resonance imaging (MRI), biological sensors (brain machine interface), RF ablation, and cell phones.

The course will include a computer project and a lab that involves RF antennas used in MRI and an imaging experiment using the 7 Tesla Human MRI System at University of Pittsburgh.

Prerequisites. **BIOENG 1310** (or equivalent).

Course Objectives. Upon completing the course, the student should be able to describe how to apply fundamental electromagnetic principles to set up and solve problems in RF devices used in medical applications.

Topics Covered

- Introduction – Faraday's Law
- Full Maxwell Eqns.
- Wave Eqn. and solutions (time domain)
- Plane waves and Polarization
- Lossy media
- Poynting vector
- Introduction to transmission lines and their types
- Smith chart
- Electromagnetic theorems
- Vectors, vector functions, gradient, divergence, curl
- Coulomb's Law, Gauss's Law, Ampere's Law, Biot-Savart Law, Ohm's Law
- Laplace and Possion equations
- Conductors, dielectrics
- Permeability, magnetic materials

- Boundary conditions
- Thermal effects of antennas in cell phones
- Thermal effects of antennas in implanted devices (MRI and biological sensors)
- Introduction to computational electromagnetics
- MRI Applications
- Electromagnetics in MRI
- MRI RF Coils/antennas
- Superconducting wires for MRI scanners

Schedule. Class meets twice a week for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (5), (6), and (7).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1024: Medical Product Design

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall, Spring.

Description. This course has been designed to provide an opportunity to learn hands-on skills used in medical product design. Course content will include instruction on sketching (pencil and paper-based), low- and medium-resolution prototyping (e.g., foam core and 3D printing), and other related topics such as ethnography and material and adhesive specification. An individual project is used as the basis to apply and extend the skills presented in class. A secondary goal of this course is to prepare students to implement some of these practices during Senior Design.

Prerequisites. **ENGR 0011** or **ENGR 0015** or **ENGR 0711** or **ET 0011**. Students must file a **BIOENG 1024 Application** to receive instructor permission for enrollment.

Course Objectives. Upon completing the course, the student should be able to leverage ethnographic skills, basic sketching and low- and medium-resolution prototyping to quickly and effectively develop a physical model of a proposed solution to a clinical problem. The student will also be able to evaluate what materials, adhesives, and ultimate manufacturing methodologies that may be suitable for actual clinical product. Finally, an understanding of the design process and, in particular, design output such as dimensioned and toleranced drawings will be discussed.

Topics Covered

- Introduction to sketching
- Foam core-based prototyping
- Human factor analysis and ethnography
- Medical product design process
- FDA Quality System Regulation and Design Controls
- Medical plastics
- Dimensioning and tolerancing

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (3), and (4).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1050: Artificial Organs (Lung and Vascular)

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall (every other year).

Description. Artificial Organs is the first of a three-course sequence that explores design, development, and clinical use of artificial organ technology. Each course in the series is stand-alone and, as such, is not a prerequisite for any other course in the series. Students may take one, two, or all three courses.

Artificial Organs is directed toward *artificial lung* and *vascular prostheses*. The basic physiology of each system (lung and vascular) is reviewed with emphasis on identifying the bioengineering design requirements for appropriate organ replacement systems. Commercially available systems are analyzed from the point of view (where applicable) of mass transfer efficiency; biomechanic and hemodynamic similarity to the host; and size and efficiency of the device. Students will be required to design an artificial organ consistent with the above-mentioned considerations.

Prerequisites. BIOENG 1220 (or equivalent).

Course Objectives. Upon completing the course, the student should be able to describe the fundamental engineering principles related to lung and vascular physiology and apply the fundamental principles to design improvements and/or new designs for artificial lung and vascular prostheses.

Topics Covered

- Lung physiology
- Extracorporeal membrane oxygenators
- Extracorporeal CO2 removal
- Implantable artificial lung
- Vascular anatomy
- Vascular pathology
- Vascular replacement (natural/synthetic)

Schedule. Class meets twice a week for 75 minutes each time or once a week for 2.5 hours. Clinical field trips may be scheduled during the first part of the term.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1) and (4).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1051: Artificial Organs 2 (Blood and Heart)

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall (every other year).

Description. Artificial Organs 2 is the second of a three-course sequence that explores design, development, and clinical use of artificial organ technology. Each course in the series is stand-alone and, as such, is not a prerequisite for any other course in the series. Students may take one, two, or all three courses.

Artificial Organs 2 is focused on *artificial blood* and *artificial heart*. The basic physiology of each system (blood and heart) is reviewed with emphasis on identifying the bioengineering design requirements for appropriate organ replacement systems. Commercially available systems are analyzed from the point of view (where applicable) of mass transfer efficiency; biomechanic and hemodynamic similarity to the host; and size and efficiency of the device. Students will be required to design an artificial organ consistent with the above-mentioned considerations.

Prerequisites. BIOENG 1220 (or equivalent).

Course Objectives. Upon completing the course, the student should be able to describe the fundamental engineering principles related to blood and cardiac physiology and apply the fundamental principles to design improvements and/or new designs for artificial blood substitutes and artificial heart devices.

Topics Covered

- Artificial blood substitutes
    - blood hematologic and rheologic properties
    - perfluorocarbon fluids
    - cross-linked hemoglobin fluids
- Artificial heart
    - circulatory physiology
    - cardiac hemodynamics
    - intra-aortic blood pump
    - total artificial heart
    - ventricular assist devices for adult and pediatric patients

Schedule. Class meets twice a week for 75 minutes each time or once a week for 2.5 hours. Clinical field trips may be scheduled during the term.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1) and (4).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1052: Artificial Organs 3 (Kidney and Liver)

Credits. 3 (Letter Grade Only).

Semesters Offered. Please note that this course is not offered on a regular basis. Please check with the Bioengineering Undergraduate Academic Administrator and/or Associate Chair for Undergraduate Education to inquire about course offering.

Description. Artificial Organs 3 is the third of a three-course sequence that explores design, development, and clinical use of artificial organ technology. Each course in the series is stand-alone and, as such, is not a prerequisite for any other course in the series. Students may take one, two, or all three courses.

Artificial Organs 3 is focused upon *artificial kidney* and *artificial liver*. The basic physiology of each system (kidney and liver) is reviewed with emphasis on identifying the bioengineering design requirements for appropriate organ replacement systems. Commercially available systems are analyzed from the point of view (where applicable) of mass transfer efficiency; biomechanic and hemodynamic similarity to the host; and size and efficiency of the device. Students will be required to design an artificial organ consistent with the above-mentioned considerations.

Prerequisites. **BIOENG 1220** (or equivalent).

Course Objectives. Upon completing the course, the student should be able to describe the fundamental engineering principles related to kidney and liver physiology and apply the fundamental principles to design improvements and/or new designs for artificial kidney and artificial liver.

Topics Covered

- Artificial kidney
  - hemodialysis
  - hemofiltration
- Artificial liver
  - blood detoxification
  - bioartificial (cell-based) liver support systems

Schedule. Class meets twice a week for 75 minutes each time or once a week for 2.5 hours. Field trips may include a visit to a dialysis center.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1) and (4).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1070: Introductory Cell Biology 1

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. Principles of cell biology in higher organisms: structure, function, biosynthesis, and macromolecular organization with a focus on macromolecular organization and function from a quantitative systems perspective.

Prerequisites. Bioengineering Sophomore or Department permission.

Course Objectives. Upon completing the two-course sequence, BIOENG 1070 and 1071, students should be able to (1) demonstrate understanding of the principles of cell structure and function, (2) describe the experimental tools used to understand cellular function such as molecular genetic techniques, biochemical analysis, and microscopy, and (3) use systems approaches to understand how cellular processes are integrated.

Topics Covered

- Structure and function of cellular organelles
- Properties of biomolecules; cellular membrane and transport
- Cell metabolism and energetics
- Genetics and principles of genetic engineering
- Protein synthesis and sorting

Schedule. Class meets twice a week for 75 minutes each day. Recitation meets once a week for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (6), and (7).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics.

BIOENG 1071: Introductory Cell Biology 2

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. Continuation of BIOENG 1070. Principles of cell biology in higher organisms: structure, function, biosynthesis, and macromolecular organization with a focus on macromolecular organization and function from a quantitative systems perspective.

Prerequisites. BIOENG 1070.

Course Objectives. Upon completing the two-course sequence, BIOENG 1070 and 1071, students should be able to (1) demonstrate understanding of the principles of cell structure and function, (2) describe the experimental tools used to understand cellular function such as molecular genetic techniques, biochemical analysis, and microscopy, and (3) use systems approaches to understand how cellular processes are integrated.

Topics Covered

- Cell motility
- Signal transduction
- Cell-cell and cell-matrix adhesion
- Extracellular matrix
- Examples of cell biology will be explored in depth where multiple cellular processes are functionally integrated such as the case of stem cell biology, immunology, and vasculogenesis

Schedule. Class meets three times a week for 50 minutes each day. Recitation meets once a week for 50 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (6), and (7).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics.

BIOENG 1072: Honors Introductory Cell Biology 2

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring, however, please note that this course is not offered on a regular basis. Please check with the Bioengineering Undergraduate Academic Administrator and/or Associate Chair for Undergraduate Education to inquire about course offering.

Description. Continuation of **BIOENG 1070**. Principles of cell biology in higher organisms: structure, function, biosynthesis, and macromolecular organization with a focus on macromolecular organization and function from a quantitative systems perspective. In addition to the materials covered in **BIOENG 1071**, **BIOENG 1072** is accompanied by a weekly one-hour seminar in which original research articles pertinent to cell biology are presented and discussed.

Prerequisites. BIOENG 1070 and 3.25 GPA or instructor permission.

Course Objectives. Upon completing the two-course sequence, BIOENG 1070 and 1072, students should be able to (1) demonstrate understanding of the principles of cell structure and function, (2) describe the experimental tools used to understand cellular function such as molecular genetic techniques, biochemical analysis, and microscopy, and (3) use systems approaches to understand how cellular processes are integrated.

Topics Covered

- Cell motility
- Signal transduction
- Cell-cell and cell-matrix adhesion
- Extracellular matrix
- Examples of cell biology will be explored in depth where multiple cellular processes are functionally integrated such as the case of stem cell biology, immunology, and vasculogenesis

Schedule. Class meets three times a week for 50 minutes each day. Recitation meets once a week for 50 minutes. Seminar meets once a week for 50 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (6), and (7).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics.

BIOENG 1075: Introduction to Cell and Molecular Biology Laboratory Techniques

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. An undergraduate laboratory course designed to complement theoretical knowledge learned in **BIOENG 1070** & **BIOENG 1071**. The course, which includes a didactic component, provide students with hands-on experience with cell culture, cellular response to biomaterials, visualization of cellular components, image analysis, fundamental protein-related techniques (isolation, purification and analyses), fundamental molecular biology techniques, and functional measurements in cells.

Prerequisites. BIOENG 1070.

Course Objectives. Upon completing the course, the student will have acquired "hands-on" skills in basic techniques in cell biology, biochemistry and molecular biology and be able to apply them in practice.

Topics Covered

- Cell culture techniques
- Cell proliferation assay
- Light microscopy (phase and fluorescence)
- Protein extraction/SDS-PAGE/western blot
- Bacterial expression and purification of protein
- Plasmid purification
- PCR
- Fundamentals of cloning

Schedule. Lecture meets once per week for two hours; laboratory meets once per week for three hours.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (4), (6), and (7).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; **and** Measure/Interpret Data on Living Systems.

BIOENG 1085: Introduction to Bioengineering Seminar

Credits. 0 (Satisfactory/Unsatisfactory).

Semesters Offered. Fall, Spring.

Description. Seminar is designed to acquaint students with aspects of bioengineering that are not normally encountered in the classroom or extracurricular activity settings. As such, Seminar is a vehicle to provide important information and communicate materials that students need to know to maximize their educational experience and develop post-graduation plans. Emphasis is placed on career planning and development and options available in the undergraduate program that will help realize post-graduation goals. Bioengineering students are required to register for, and satisfactorily complete, **BIOENG 1085** six times.

Prerequisites. Bioengineering students only.

Course Objectives. Student awareness of opportunities that are available and knowledge about how to utilize the opportunities for their benefit.

Topics Covered (not exhaustive)

- Options available in the Bioengineering program (track area, faculty research, degree progress/planning)
- Options available through the Swanson School of Engineering (study abroad, co-op, minors)
- Options available through the University (study abroad, dual majors, career services, preprofessional health services)
- Career paths for engineers (industry, graduate school, medical school, law school)

Schedule. Class meets once a week for 50 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (4) and (7).

BIOENG 1086: Bioengineering Seminar for Minors

Credits. 0 (Satisfactory/Unsatisfactory).

Semesters Offered. Fall, Spring.

Description. Selected, bioengineering-related topics are presented in a one-hour lecture format by members of the bioengineering community of both the University of Pittsburgh and other institutions.

Prerequisites. Undergraduates in other departments obtaining a Minor in Bioengineering.

Course Objectives. Student awareness of opportunities that are available and knowledge about how to utilize the opportunities for their benefit.

Topics Covered (not exhaustive)

- Bioengineering-related topics
- Career paths for engineers (industry, graduate school, medical school, law school)

Schedule. Class meets once a week for 50 minutes.

BIOENG 1095: Special Projects

Credits. 1 to 6 (Letter Grade Only).

Semesters Offered. Fall, Spring, Summer.

Description. Special Projects provides an opportunity for students to develop an individual research project under the guidance of a faculty member/mentor. Projects can involve laboratory research, engineering design, or instructional development. While the project must be related to bioengineering, the mentor can be a faculty member in any department or hospital affiliated with the University of Pittsburgh.

Prerequisites. A **BIOENG 1095 Application** must be completed and approved prior to registration for **BIOENG 1095**.

Restrictions

- Students **cannot** be paid to perform any project work conducted for **BIOENG 1095** credit
- Bioengineering students can register for **at most** two credits of **BIOENG 1095** prior to completing **BIOENG 1002**: Intramural Internship
- Bioengineering students can use **only one 3-credit BIOENG 1095** to satisfy degree requirements

Additional Description. A written report documenting the project and project outcomes is required. Typical report format (abstract, introduction, methods, results, discussion, references) is expected. The length of the report should reflect the number of credits received. The report must be submitted to both the Bioengineering Associate Chair for Undergraduate Education and the mentor. The mentor will evaluate the quality of the project and report and submit a letter grade recommendation to the Bioengineering Associate Chair for Undergraduate Education.

ABET Student Outcomes (see ABET Student Outcomes section for details). (3) and (6).

BIOENG 1096: Undergraduate Teaching Experience

Credits. 1 or 2 (Satisfactory/No Credit).

Semesters Offered. Fall, Spring.

Description. Undergraduate Teaching Experience provides students an opportunity to volunteer as an Undergraduate Teaching Assistant (TA) or Grader. Undergraduates can participate in helping develop and deliver lecture content, managing recitations or laboratories, developing and/or grading quizzes, evaluating homework, and general review of course materials.

Prerequisites. A **BIOENG 1096 Application** must be completed and approved prior to registration for **BIOENG 1096**.

Restrictions

- Students registered for **BIOENG 1096 cannot** be paid for work associated with the teaching experience
- Faculty are generally responsible for recruiting undergraduate TAs for their course
- Students are encouraged to contact faculty if they have a particular interest in serving as a TA for a course

BIOENG 1150: Bioengineering Methods & Applications

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. Bioengineering Methods & Applications uses laboratory experiences to illustrate principles taught in several bioengineering core classes, such as:

- **BIOENG 1070** & **BIOENG 1071**: Cell Biology
- **BIOENG 1210**: Bioengineering Thermodynamics
- **BIOENG 1220**: Biotransport Phenomena
- **BIOENG 1310**: Signals and Systems (Bioinstrumentation)
- **BIOENG 1630**: Biomechanics 1 - Mechanical Principles of Biological Systems

which are pre- or co-requisites for taking **BIOENG 1150**.

In addition to being exposed to particular laboratory skills for each of the experimental modules in the course, students are expected to practice previously developed skills in technical writing, creating tables and graphs, data analysis, and statistics to create professional quality laboratory reports that document each module.

Corequisites. **BIOENG 1071** or **BIOENG 1072** and **BIOENG 1220** and **BIOENG 1310** and **BIOENG 1320** and **BIOENG 1630**.

Course Objectives. Upon completing the course, the student should be able to state and describe the basic components of a laboratory report and create well-written archival documents that reflect professional quality work.

Laboratory topics may include

- Biorheology (Biotransport)
- Surface Tension (Biothermodynamics)
- Electrochemistry (Biothermodynamics)
- Exercise Physiology (Biothermodynamics)
- Ligaments (Biomechanics)
- Motion Analysis – Balance (Biomechanics)
- Motion Analysis – Gait (Biomechanics)
- Signal Acquisition (Biological Signals)
- Light Microscopy (Cell Biology)
- Tribology (Biomechanics)

- RF Imaging (Biological Signals)

Schedule. Class meets once a week for 75 minutes; laboratory once a week for 3 hours.

ABET Student Outcomes (see ABET Student Outcomes section for details). (3), (5), and (6).

Bioengineering Program Criteria. Measure/Interpret Data on Living Systems.

BIOENG 1160: Bioengineering Design 1

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. Bioengineering Design 1 & 2 provides an opportunity for students to extend skills and knowledge acquired during undergraduate education to the design (or redesign) of a medical product. Students are introduced to key facets of the medical product design process and develop an understanding of unique regulatory and reimbursement requirements. Student teams identify unmet clinical needs as the basis for a design project as part of a several week ethnography effort. A range of client, clinical, and technical mentors serve as advisors to the student teams. Verification and validation plan and testing protocols guide student teams during evaluation and iterative refinement activities in the second semester (BIOENG 1161). The student teams formulate a comprehensive design history file that establishes criteria by which success of the team's prototyping efforts will be evaluated during both the first and the second semester. The first semester culminates with student presentation of their product prototype at the Swanson Design Expo.

Prerequisites. Bioengineering Seniors only.

Course Objectives. Students will be able to apply appropriate design-related procedures and tools, formulate and maintain design history documents, conduct preliminary market and reimbursement studies, and address regulatory requirements for a medical product.

Topics Covered

- Leveraging state-of-the-art design tools such as computer aided engineering (SolidWorks), finite element analysis and computational fluid mechanics (SolidWorks Simulation and Flow Simulation), and data interfacing and control (LabVIEW)
- Developing the student's ability to synthesize and apply engineering and scientific principles to solution of real-world problems
- An introduction to unique requirements medical product design process
- An introduction to assessment/prediction component and product reliability
- Construction of verification and validation plans including leveraging statistical design of experiments (DOX) techniques (DesignExpert)
- Developing the student's ability to effectively document and communicate throughout the product design process – both orally and in writing
- Introduction to relevant business model discovery and accounting, finance (e.g., the time value of money), and marketing principles including use of the Osterwalder business model canvas to evaluate product-market fit
- Introduction to the fabrication and mass-production techniques used in the medical product industry

- Developing an ability to identify an unmet clinical need using ethnographic techniques

Schedule. Class meets once a week for 3 hours.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (2), (3), (4), (5), and (7).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1161: Bioengineering Design 2

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. Student teams continue execution of their team-based design projects with a focus on verification and, in particular, validation activities. The second semester culminates with each student team submitting their work to one or more design competitions and conferences and giving oral and poster presentations at School and Department sponsored events. Final team evaluation is based on the thoughtfulness and thoroughness of the completed project and final design history file submission (evaluated, within reason, consisting with FDA's Quality System Inspection Technique).

Prerequisites. BIOENG 1160.

Course Objectives. Students will be able to apply appropriate product design-related procedures and tools, maintain design history files, conduct preliminary market/reimbursement studies, and address regulatory affairs in developing a prototype biomedical product or equivalent.

Topics Covered

- Leveraging state-of-the-art design tools such as computer aided engineering (SolidWorks), finite element analysis and computational fluid mechanics (SolidWorks Simulation and Flow Simulation), and data interfacing and control (LabVIEW)
- Developing the student's ability to synthesize and apply engineering and scientific principles to solution of real-world problems
- An introduction to unique requirements medical product design process
- An introduction to assessment/prediction component and product reliability
- Construction of verification and validation plans including leveraging statistical design of experiments (DOX) techniques (DesignExpert)
- Developing the student's ability to effectively document and communicate throughout the product design process – both orally and in writing
- Introduction to relevant business model discovery and accounting, finance (e.g., the time value of money), and marketing principles including use of the Osterwalder business model canvas to evaluate product-market fit
- Introduction to the fabrication and mass-production techniques used in the medical product industry
- Developing an ability to identify an unmet clinical need using ethnographic techniques

Schedule. Class meets once a week for 3 hours.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (2), (3), (4), (5), (6), and (7).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; Bio/Biomedical Devices, Systems, Parts, & Processes; **and** Measure/Interpret Data on Living Systems.

BIOENG 1210: Bioengineering Thermodynamics

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall, Spring.

Description. Conservation principles are fundamental and ubiquitous in engineering applications. Biothermodynamics uses an interactive framework to explore the development and use of fundamental methodology in application of conservation principles to describe the flow of mass and energy in biological and physiological processes and, in particular, heat transfer in biomedical applications.

Prerequisites. **MATH 0290** and **PHYS 0175** or **PHYS 0476** and **CHEM 0960** or **CHEM 0120** or **CHEM 0720**.

Course Objectives. Upon successfully completing Biothermodynamics, the student should be able to state and apply fundamental concepts in mass and energy conservation, at both the macroscopic and microscopic scales, and to set up and solve problems related to mass and energy conservation in relevant physiological systems and biomedical applications.

Topics Covered

- Units/significant figures
- Conservation of mass (mass and population balances)
- First Law of Thermodynamics (conservation of energy)
- Second Law of Thermodynamics (entropy)
- Free energy and associated thermodynamic relations
- Isothermal versus adiabatic processes
- Applications to heat transfer:
  - Macroscopic approaches
  - Microscopic approaches
  - Steady-state versus time dependent problems

Schedule. Class meets twice weekly for 75 minutes; recitation once a week for 50 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1211: Honors Bioengineering Thermodynamics

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring, however, please note that this course is not offered on a regular basis. Please check with the Bioengineering Undergraduate Academic Administrator and/or Associate Chair for Undergraduate Education to inquire about course offering.

Description. Conservation principles are fundamental and ubiquitous in engineering applications. Biothermodynamics uses an interactive framework to explore the development and use of fundamental methodology in application of conservation principles to describe the flow of mass and energy in biological and physiological processes and, in particular, heat transfer in biomedical applications. In addition to the materials covered in **BIOENG 1210** (Bioengineering Thermodynamics), **BIOENG 1211** includes a weekly seminar in which students are expected to read and discuss current journal publications of interest to Bioengineering Thermodynamics.

Prerequisites. **MATH 0290** and **PHYS 0175** or **PHYS 0476** and **CHEM 0960** or **CHEM 0120** or **CHEM 0720** and 3.25 GPA or instructor permission.

Course Objectives. Upon successfully completing Biothermodynamics, the student should be able to state and apply fundamental concepts in mass and energy conservation, at both the macroscopic and microscopic scales, and to set up and solve problems related to mass and energy conservation in relevant physiological systems and biomedical applications.

Topics Covered

- Units/significant figures
- Conservation of mass (mass and population balances)
- First Law of Thermodynamics (conservation of energy)
- Second Law of Thermodynamics (entropy)
- Free energy and associated thermodynamic relations
- Isothermal versus adiabatic processes
- Applications to heat transfer:
    - Macroscopic approaches
    - Microscopic approaches
    - Steady-state versus time dependent problems

Schedule. Class meets twice weekly for 75 minutes; recitation once a week for 50 minutes. Seminar meets once a week for 50 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1218: Emerging Biomedical Technologies (Honors)

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. Emerging Biomedical Technologies is offered by Rehabilitation Science and cross-listed with Bioengineering. The purpose of this course is to provide the students with an understanding of stem cell biology, tissue engineering, and related applications involved in rehabilitation sciences and regenerative medicine. The course material is designed to aid students considering a future as researchers in biomedical sciences laboratories or biotechnology research and development. It will provide digests of the latest research technologies and clinical applications in these fields. Students will be encouraged to synthesize concepts aimed to test solutions and therapies to improve human health by use of modern biomedical technologies. The lecture and discussion format give students a broad background and the opportunity to apply critical thinking skills to recent published findings.

Prerequisites. **BIOENG 1210** or instructor permission.

Course Objectives. Students who satisfactorily complete the course should be able to:

1. Describe the emergent life science technologies covered in the course
2. Describe the biology of stem cells, their unique characteristics, and uses as therapies for disease and injury
3. Describe different approaches used in gene and cell therapeutic strategies
4. Describe the complexity of ethical and legal issues involved in this line of biomedical research
5. Describe the process of moving research into the translational phase with sufficient knowledge of the processes of FDA approval of therapies
6. Demonstrate an ability to effectively search for, analyze and critique current scientific publications on stem cell biology, cell and gene therapy and tissue engineering
7. Synthesize concepts aimed to test solutions and therapies to improve human health by use of modern biotechnologies discussed in class

Topics Covered

- Introduction to stem cells: differentiation and development, types of stem cells-- Embryonic, Adult derived, and Induced pluripotent stem cells
- Animal models of injury, transgenic strains, other related material
- Cell therapy applications: Experimental and clinical applications
- Gene therapy applications: Experimental and clinical applications
- Biomaterials involved in tissue engineering and cell-based constructs

- Nano-biotechnology, drug packaging, delivery and bio-printing/patterning technologies
- Fluorescent microscopy, cell tracking, and in vivo imaging
- Health of cells in culture: diagnostics: karyotypes, Fluorescent in situ hybridization, and molecular genetic testing
- Introduction to microarray technology and applications
- Biotechnology Industry, FDA regulations, and Patenting
- Ethical issues associated with use of modern biotechnologies

Schedule. Class meets once a week for 2 hours and 50 minutes each time.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1) and (4).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1220: Biotransport Phenomena

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall, Spring.

Description. Biotransport Phenomena follows logically from Biothermodynamics (**BIOENG 1210**). Thermodynamics principally looks at systems in equilibrium, along with nonequilibrium heat transport and exchange problems. Biotransport Phenomena principally looks at fluid and mixture systems disrupted from equilibrium. The fundamental principles of momentum and species mass transfer are developed and illustrated through applications to practical problems pertaining to physiological and biomedical processes. Students are introduced to the use of conservation balances to describe macroscopic and microscopic properties of a system.

Prerequisites. **MATH 0240** and **BIOENG 1210** or **BIOENG 1211** (or equivalent).

Course Objectives. Upon completing the course, the student should be able to describe the fundamental principles pertaining to biomedical fluid mechanics and transport phenomena and apply the fundamental principles to set up and solve problems in physiological systems and design of medical devices.

Topics Covered

- Reynolds Transport Theorem and mass conservation
- Momentum conservation and Bernoulli's principle
- Viscous flow
- Nonnewtonian flow
- Dimensional analysis
- Friction and drag
- Steady species diffusion
- Convection and diffusion
- Unsteady species diffusion
- Mass transfer coefficients

Schedule. Class meets twice weekly for 75 minutes; recitation once a week for 50 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (2), (5), and (7).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1241: Societal, Political and Ethical Issues in Bioengineering

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall, Spring.

Description. Engineering, as a profession, has ethical obligations to society that go beyond the simple application of technology as learned in science and technology courses. Bioethics seeks to supplement technological aspects of bioengineering by engaging students in an analysis of the effects of bioengineering developments on society, focusing on safety of the public as a primary ethical concern. Students are educated on a variety of ethical tools that enable them to analyze fictional, yet realistic, cases. Students are evaluated individually, as well as in groups, with a particular focus on the ethical issues developed in a group case project.

Prerequisites. Bioengineering Juniors/Seniors and Department permission.

Course Objectives. Upon completion of the course, students will be able to recognize, articulate, and resolve ethical issues within the arena of bioengineering.

Topics Covered

- Safety as a primary ethical concern of bioengineering
- Professionalism
- Methods of ethical analysis and Codes of Ethics
- Truth telling and Academic Honesty
- Animal Research
- Human Enhancements
- Confidentiality
- Cost/Risk vs Benefit
- Organ Donation

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (4).

BIOENG 1255: Dynamic Systems: A Physiological Perspective

Credits. 4 (Letter Grade Only).

Semesters Offered. Fall.

Description. A foundation of basic systems concepts is built through combining modeling of dynamic systems with physiological examples. Mathematical models of physiological systems are developed using a combination of systems understanding (circuits, analogous thinking, engineering synthesis and analysis, and integrative system approaches in solving problems) and bioengineering design (recognizing the potential applications of both engineering principles to biology and biological principles to engineering). These models are then used to address biological/clinical questions. Upon completing the course, the student should be able to: demonstrate skill and competence in methods of dynamic systems modeling through (a) building dynamic models of bioelectrical, biomechanical, biochemical, and physiological systems, (b) solving systems of equations representing dynamic models including analytical, numerical, and graphical software methods, (c) validating models including descriptive, predictive, and explanative validation, and (d) applying models to scientific and engineering applications including analysis and synthesis relative to identification and simulation. Describe physiological processes in dynamic system terms. Students are expected to be very proficient in electrical circuits since they will apply their knowledge on circuits throughout the entire course.

Prerequisites. **BIOENG 1320** (or equivalent) and **BIOSC 1250** (or equivalent).

Course Objectives. Upon completing the course, the student should be able to:

- Demonstrate skill and competence in methods of dynamic systems modeling through:
  - building dynamic models of bioelectrical, biomechanical, biochemical, and physiological systems
  - solving systems of equations representing dynamic models including analytical, numerical, and graphical software methods
  - validating models including descriptive, predictive, and explanative validation
  - applying models to scientific and engineering applications including analysis and synthesis relative to identification and simulation
- Describe physiological processes in dynamic system terms

Topics Covered

- Use of balancing techniques in building models of conserved quantities such as: electrical charge, material, energy, momentum, etc.
- Relative roles of theory (physical laws) and empirical observation (constitutive relations) in model construction

- Distinctions between deterministic vs. probabilistic systems; linear vs. nonlinear systems; and time-varying vs. time-invariant systems, spatially lumped vs. distributed systems
- Contrast the use of modeling in engineering analysis, synthesis, and design vs. its use in scientific analysis, prediction, and explanation
- Physiological systems: cardiovascular, body fluid, respiratory, metabolic, neuro-endocrine, bio-electric, and musculoskeletal

Schedule. Class meets twice weekly for 75 minutes; laboratory once a week for 2.5 hours.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (3), (5), and (6).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1310: Linear Systems and Electronics 1 (Bioinstrumentation)

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall, Spring.

Description. Bioinstrumentation covers electronic circuit theory and the practical aspects of building electronic prototypes. The mathematics of complex exponentials and complex impedance are also covered. A series of projects are built by each student individually, using a system of student-owned electronics components and tools called the PittKit. The kit includes a special apparatus, the Breadboard Laboratory Interface Processor (BLIP) which each student constructs, and which acts as a logging voltmeter, a frequency meter, a logic analyzer, a waveform generator, and a pulse duration meter. The Micro-BLIP, based on the popular Arduino "Micro" microcontroller, interfaces to any computer via a USB port, without requiring any special software to be installed on the computer. Students may reprogram the microcontroller for projects after the course.

Prerequisites. **MATH 0240** and **PHYS 0175** (or equivalent).

Course Objectives. After completing the course, the student should be able to design and construct prototypes of useful, simple circuits, such as preamplifiers and signal conditioners for sensors, as well as use off-the-shelf modules to construct laboratory instrumentation. Additionally, the student should be able to describe applications to other linear systems such as those found in physiological systems with greater clarity from having worked with circuits.

Topics Covered

- DC circuit theory
- AC circuit theory
- Sensors
- Digital logic
- Basic computer architecture
- Basic high frequency theory
- Basic electrochemistry and membrane potentials

Schedule. Class meets twice weekly for 75 minutes; laboratory once a week for 2.5 hours.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (6), and (7).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems; Bio/Biomedical Devices, Systems, Parts, & Processes; **and** Measure/Interpret Data on Living Systems.

BIOENG 1320: Biological Signals & Systems

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall, Spring.

Description. The theory and application of linear time-invariant (LTI) systems is explored, with emphasis on an appreciation of the description and analysis of biomedical signals and systems via LTI methods.

Prerequisites. **BIOENG 1310** (or equivalent) and **MATH 0240** and **MATH 0290**.

Course Objectives. After completing the course, the student should be able to state the properties of LTI systems; be able to test whether a system is LTI; know how to obtain, and interpret, the frequency response, impulse response, step response, and transfer function of a system. The student should also be able to demonstrate mastery of the mathematical skills of convolution and integral transform techniques.

Topics Covered

- Linear, time-invariant (LTI) systems: definition; input-output relations (convolution); impulse response; step response; stability; causality; differential equation description
- Frequency (Fourier) analysis: response of LTI systems to sinusoids; Fourier transform, Fourier series; frequency response of LTI systems
- Systems and Transforms: Fourier, Laplace; transfer function; Closed-loop (feedback) control systems; stability; causality; inverse system; LTI filters: low-pass, high-pass, band-pass, pole-zero plots and relation to time and frequency domain responses
- Discrete-time signals and systems: Sampling and aliasing; difference equations; Z-transform

Schedule. Class meets twice weekly for 75 minutes; recitation once a week for 50 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (3), (5), and (6).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics **and** Solving Bio/Biomedical Problems.

BIOENG 1330: Biomedical Imaging

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. Biomedical Imaging introduces the major imaging modalities (x-ray, CAT-scan, MRI, ultrasound) used in clinical medicine and related biomedical research, as well as the fundamentals of images, from a signals and systems standpoint.

Prerequisites. **BIOENG 1320** (or equivalent).

Course Objectives. After completing the course, the student should be able to understand the use of imaging modalities to determine anatomical or physiological function and apply physics and signal processing in medical imaging for particular research applications.

Topics Covered

- Signal processing background for imaging
- X-Ray and Computed Tomography (CT)
- Nuclear Medicine
- Ultrasound
- Magnetic Resonance Tomography
- Image Analysis and Visualization

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (3), and (7).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1340: Introduction to Medical Imaging and Image Analysis

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. Introduction to Medical Imaging and Image Analysis presents the physics of image formation as well as methods for tomographic image reconstruction for major medical imaging modalities, including X-ray Computed Tomography (CT) and Magnetic Resonance Imaging (MRI). Also introduced are fundamentals of digital image processing, with particular emphasis on medical applications, including basic techniques to enhance image quality, image de-noising, methods for extracting, classifying, and tracking features of and objects in images, etc. Students will learn how to implement these techniques in MATLAB (The MathWorks Inc., Natick, MA) to solve practical image processing problems. MATLAB exercises will demonstrate to students how filtering operations applied in the image domain or the Fourier domain affect medical images. In addition to these fundamentals, more advanced algorithmic approaches for image segmentation and image as well as point-cloud registration techniques will also be reviewed.

Prerequisites. **BIOENG 1320** (or equivalent) and **MATH 0240** and **MATH 0290** (or equivalent).

Course Objectives. Upon course completion, students will have a strong fundamental understanding of the physics behind tomographic imaging devices for medical imaging. More specifically, students will be able describe the physics of image formation, build linear systems models of imaging devices and further programmatically simulate image formation of specific imaging modalities relevant to biomedical imaging.

This course is grounded firmly on mathematical modeling of imaging systems and will therefore offer students a keen intuition in regard to designing effective image processing pipelines for visualization and analysis of acquired images from a range of 1D, 2D, 3D and 4D (i.e. 3D + time) biological and medical imaging modalities.

Topics Covered

- Principles of imaging from major modalities
- Image visualization and rendering
- Fundamental image filtering in the time domain and frequency domain
- Basic medical and biological image processing
- Applications of medical image processing
- Statistical data analysis
- Machine learning for biomarker-based classification

Schedule. Class meets once per week for 150 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (3), and (7).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1351: Biosignal Acquisition and Analysis

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. The objective of this course is to develop data acquisition interfaces that include software and hardware to interact with and sample real world phenomena with bioengineering applications. Students will build circuits and will learn to work with several toolboxes and advanced features in MATLAB to build graphical user interfaces (GUIs), communicate with data acquisition systems (DAQs) for measuring signals with sensors and/or controlling actuators to interact with the physical world, and perform signal processing and analysis functions to extract meaningful information from electrical and/or biological measurements. Practical applications may include measuring and analyzing bioelectric phenomena related to heart rate or tissue impedance, processing and analyzing neural signals collected from implanted electrodes in the brain, etc.

Prerequisites. **ENGR 0012** or **CS 0441** and **BIOENG 1310**.

Course Objectives. Upon completing the course, students should be able to successfully create the interfaces combining computer programs and hardware to measure, process, and manipulate biological signals; and develop written and oral technical communication skills. In addition, students will be able to create solutions for real world engineering problems after completing this course successfully.

Topics Covered

- Data Acquisition Systems (DAQs)
- Sensors & Actuators
- Signal Conditioning and Filters
- Graphical User Interfaces (GUIs)
- Signal Extraction and Recovery Using PCA and ROC
- Complex Impedance and Bio-Electric Interfaces
- Frequency Domain Analysis
- Modeling Dynamic Systems
- Neural Spike Sorting

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (2), (3), (5), and (7).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems; Bio/Biomedical Devices, Systems, Parts, & Processes; **and** (Measure/Interpret Data on Living Systems).

BIOENG 1355: Medical Product Regulation and Reimbursement

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. This course provides an introduction to the Food and Drug Agency's (FDA) medical product development requirements. Also included is an overview of medical product reimbursement of the Centers for Medicare and Medicaid Services (CMS). The course presents this material using case studies that are prepared by the student prior to class and discussed during class.

Prerequisites. Bioengineering sophomore & junior students. Non-Bioengineering students require instructor permission.

Course Objectives. Upon completing the course, the student should be familiarized with: (a) how the history of the FDA affects the Agency's perspectives and regulatory activities; (b) an introduction to quality systems with a focus on FDA's Quality System Regulation (QSR); (c) an overview of the key elements of the Design Controls subsection of the FDA QSR; (d) how the regulatory requirements in Europe contrast with those of the FDA; (e) how FDA regulatory requirements differ from reimbursement policies of the Centers for Medicare and Medicaid Services (CMS).

Topics Covered

- History and mission of the U.S. Food and Drug Agency (FDA)
- Medical product reimbursement in the U.S.
- FDA pre-market requirements
- Special, abbreviated, and *de novo* 510(k)'s as well as humanitarian device exemption (HDE)
- Introduction to quality systems (e.g., ISO 9001, JCAHO, and FDA QSR)
- Relationship between FDA's Quality System Regulation (QSR; 21 CFR 820) and ISO 9001
- FDA QSR - Design Controls 21 CFR 820.30
- FDA Guidance documents and Standards (ISO 13485 and ISO 14971)
- Design Input and hazard and risk analysis (21 CFR 820.30(g))
- Design Output – Verification and Validation (21 CFR 820.30(f) 21 CFR 820.30(g))
- Design documentation, changes, and document control – (21 CFR 820.30(i))
- Post-market requirements (labeling, advertising, post-marketing surveillance)
- Centers for Medicare and Medicaid Services (CMS)

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (2), (3), and (4).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1370: Computational Simulation in Medical Device Design

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall (every other year). Please check with the Bioengineering Undergraduate Academic Administrator and/or Associate Chair for Undergraduate Education to inquire about course offering.

Description. Computational simulation is becoming an increasingly utilized method to assess the performance of medical devices. This course provides students with a hands-on learning experience on how to use computational simulation in the modeling and design of medical devices. The course details the important steps in simulations from preprocessing to solution to post-processing and data presentation. Commercially available software programs will be introduced and used to simulate a variety of physical phenomena (solid, fluid, transport) pertinent to medical device design.

Prerequisites. **BIOENG 1630**.

Course Objectives. Upon completing the course, the student should be able to simulate the solid, fluid, and transport phenomena that are useful in medical device design. Particular attention will be placed on avoiding common mistakes in the preprocessing and interpretation of computational results.

Topics Covered

- Geometry creation
- Discretization
- Appropriate assignment of material properties
- Solver management
- Error mitigation and debugging
- Postprocessing and data presentation
- Data interpretation
- Introduction to design optimization

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1) and (3).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1383: Biomedical Optical Microscopy

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. Optical imaging microscopy techniques have become essential tools to investigate biological processes and diagnose diseases at unprecedented cellular and molecular levels. Biomedical researchers have an increasingly important need both to understand the advantages and limitations of the various types of optical microscopy and to apply the appropriate microscopy technique to solve specific biomedical problems. Biomedical Optical Microscopy is a comprehensive exploration of the basic principles of optical microscopy and imaging techniques commonly used in biomedical research.

Prerequisites. One of **PHYS 0102**, **PHYS 0175**, **PHYS 0106**, **PHYS 0476**, **PHYS 0111**, **PHYS 1306**, or **PHYS 1361**, or **BIOENG 1075**.

Course Objectives. Upon completion of the course, the student should be able to describe the basic principles of common optical imaging microscopy techniques, able to apply an optical microscopy technique to address biological questions, and able to perform basic quantitative image analysis.

Topics Covered

- Physical basis of light and image formation
- Principles and applications of basic optical microscopy techniques (bright-field, dark-field, phase contrast, interference, fluorescence microscopy)
- Principles and applications of advanced optical microscopy techniques (confocal, deconvolution, two-photon, second-harmonic generation, optical coherence tomography, etc.)
- Basic concepts in quantitative image analysis

Schedule. Class meets twice a week for 75 minutes each day.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (3), and (7).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1533: Controlled Drug Delivery

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. Controlled Drug Delivery explores the physics, chemistry, and material science rationale behind the engineering of controlled drug delivery systems, which stands as a 114-billion-dollar industry. To this end, the course focuses on topics at the interface between chemical engineering and medicine, such as polymer chemistry, biomaterials, pharmacokinetics, and transport phenomena. Pertinent pharmaceutical examples that are discussed include: transdermal, aerosol, oral, gene, and targeted cellular delivery, with emphasis placed on fabrication considerations and the relevant physiological environment.

Prerequisites. **BIOENG 1220** (or equivalent) and **BIOSC 1000** (or equivalent).

Course Objectives. Upon completing the course, the student should be able to state the constraints on material properties posed by the physiological environment; use the fundamentals of polymers, diffusion, degradation, modeling and pharmacokinetics to solve problems specific to controlled drug delivery; and demonstrate ability to search and summarize primary research literature, write a review article, and deliver a cohesive oral presentation.

Topics Covered

- Polymer basics
- Drug delivery systems (reservoir, matrix, bio-erodible systems)
- Pharmacokinetics and biodistribution of drug delivery systems
- Drug elimination and fate
- Externally controlled systems
- Micro- and Nano-particle based delivery
- Cell and gene delivery
- Delivery of vaccines (oral, pulmonary, transdermal)
- Relevant FDA regulations

Schedule. Class meets twice a week for 75 minutes each day.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (2), (3), (4), (5), and (7).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1580: Biomedical Applications of Signal Processing

Credits. 4 (Letter Grade Only).

Semesters Offered. Spring.

Description. The fundamentals of digital signal processing of time series are developed, via applied exercises and projects with a focus on medical and biological signal analysis and interpretation. Biomedical applications are selected from a variety of areas, such as cardiovascular, gait and balance, electrophysiological (EEG, EKG, ECoG, etc.) and neural signal processing, among others.

Prerequisites. **BIOENG 1320** (or equivalent).

Course Objectives. Upon completion of this course, students should be able to properly acquire data in digital form; perform standard methods of spectral analysis; implement and apply linear time-invariant discrete-time filters; and demonstrate basic skills in digital signal processing.

Topics Covered

- Review of LTI systems theory
- Continuous-time to discrete-time: Sampling, Nyquist theorem, anti-aliasing filters; s-domain to z-domain mapping
- Noise removal and digital filtering: FIR and IIR filters; median filtering
- Closed-loop (feedback) control systems
- Signal detection: stochastic vs. deterministic signals; correlation; the matched filter
- Spectral analysis: the discrete-time Fourier transform (DTFT) and the discrete Fourier transform (DFT); periodogram; Welch's method; Thomson's method; parametric (AR) methods

Schedule. Class meets twice weekly for 75 minutes; laboratory once a week for 2.5 hours.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1) and (6).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1586: Quantitative Systems Neuroscience

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. The course examines some of the major scientific results in behavioral neuroscience, and the mathematical and computational principles of brain function they illustrate. Neuroscience topics include sensory transduction, visual processing, motor control, and neural prosthetics. Students learn to apply techniques from signals and systems, statistics, machine learning, information theory, and control theory to neuroscience data sets. Course format consists of lectures and student-led discussions of important publications in neuroscience.

Prerequisites. (**BIOENG 1071** or **BIOENG 1072**) and **BIOENG 1320** or instructor permission.

Course Objectives. Upon completion of this course, the student should be able to:

- Describe organizing principles of brain function, from biological and theoretical perspectives
- Apply statistics, signal processing, and machine learning techniques to the analysis of biological data sets
- Design novel experiments, analyses, and data interpretation
- Demonstrate critical evaluation scientific and technical literature

Topics Covered

- Sensory transduction
- How neurons compute
- Sensory and motor systems
- Neural prosthetic decoding Introduction

Schedule. Three hours of scheduled meeting per week. Time is generally divided as two hours for lecture, one hour for student-led discussions of the primary literature in behavioral and computational neuroscience.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (3), and (6).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1615: Introduction to Neural Engineering

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. This is an introductory neural engineering course for graduate and upper level undergraduate students interested in implantable neural interface technologies. The course covers the basic neuroscience principles that govern engineering of neural interfaces and provides a comprehensive overview of the bioengineering approaches used in neural engineering research.

Prerequisites. Upper level undergraduate students.

Course Objectives. After completing the course, the students should become familiar with the sources and features of neural signals as well as basic cortical electrode technologies. Students will be able to build fundamental tools for neural electrophysiology signal processing, basic imaging and histology data quantification. Students will be provided with raw neural recording and histology datasets, and will learn to assemble MATLAB-based tools for basic signal processing and analysis.

Topics Covered

- Molecular biophysics and cellular neuroscience: Neurons; Cortical organization; Neurophysiology; Basic neural circuits; Sources of brain signals
- Basic neural computation: Neural spike data processing; Neural oscillations
- Combining electrical and imaging technologies: Chronic Electrodes; Two-photon imaging; Calcium reporters; Optogenetics; Intrinsic optical imaging; functional MRI
- Non-neuronal cells and immune system in the brain: Blood-brain barrier; Neuroglia
- Immunohistochemistry and image quantification: Tissue Labeling; Cell counting; Evaluating cell migration and local neurogenesis
- Neural Interface Design: Electrical characterization; Electrical stimulation; Electrode electrochemistry; Stimulation safety; Circuit modeling

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (2), (3), (4), (5), and (7).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics **and** Solving Bio/Biomedical Problems.

BIOENG 1620: Introduction to Tissue Engineering

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. Tissue engineering (TE) is defined as the development and manipulation of laboratory-grown molecules, cells, tissues, or organs to replace and/or support the function of injured body parts. TE is highly interdisciplinary and therefore crosses numerous engineering and medical specialties. The course introduces students to the fundamentals of TE and the biomaterials, cells and growth factors used in TE through consideration of cell and tissue biology, biomaterials, drug delivery, engineering methods and design, and clinical implementation. Specific applications include skin, nerve, bone, and soft tissue regeneration. Throughout the course ties are made between the topic of study and clinically relevant situations.

Prerequisites. BIOENG 1810 (or equivalent).

Course Objectives. Upon completion of this course, students should be able to:

- Describe basic principles behind human cell and tissue biology
- Describe the general types of biomaterials used in tissue engineering
- Describe techniques utilized to design, fabricate, and functionally assess tissue engineering systems
- Apply the combined knowledge of tissue organization and tissue engineering strategies to design a unique, reasonable tissue engineering solution

Topics Covered

- Tissue engineering
- Biomaterials
- Stem cells
- Drug delivery
- Preclinical and clinical studies

Schedule. Class meets twice a week for 75 minutes each day.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (2), (3), (4), (5), and (7).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics **and** Solving Bio/Biomedical Problems.

BIOENG 1630: Biomechanics 1 – Mechanical Principles Applied to Biological Systems

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. Biomechanics 1 is a first course in undergraduate biomechanics that applies and builds on the concepts of statics, dynamics, and mechanics of materials as applied to human activities and tissues. After briefly reviewing equilibrium concepts and free body diagrams as applied to the human body, principles from kinetics are used to develop dynamic descriptions of human motion. Finally, engineering concepts employed in description of the fundamental strength of materials are applied to biological tissues.

Prerequisites. **ENGR 0135**.

Course Objectives. After completion of the course, students should be able to describe the general characteristics and material properties for tissue and organs studied in the course, analyze the forces at a skeletal joint for various static and dynamic human activities, state and use the concepts of balance and stability in describing human motion, and compute the stresses and strains in biological tissues, given loading conditions and material properties.

Topics Covered

- Analysis of forces in static biological systems
- Concept of balance and stability
- Linear and angular dynamics of human movement
- Application of stress and strain analysis to biological tissues

Schedule. Class meets twice a week for 75 minutes each day. Recitation meets once a week for 50 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1).

Bioengineering Program Criteria. Solving Bio/Biomedical Problems.

BIOENG 1631: Biomechanics 2 – Introduction to Biodynamics and Biosolid Mechanics

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. Modern biomechanics is an increasingly diverse field that encompasses the mechanics of the whole body, all the way down to the cellular and molecular levels. Students are introduced to fundamental concepts and techniques of biodynamics and biosolid mechanics which provide the basis for Biomechanics 3 and 4. General approaches used in mechanics are introduced throughout the semester and applied in several laboratories.

Prerequisites. **BIOENG 1630** (or equivalent).

Course Objectives. Upon completing the course, the student should be able to (1) Demonstrate recall of functional anatomy of musculoskeletal system; (2) Perform inverse dynamic analyses; (3) Describe the principles of basic muscle biomechanics; (4) Perform analyses of deformable bodies (including viscoelastic materials); and (5) Describe general experimental techniques for rigid and deformable body analyses.

Topics Covered

- Inverse dynamic analyses and anthropometry
- Overview of lower extremity – musculoskeletal anatomy
- Functional models of skeletal muscle
- Constitutive relations, extension, compression, torsion, bending, inflation, and viscoelasticity of deformable tissues

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1) and (4).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1632: Biomechanics 3 – Biodynamics of Movement

Credits. 3 (Letter Grade Only).

Semesters Offered. Spring.

Description. Biodynamics, the area of focus in Biomechanics 3, is the study of large-scale movements in biologic systems. As such, the course focuses on the analysis of human movement, which is used in clinical and research settings to understand how various pathologies impact movement and how interventions can be implemented to aid those affected by movement disorders. We cover the fundamentals of biomechanics of human movement using mechanical modeling techniques. The major focus is kinematic analyses in three dimensions using matrix techniques. Some fundamentals of kinetics are covered as well, 2D and 3D inverse dynamics.

Prerequisites. **BIOENG 1631** and **MATH 0280** (or equivalent).

Course Objectives. Upon completing the course, the student should be able to describe basic methods of kinematic/kinetic analysis used in multi-link systems and be able to implement the methods in the analysis of human movement. Students should also be able to apply the methods to study common human movements, e.g. gait analyses, eye movement analyses, etc. Finally, students should be able to use the computer programming language, MATLAB, to perform computations on kinematic data.

Topics Covered

- Coordinate systems
- Matrix methods of translation and rotations
- MATLAB methods of analysis
- Euler angles
- Eye movement analyses, gait analyses
- Joint configurations
- Kinematic chain systems
- Anthropometrics
- 2D- and 3D- inverse dynamics
- Motion capture equipment
- Introduction to OPENSIM (musculoskeletal modeling and simulation software package)
- Overview of concepts needed to understand filtering of movement data

Schedule. Class meets twice a week for 75 minutes each day. Laboratories are included using instrumentation in the Human Movement and Balance Laboratory.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1633: Biomechanics 4 – Biomechanics of Organs, Tissues, and Cells

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. Modern biomechanics is an increasingly diverse field that encompasses the mechanics of the whole human body, including all the way down to the cellular and molecular levels. Biomechanics 4 builds upon biomechanics fundamentals learned in BIOENG 1630 and 1631 in building a comprehensive application of biosolid mechanics to describe the mechanical behavior of soft and hard biological tissues. The course provides fundamental concepts in the development and application of constitutive models, as well as a foundation for more advanced topics that are covered in graduate school. Mathematica™ (Wolfram Research, Inc.) is used both in class and for assignments.

Prerequisites. **BIOENG 1631** and **MATH 0280** (or equivalent).

Course Objectives. Upon completing the course, the student should be able to formulate biomechanics constitutive models that describe soft and hard tissues and use Mathematica™ as a framework for exploring the impact of model parameters in the model description.

Topics Covered

- Intro to indicial notation
- Thermoelasticity
- General linear elasticity and material symmetry
- 3-D stress and strain states
- Applied nonlinear optimization
- Viscoelasticity
- Stress-strain relations for finite deformations
- Usage of the software package Mathematica™ (Wolfram Research, Inc.)

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (4), and (6).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1680: Biomedical Applications of Control

Credits. 4 (Letter Grade Only).

Semesters Offered. Spring.

Description. The effect of feedback control on analysis and design is explored, with an emphasis on biological and physiological systems.

Prerequisites. BIOENG 1320 (or equivalent).

Course Objectives. Upon completing this course, students should be able to:

- Construct mathematical models of physiological systems
- Analyze temporal dynamics of a physiological system using linear systems concepts
- Characterize the effects of feedback and controller on system performance
- Design linear controllers to meet desired system specifications

Topics Covered

- Modeling of physiological systems:
  - Balanced equations
  - Block diagrams
  - Transfer functions
- Specifications of feedback systems:
  - Dynamic response
  - Pole/zero analysis
  - Stability analysis
  - PID control
- Design of feedback controllers:
  - Root-locus method
  - Compensation
- Stability of feedback systems:
  - Frequency response and Bode plots
  - Nyquist stability and Nyquist plots
  - Time delays
- State-space representation

Schedule. Class meets twice weekly for 75 minutes; laboratory once a week for 2.5 hours.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (3), and (6).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics; Solving Bio/Biomedical Problems; **and** Bio/Biomedical Devices, Systems, Parts, & Processes.

BIOENG 1810: Biomaterials and Biocompatibility

Credits. 3 (Letter Grade Only).

Semesters Offered. Fall.

Description. Undergraduate students are introduced to an advanced understanding of biomaterials and the use of biomaterial in areas such as artificial organs, implantable devices and tissue engineering. Throughout the course, ties are made between the topic of study and clinically relevant biomaterial performance. The course introduces various biomaterials, such as polymers, metals, and ceramics, with the focus on biomaterial synthesis, characterization, structure-property relationship and surface modification. Biocompatibility issues of biomaterials will be discussed from different aspects such as protein adsorption, foreign body reaction, immune and inflammatory response, and sterilization. Finally, examples of clinical applications are discussed.

Prerequisites. **CHEM 0320** and (**BIOSC 1000** or **BIOSC 1810** or **CHEM 1810** or **CHEM 1880**).

Course Objectives. Upon completing the course, the student should be able to:

- State the basic principles behind human tissue response to artificial surface implantation
- Describe the general types of materials used in soft and hard tissue replacements, drug delivery devices, and extracorporeal devices
- Describe techniques utilized to control the physiologic response to artificial surfaces
- Identify various design strategies and clinical applications of biomaterials

Topics Covered

- Material science of (polymer, metals, ceramics, glasses, and nature derived materials)
- Surface modification and immobilization
- Protein adsorption and cell adhesion
- Immune response, inflammatory response, and foreign body reaction
- Infection and sterilization
- In vitro and in vivo evaluation
- Clinical applications (cardiovascular, neurological, drug delivery etc.)

Schedule. Class meets twice a week for 75 minutes each day.

ABET Student Outcomes (see ABET Student Outcomes section for details). (1), (3), (4), and (5).

Bioengineering Program Criteria. Applying Principles of Biology, Physiology, & Statistics **and** Solving Bio/Biomedical Problems.

ENGR Courses Administered by Bioengineering

ENGR 0501: Music Engineering (Honors)

Credits. 1 (Satisfactory/No Credit).

Semesters Offered. Fall, Spring.

Description. An honors course directed toward development of basic skills in recording engineering through expanded understanding of the science and engineering of music. The course will use the Music Engineering Laboratory (MEL) located in Benedum Hall. The MEL is a state-of-the-art sound recording facility with research and educational capabilities for sound recording and music engineering. Students are expected to have a strong interest in recording and must have prior musical experience.

Prerequisites. Instructor permission required.

Course Objectives. Students will learn and demonstrate practical experience in recording and knowledge of operating the studio.

Topics Covered

- Recording engineering (microphones, amplifiers, mixing, filtering, special effects)

Schedule. Class meets once a week for 60 minutes, attendance required. Additionally, students will schedule time in the MEL for individual projects.

ENGR 1770: Engineering Foundations of Music (Honors)

Credits. 3 (Letter Grade Only).

Semesters Offered. Please note that this course is not offered on a regular basis. Please check with the Bioengineering Undergraduate Academic Administrator and/or Associate Chair for Undergraduate Education to inquire about course offering.

Description. Since Paleolithic times, engineering has been applied to the production of music, but advances in the past few centuries, including sound recording, the introductions of electronics, and a greater understanding of the physics, mathematics, and psychology of sound, have greatly expanded what a student can learn in the field of Music Engineering. This is a lecture course about the engineering aspects of music, including the following general topics: the physics of sound and the mathematics of harmony; the means of creation through mechanical musical instruments, including the human voice, as well as electronic instruments; recording, reproduction, and enhancement though signal processing; interaction with human perceptual, cognitive, and motor systems. Assuming knowledge of differential and integral calculus, the course will develop (or review) a basic understanding of convolution and Fourier analysis through examples in the engineering aspects of music. Starting with an historical perspective on technology, we will extrapolate a look into the future of Music Engineering.

Prerequisites. **MATH 0220** and **MATH 0230** (or equivalent). Instructor permission required.

Course Objectives. Upon completing the course, students will be able to describe engineering aspects of musical instruments, reproduction, and processing and apply the mathematical and physical basis for sound and the theory of harmony in understanding the system of interaction between human and machine that constitutes music.

Topics Covered

- Convolution and Fourier analysis
- Physics of sound
- Mathematics of harmony
- Physics of mechanical instruments
- Recording and reproduction of music
- Electronic processing of sound
- Electronic synthesis of music
- Psychophysics of music

Schedule. Class meets twice weekly for 75 minutes.

ABET Student Outcomes

ABET Student Outcomes are outcomes (1) through (7), plus any additional outcomes that may be articulated by the program (see **Bioengineering Program Criteria** for each course, if applicable). Attainment of ABET student outcomes prepares graduates to enter the professional practice of engineering.

ABET Student Outcomes (1) through (7)	As Reflected on University of Pittsburgh's Office of Measurement of Evaluation and Teaching (OMET) Survey
(1) An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	• Your ability to identify, formulate, and solve complex engineering problems by applying principles of *engineering* • Your ability to identify, formulate, and solve complex engineering problems by applying principles of *science* • Your ability to identify, formulate, and solve complex engineering problems by applying principles of *mathematics*
(2) An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	• Your ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare • Your ability to apply engineering design to produce solutions that meet specified needs with consideration of global, cultural, and social factors (i.e., sustainability principles) • Your ability to apply engineering design to produce solutions that meet specified needs with consideration of environmental and economic factors (i.e., sustainability principles)
(3) An ability to communicate effectively with a range of audiences	• Your ability to effectively communicate verbally with a wide range of audiences • Your ability to effectively communicate in writing to a wide range of audiences

ABET Student Outcomes (1) through (7)	As Reflected on University of Pittsburgh's Office of Measurement of Evaluation and Teaching (OMET) Survey
(4) An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	• Your ability to recognize ethical and professional responsibilities in engineering situations • Your ability to make informed judgments that consider the impact of engineering solutions in global and societal contexts (i.e., sustainability principles) • Your ability to make informed judgments that consider the impact of engineering solutions in economic and environmental contexts (i.e., sustainability principles)
(5) An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	• Your ability to function effectively on a team whose members together provide an inclusive environment, collaboration, and leadership • Your ability to function effectively on a team whose members together establish goals, plan tasks, and meet objectives
(6) An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	• Your ability to develop appropriate experiments • Your ability to conduct appropriate experiments • Your ability to analyze and interpret data and use engineering judgment to draw conclusions
(7) An ability to acquire and apply new knowledge as needed, using appropriate learning strategies	• Your ability to embrace new learning strategies to independently acquire and apply new knowledge to solve engineering problems

4

Minors and Certificates

A minor and/or certificate on a student's transcript and resume distinguishes the student as someone who has gone beyond the minimum requirements to get their degree. The minor (certificate) identifies additional skills, knowledge, and abilities that students have acquired. Obtaining a minor or certificate generally requires completing a focused series of five to seven courses. With proper planning, one or more courses can be used to satisfy both major and minor or certificate requirements. Early planning can maximize the educational experience. Requirements for minors and certificates vary by department and program.

Disclaimer. While we attempt to keep the information presented here current, departments can change minor requirements without our knowledge. Resolution of any conflict or discrepancy that exists between what is described in this document and the page/document for the department offering the minor defaults to the department offering the minor.

Note. Many courses require prerequisites, e.g., **MEMS 1028** has a prerequisite of **ENGR 0145**. The prerequisite requirement means that students need the listed course or its equivalent to do well in the course. **BIOENG 1630** is the Bioengineering equivalent of **ENGR 0145** and, thus, Bioengineering students do not need to take **ENGR 0145** (and cannot use **ENGR 0145** as an advanced engineering/science/technical course). **Always check with the department offering the minor to see whether stated prerequisites are needed or whether equivalent course(s) that have or will be completed can be used**.

Note About Declaring Minor(s). The Swanson School of Engineering (SSoE) Administration Office recommends completing the **graduation application form** during the semester prior to graduation. For example, if graduating in Spring semester, then it is recommended that the form be completed during Fall semester (specifically, after registering for Spring classes). Minor(s) can then be declared on the graduation application form. Please note that if a minor outside of SSoE is being intended for, e.g. a minor in Computer Science, then it is highly recommended that students communicate, as soon as possible, with the administrative office for the school offering the minor in order to register the minor there. This way, it is guaranteed that students will have a seat in the courses required to obtain the minor.

Minor in Bioengineering

Undergraduates in other departments can obtain a Minor in Bioengineering by satisfactorily completing (**grade of C or better**) one Bioengineering seminar and five courses for a total of 16 credits.

Students interested in a Bioengineering Minor are required to submit a completed **Bioengineering Minor Checklist** to the **Bioengineering Undergraduate Academic Administrator** for course approvals **prior to** enrolling in BIOENG courses in order to ensure that the requirements for the minor are fulfilled. Approval to use substitute courses to meet minor requirements must be obtained in advance from the Bioengineering Associate Chair for Undergraduate Education.

Bioengineering Minor Requirements

- Bioengineering seminar
  - **BIOENG 1086** (0 credits): Bioengineering Seminar for Minors – Attend a minimum of 6 seminar presentations
- Basic Life Science course

  Acceptable course options include (others may be used with permission)
  - **BIOENG 1070** (3 credits): Introductory Cell Biology 1
  - **BIOENG 1071** (3 credits): Introductory Cell Biology 2
  - **BIOSC 0150** (3 credits): Foundations of Biology 1
  - **BIOSC 0160** (3 credits): Foundations of Biology 2
  - **BIOSC 1000** (3 credits): Principles of Biochemistry, or
    - **BIOSC 1810** (3 credits): Macromolecular Structure and Function, or
    - **CHEM 1810** (3 credits): Chemical Biology, or
    - **CHEM 1880** (3 credits): Chemical Biology for Engineers
  - **BIOSC 1250** (3 credits): Introduction to Human Physiology
  - **HRS 1023** (4 credits): Human Physiology
- Course in statistics
  - **ENGR 0020** (4 credits): Probability and Statistics for Engineers 1 (SSoE students) or
  - **ENGR 0021** (3 credits): Probability and Statistics for Engineers (SSoE students) or
  - **STAT 1000** (4 credits): Applied Statistical Methods (Non-SSoE students)
- Three BIOENG elective courses (9 credits total)

  See **Undergraduate Bioengineering Course Descriptions section** for the list of undergraduate BIOENG courses.

  Note. Students must meet prerequisites (or equivalent) to enroll in BIOENG courses.

Note. BIOENG 1070 and **BIOENG 1071** are considered Basic Life Science Courses. Neither can be used to satisfy a BIOENG elective course requirement.

Note. BIOENG 1241 (3 credits): Societal, Political and Ethical Issues in Biotechnology is a humanities/social science course that is restricted to Department of Bioengineering students only. The course cannot be used to satisfy a BIOENG elective course requirement.

Note. BIOENG 1095: Special Projects cannot be used to satisfy a BIOENG elective course requirement.

Minor in Chemical Engineering

Bioengineering majors can earn a **Minor in Chemical Engineering** by taking:

- **CHE 0100** (6 credits): Foundations of Chemical Engineering and **CHE 0101** (1 credit): Foundations of Chemical Engineering Laboratory
- **CHE 0400** (5 credits): Reactive Process Engineering and **CHE 0401** (1 credit): Reactive Process Engineering Laboratory.

Please note that neither course satisfies an elective in any Bioengineering Track. Both can, however, be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement.

Minor in Computer Engineering

Bioengineering majors can earn a **Minor in Computer Engineering** by completing three sophomore-level required courses and two advanced elective courses. Specifically,

- **ECE 0201** (3 credits): Digital Circuits and Systems
- **ECE 0202** (3 credits): Embedded Processors and Interfacing
- **ECE 0301** (3 credits): ECE Problem Solving with C++
- Two advanced elective courses selected from:
  - **ECE 0302** (3 credits): Data Structures and Algorithms
  - **ECE 1110** (3 credits): Computer Organization and Architecture
  - **ECE 1140** (3 credits): Systems and Project Engineering
  - **ECE 1150** (3 credits): Computer Networks
  - **ECE 1155** (3 credits): Information Security
  - **ECE 1175** (3 credits): Embedded Systems Design
  - **ECE 1195** (3 credits): Advanced Digital Design

Minor in Computer Science

Requirements for a **Minor in Computer Science** are:

- **CMPINF 0401** (4 credits): Intermediate Programming
- **CS 0445** (3 credits): Algorithms and Data Structures 1
- **CS 0447** (3 credits): Computer Organization and Assembly Language
- **CS 1501** (3 credits): Algorithms and Data Structures 2

And one of the two courses:

  - **CS 0441** (3 credits): Discrete Structures for Computer Science

- **CS 0449** (3 credits): Introduction to Systems Software

Bioengineering students can use two of the courses to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The other three courses are in addition to Bioengineering major requirements.

Minor in Electrical Engineering

Bioengineering majors can earn a **Minor in Electrical Engineering** by completing three required courses and three elective courses. Specifically,

- **ECE 0101** (3 credits): Linear Circuits and Systems (satisfied by **BIOENG 1310**)
- **ECE 0102** (3 credits): Microelectronics and Circuits
- **ECE 0402** (3 credits): Signals, Systems, and Probability (possibly satisfied by **BIOENG 1320**; please check with EE Program Director)
- Two elective courses selected from:
  - **ECE 0201** (3 credits): Digital Circuits and Systems
  - **ECE 1212** (3 credits): Electronics Circuit Design Lab
  - **ECE 1247** (3 credits): Semiconductor Device Theory
  - **ECE 1259** (3 credits): Electromagnetics
  - **ECE 1560** (3 credits): Digital Signal Processing (possibly satisfied by **BIOENG 1580**; please check with EE Program Director)
  - **ECE 1673** (3 credits): Linear Control Systems
  - **ECE 1701** (3 credits): Fundamentals of Electric Power Engineering

Note. Bioengineering students may not use credit for both **ECE 1673** (3 credits): Control Systems and **BIOENG 1680** toward graduation (duplication of course content).

Minor in Environmental Engineering

Bioengineering majors can earn a **Minor in Environmental Engineering** by completing five courses. Specifically,

- **CEE 1412** (3 credits): Introduction to Hydrology
- **CEE 1503** (3 credits): Introduction to Environmental Engineering
- **CEE 1505** (3 credits): Water Treatment and Distribution System Design or
  - **CEE 1515** (3 credits): Water Collection and Treatment Plant Design
- **CEE 1513** (3 credits): Environmental Engineering Processes
- **CEE 1514** (3 credits): Environmental Impact Assessment

None of the courses can be used for any Bioengineering Track elective. Two can, however, be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The remaining three are in addition to Bioengineering major requirements.

Minor in Exercise Science

Requirements for a **Minor in Exercise Science** are:

- Required courses
  - **HHD 1011** (3 credits): Applied Human Anatomy
  - **HHD 1012** (1 credit): Applied Human Anatomy Lab
  - **HHD 1033** (3 credits): Human Physiology
  - **HHD 1042** (3 credits): Physiology of Exercise
  - **HHD 1224** (3 credits): Fitness Assessment and Exercise Prescription
- Elective courses (5-6 credits)
  - **HHD 1044** (3 credits): Biomechanics (possibly satisfied by **BIOENG 1630**; please check with ES Program Director)
  - **HHD 1233** (2 credits): Principles of Strength and Conditioning
  - **HHD 1226** (3 credits): Assessment and Prescription for Special Populations
  - **HHD 1487** (3 credits): Chronic Disease and Obesity

Note. Starting in January 2022, HPA (Health and Physical Activity) designator changed to HHD (Health and Human Development). Course numbers, however, remain intact.

Minor in Industrial Engineering

Bioengineering majors can earn a **Minor in Industrial Engineering** by completing three required courses and two elective courses. Specifically,

- Required courses
  - **ENGR 0020** (4 credits): Probability and Statistics for Engineers 1 (prior to Fall 2022) or **ENGR 0021** (3 credits): Probability and Statistics for Engineers (starting Fall 2022)
  - **IE 1054** (3 credits): Productivity Analysis
  - **IE 1081** (3 credits): Operations Research
- Elective courses (any 2 of the following)
  - **IE 1035** (3 credits): Engineering Management
  - **IE 1040** (3 credits): Engineering Economic Analysis
  - **IE 1051** (3 credits): Engineering Product Design
  - **IE 1052** (3 credits): Manufacturing Processes and Analysis

- **IE 1055** (3 credits): Facility Layout and Material Handling
- **IE 1061** (3 credits): Human Factors Engineering
- **IE 1080** (3 credits): Supply Chain Analysis
- **IE 1082** (3 credits): Probabilistic Methods in Operations Research
- **IE 1083** (3 credits): Simulation Modeling

Note that above requirements are for students that begin their coursework Fall 2019 and beyond. Prior to Fall 2019, students should adhere to:

- Required courses
  - **ENGR 0020** (4 credits): Probability and Statistics for Engineers 1 (prior to Fall 2022) or **ENGR 0021** (3 credits): Probability and Statistics for Engineers (starting Fall 2022)
  - **IE 1054** (3 credits): Productivity Analysis
- Elective courses (any 3 of the following)
  - **IE 1035** (3 credits): Engineering Management
  - **IE 1040** (3 credits): Engineering Economic Analysis
  - **IE 1051** (3 credits): Engineering Product Design
  - **IE 1052** (3 credits): Manufacturing Processes and Analysis
  - **IE 1061** (3 credits): Human Factors Engineering
  - **IE 1080** (3 credits): Supply Chain Analysis
  - **IE 1081** (3 credits): Operations Research
  - **IE 1083** (3 credits): Simulation Modeling

Since Bioengineering majors are required to take statistics (**ENGR 0020** – prior to Fall 2018, and **BIOENG 1000** – starting Fall 2018), the Industrial Engineering Minor requires 4 additional courses.

Bioimaging and Signals and Cellular Engineering Track students can use two of the four courses to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The other two courses are in addition to Bioengineering major requirements.

Biomechanics Track students can use **IE 1061** as a track elective. Two courses can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The fourth course would then be in addition to Bioengineering major requirements.

Medical Product Engineering Track students can use **IE 1040**, **IE 1051**, **IE 1052**, **IE 1061**, and **IE 1080** as track electives. **IE 1054** and **IE 1081** can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement.

Minor in Material Science Engineering

Bioengineering majors can earn a **Minor in Materials Science Engineering** by completing five courses. Specifically,

- **ENGR 0022** (3 credits): Materials Structure and Properties
- **MEMS 0040** (3 credits): Materials and Manufacturing
- **MEMS 1053** (3 credits): Structure of Crystals and Diffraction
- **MEMS 1059** (3 credits): Phase Equilibria in Multi-Component Materials
- **MEMS 1063** (3 credits): Phase Transformations and Microstructure Evolution

ENGR 0022 is a track elective for **Biomechanics** and **Medical Product Engineering Track** students. None of the courses can be used for any other Bioengineering track elective. Two of the courses can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. Any remaining courses are in addition to Bioengineering major requirements.

Minor in Mechanical Engineering

Bioengineering students can earn a **Minor in Mechanical Engineering** by completing two required courses and three elective courses in one of four focused option areas.

Required Courses

- **MEMS 0024** (3 credits): Introduction to Mechanical Engineering Design – Medical Product Engineering track elective – satisfied by combination of **BIOENG 1024** and **BIOENG 0050**
- **MEMS 1028** (3 credits): Mechanical Design 1 – Biomechanics and Medical Product Engineering (*technical focus* only) track elective

  Note. BIOENG 1630 satisfies the **ENGR 0145** prerequisite for **MEMS 1028**

Elective Courses Based on Focus Options

- **Thermal-Fluids Option**
  - **MEMS 0051** (3 credits): Introduction to Thermo-Fluids Engineering – satisfied by **BIOENG 1210**
  - **MEMS 0071** (3 credits): Introduction to Fluid Mechanics
  - and either
    - **MEMS 1051** (3 credits): Applied Thermodynamics or
    - **MEMS 1071** (3 credits): Applied Fluid Dynamics
- **Dynamic Systems Option**
  - **MEMS 1014** (3 credits): Dynamic Systems – satisfied by **BIOENG 1255**

- **MEMS 1015** (3 credits): Rigid-Body Dynamics – Biomechanics track elective
- **MEMS 1045** (3 credits): Automatic Controls (or ECE controls course)

- **Mechanical Design Option**
  - **MEMS 1029** (3 credits): Mechanical Design 2 – satisfied by **BIOENG 1161**
  - **MEMS 1033** (3 credits): Fracture Mechanics for Manufacturing and Performance
  - **MEMS 1047** (3 credits): Finite Element Analysis – Biomechanics track elective
- **Mechanical Measurements Option**
  - **MEMS 1014** (3 credits): Dynamic Systems – satisfied by **BIOENG 1255**
  - **MEMS 1041** (3 credits): Mechanical Measurements 1
  - **MEMS 1042** (3 credits): Mechanical Measurements 2

Depending upon elected track, Bioengineering students have several different possibilities to earn a Mechanical Engineering minor.

Bioimaging and Signals Track students: none of the courses in any option can be used as a track elective. Two courses can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. Two, and possibly three, courses are in addition to Bioengineering major requirements.

Biomechanics Track students: **MEMS 1028** is a track elective.

- Thermal-Fluids Option

  BIOENG 1210 (**MEMS 0051**) is a required course for Bioengineering majors. Two of **MEMS 0024**, **MEMS 0071**, or **MEMS 1051** (or **MEMS 1071**) can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The third course would be in addition to Bioengineering major requirements.
- Dynamics Systems Option

  BIOENG 1255 (**MEMS 1014**) is a core selective option for Bioengineering majors. **MEMS 1015** is a track elective. **MEMS 0024** and **MEMS 1045** can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement.
- Mechanical Design Option

  BIOENG 1161 (**MEMS 1029**) is a required course for Bioengineering majors. **MEMS 1047** is a track elective. **MEMS 0024** and **MEMS 1033** can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement.
- Mechanical Measurements Option

  BIOENG 1255 (**MEMS 1014**) is a core selective option for Bioengineering majors. Two of **MEMS 0024**, **MEMS 1041**, or **MEMS 1042** can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The third course would be in addition to Bioengineering major requirements.

Cellular Engineering Track students: none of the courses in any option can be used as a track elective. Two courses can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. Two, and possibly three, courses are in addition to Bioengineering major requirements.

Medical Product Engineering Track students:

- **Business focus**: **MEMS 0024** is a track elective. None of the courses in any option can be used as a track elective. Two courses can be used to satisfy the Bioengineering 2-course, 6 -credit advanced engineering/science/technical elective requirement. One, and possibly two, courses are in addition to Bioengineering major requirements.
- **Technical focus**: **MEMS 0024** and **MEMS 1028** are track electives.
    - **Thermal-Fluids Option**

      BIOENG 1210 (**MEMS 0051**) is a required course for Bioengineering majors. **MEMS 0071** and **MEMS 1051** (or **MEMS 1071**) can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement.
    - **Dynamics Systems Option**

      BIOENG 1255 (**MEMS 1014**) is a core selective option for Bioengineering majors. **MEMS 1015** and **MEMS 1045** can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement.
    - **Mechanical Design Option**

      BIOENG 1161 (**MEMS 1029**) is a required course for Bioengineering majors. **MEMS 1033** and **MEMS 1047** can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement.
    - **Mechanical Measurements Option**

      BIOENG 1255 (**MEMS 1014**) is a core selective option for Bioengineering majors. **MEMS 1041** and **MEMS 1042** can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement.

Minor in Polymer Engineering

The **Minor in Polymer Engineering** consists of six courses.

Core Courses

- **CHE 1754** (3 credits): Principles of Polymer Engineering
- **CHEM 1600** (3 credits): Synthesis and Characterization of Polymers and **CHEM 1605** (1 credit): Synthesis and Characterization of Polymers Laboratory

Required Chemistry Courses

- **CHEM 0310** (3 credits): Organic Chemistry 1
- **CHEM 0320** (3 credits): Organic Chemistry 2

Two Research Projects with Polymer Content

- **CHE 1097** (1-12 credits): Special Project
- **CHEM 1710** (1-6 credits): Undergraduate Research

CHEM 0310 and **CHEM 0320** are track electives for all tracks. With prior approval of the Bioengineering Associate Chair for Undergraduate Education and Chemical Engineering Vice Chair for Undergraduate Education, **BIOENG 1095** can be used to satisfy the **CHE 1097** research project requirement as long as a significant polymer content is part of the research project. None of the core or research project courses can be used for any Bioengineering track elective. Two can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The remaining two are in addition to Bioengineering major requirements.

Minor in Chemistry

Many routes exist to obtain a **Minor in Chemistry**. The most common route for Bioengineering majors is:

- Two courses in Freshman Chemistry
  - First course: **CHEM 0110** (4 credits): General Chemistry 1, or **CHEM 0710** (4 credits): General Chemistry 1 (Honors), or **CHEM 0760** (3 credits): General Chemistry for Engineers 1 (Honors), or **CHEM 0960** (3 credits): General Chemistry for Engineers 1
  - Second course: **CHEM 0120** (4 credits): General Chemistry 2, or **CHEM 0720** (4 credits): General Chemistry 2 (Honors), or **CHEM 0770** (3 credits): General Chemistry for Engineers 2 (Honors), or **CHEM 0970** (3 credits): General Chemistry for Engineers 2
- **CHEM 0310** (3 credits): Organic Chemistry 1
- **CHEM 0320** (3 credits): Organic Chemistry 2
- **CHEM 0345** (2 credits): Organic Laboratory
- **BIOSC 1000** (3 credits): Principles of Biochemistry or **BIOSC 1810** (3 credits): Macromolecular Structure and Function

Bioengineering majors are required to take Freshman Chemistry.

Cellular Engineering Track students are required to take **CHEM 0310**, **CHEM 0320** and **BIOSC 1000** (or **BIOSC 1810** or **CHEM 1810** or **CHEM 1880**) as part of the track requirements. **CHEM 0345** is in addition to Bioengineering major requirements.

Bioimaging and Signals, **Biomechanics**, and **Medical Product Engineering Track** students can use **CHEM 0310** and **CHEM 0320** to satisfy two track electives. **BIOSC 1000** can be used to satisfy one of the Bioengineering 2-course, 6- credit advanced engineering/science/technical elective requirement. **CHEM 0345** is in addition to Bioengineering major requirements.

Minor in Mathematics

Bioengineering majors can earn a **Minor in Mathematics** by completing at least 15 credits in mathematics courses, **with a grade of C or better**, as follows:

- At least 9 credits of courses numbered 0250 or higher
- At least 6 credits of courses numbered 1000 or higher
- Students **cannot** use both **MATH 0280** and **MATH 1180** nor both **MATH 0290** and **MATH 1270**

Since Bioengineering majors are required to take **MATH 0280** or **MATH 1180** or **MATH 1185** and **MATH 0290** or **MATH 1270**, the second requirement (two courses numbered 1000 or higher) can be satisfied with required courses.

Regardless, a Mathematics Minor requires 3 additional courses.

Bioimaging and Signals, **Cellular Engineering**, and **Medical Product Engineering Track** students can use two of the three math courses to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The third course would be in addition to Bioengineering major requirements.

Biomechanics Track students can use two advanced math courses (**MATH 1080** and **MATH 1360**) to satisfy track requirements. The third course can be used to satisfy one of the Bioengineering 2- course, 6-credit advanced engineering/science/technical elective requirement.

Note: The Department of Mathematics offers two courses (**MATH 0413** and **MATH 1230**) with a **W** designation that can be used to satisfy the **W** requirement for graduation.

Minor in Neuroscience

Requirements for a **Minor in Neuroscience** are a minimum of 14 credits distributed as follows:

- **NROSCI 1000** (3 credits): Introduction to Neuroscience or **NROSCI 1003** (4 credits): Introduction to Neuroscience (Honors)

  Note. Grade of C or better required for both semesters of freshman chemistry **and BIOENG 1070/1071**.

  Note. Grade of C or better required to continue with minor program.
- Three core courses:
  - **NROSCI 1011** (3 credits): Functional Neuroanatomy or **NROSCI 1013** (4 credits): Functional Neuroanatomy (Honors)

- **NROSCI 1012** (3 credits): Neurophysiology or **NROSCI 1018** (4 credits): Neurophysiology (Honors)
- **NROSCI 1017** (3 credits): Synaptic Transmission or two of the three core courses plus another advanced elective

Bioengineering students can accomplish the 14-credit requirement in several ways:

- Take at least two Honors courses from **NROSCI 1003**, **NROSCI 1013**, **NROSCI 1018**

  Note. Four lecture courses required to achieve at least 14 credits with this option.

- Take at least one Honors course from **NROSCI 1003**, **NROSCI 1013**, **NROSCI 1018**, two of the three core courses, and an advanced NROSCI elective plus **NROSCI 1800**. **NROSCI 1800** is a 1-credit writing practicum that also satisfies the **W** requirement.
  Note: Four lecture courses plus writing practicum required to achieve 14 credits with this option.

- Take **NROSCI 1000**, two of the three core courses, and two advanced NROSCI elective courses

  Note. Five lecture courses required – even if one of them is Honors.

Bioimaging and Signals Track students can use two of the courses to satisfy track requirements and the other two courses to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement.

Biomechanics, **Cellular Engineering**, and **Medical Product Engineering Track students** can use two courses to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The other two courses are in addition to Bioengineering major requirements.

Note. NROSCI 1800 can be used to satisfy the **W** requirement but cannot be used as a track or advanced engineering/science/technical elective.

Note. Please note that early planning for a Neuroscience Minor is important because some required prerequisite courses are offered only once a year.

Minor in Physics

Requirements for a **Minor in Physics** are:

- **PHYS 0174** (4 credits): Basic Physics for Science and Engineering 1 or **PHYS 0475**: Introductory Physics for Science and Engineering 1 (Honors)
- **PHYS 0175** (4 credits): Basic Physics for Science and Engineering 2 or **PHYS 0476**: Introductory Physics for Science and Engineering 2 (Honors)
- **PHYS 0219** (2 credits): Basic Laboratory Physics for Science and Engineering
- **PHYS 0477** (4 credits): Introduction to Thermal Physics, Relativity, and Quantum Mechanics

- One of:
  - **PHYS 0481** (3 credits): Principles of Modern Physics 2
  - **PHYS 1374** (3 credits): Solid State Physics
  - **PHYS 1375** (3 credits): Foundations of Nanoscience
  - **PHYS 1376** (3 credits): Introduction to Biological Physics
  - **PHYS 1378** (3 credits): Introduction to Nuclear and Particle Physics

Since Bioengineering majors are required to take **PHYS 0174** and **PHYS 0175** (or the Honors equivalents), a Physics Minor requires 3 additional courses. While none of the remaining three counts as a requirement or elective in any track, **PHYS 0477**, **PHYS 0481**, **PHYS 1374**, **PHYS 1375**, **PHYS 1376**, and **PHYS 1378** can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. **PHYS 0219** (a laboratory course) is in addition to Bioengineering major requirements.

Minor in Social Work

Requirements for a **Minor in Social Work** are (complete, with a grade of **C- or better**, 12 credits):

- **SOCWRK 1000** (3 credits): Introduction to Social Work (this course must be included in the minor; also, it is required for all subsequent courses apart from **SOCWRK 1005**)
- **SOCWRK 1005** (3 credits): Foundations of the Welfare State
- **SOCWRK 1006** (3 credits): Policy Analysis
- **SOCWRK 1035** (3 credits): Global Perspectives in Social Work
- **SOCWRK 1040** (3 credits): Poverty and Income Inequality: Social Responses
- **SOCWRK 1058** (3 credits): Economics and Social Work
- **SOCWRK 1079** (3 credits): Child Welfare Services
- **SOCWRK 1088** (1-3 credits): Special Topics

International Engineering Studies Certificate

An innovative International Engineering Certificate Program has been created for those students who wish to enhance their degree program with an education abroad experience.

Students in the Swanson School of Engineering may earn a certificate in International Engineering Studies (IES) by completing a minimum set of requirements that include an approved, educational international experience and associated cultural enrichment and language studies. The certificate will indicate the country and language in which the IES program was completed.

For details, please visit the **International Engineering Studies Certificate** webpage.

Engineering for Humanity Certificate

The Engineering for Humanity Certificate is open to all undergraduate students and both guides and formalizes student participation in engineering projects in which social and/or environmental sustainability is a core thrust.

For details, please visit the **Engineering for Humanity Certificate** webpage.

Nuclear Engineering Certificate

The undergraduate Certificate in Nuclear Engineering is a five-course sequence consisting of three nuclear engineering courses and two discipline specific courses related to nuclear engineering from the various engineering departments. Any undergraduate engineering students in the Swanson School of Engineering and can earn the certificate in conjunction with an undergraduate engineering degree.

For details, please visit the **Nuclear Engineering Certificate** webpage.

Innovation, Product Design, and Entrepreneurship Certificate

Innovation and entrepreneurship has been credited as being a key driving factor in the US economy. Even inside the corporation, employers seek engineers with skills to contribute to the rapid movement of products from conception to market. With this emphasis on minimizing the time to market whether in a startup or a large corporation, it has become essential for engineers to integrate business strategies and customer focus with new product design skills.

The Certificate in Innovation, Product Design, and Entrepreneurship cuts across the Swanson School of Engineering and into the College of Business Administration to offer students the diverse skills to complement their technical engineering focus. The program offers a comprehensive set of courses that address principles in business, design, and innovation, and takes advantage of state-of-the-art makerspaces.

For details, please visit the **Innovation, Product Design, and Entrepreneurship Certificate** webpage.

Conceptual Foundations of Medicine Certificate

The **Conceptual Foundations of Medicine Certificate** is offered through the History and Philosophy of Science (HPS) department. The undergraduate certificate program is designed to offer a group of related courses in the areas of medical ethics, the nature of explanation and evidence in the biomedical sciences, and social problems such as assessments of alternative forms of health care delivery. The program is likely to be of particular interest to pre-med students and others interested in health-related professions but is intended to appeal to all students interested in social and philosophical problems in the biomedical sciences.

Requirements for the certificate are:

- The two introductory core courses (**HPS 0612** and **HPS 0613**) in Conceptual Foundations of Medicine;
- A two-term college-level course in biology;
- Two additional courses in a variety of departments dealing with social and conceptual issues in the biomedical sciences. The two elective courses must be in different departments;
- Students must achieve at least a C grade in each of the required courses, and at least a C+ average in the overall certificate requirements.

HPS 0612 and **HPS 0613** are approved engineering humanities/social science electives and can be used to satisfy the depth requirement. **BIOENG 1070** and **BIOENG 1071** satisfy the two-term college-level course in biology requirement. **BIOENG 1241** is accepted as one of the additional upper-level courses dealing with social and conceptual issues in the biomedical sciences. The other upper-level course requirement can be satisfied within the humanities/social science requirements. Proper planning during the Freshman year will facilitate meeting the requirements. A list of acceptable courses can be found on the certificate webpage.

Nanoscience and Engineering Certificate

The Nanoscience and Engineering Certificate is offered through the Department of Physics.

Required Courses

- **ENGR 0240** Nanotechnology and Nanoengineering
- **PHYS 1375/CHEM 1630** Foundations of Nanoscience
- **ENGR/CHEM 1730** or **PHYS 1903** Directed Research in Nanoscience or Nanotechnology

Elective Courses (Two Courses Must Be Selected)

- **CHEM 1410** or **CHEM 1420** Physical Chemistry 1 or 2 (3 credits) or **CHEM 1480** Intermediate Physical Chemistry (3 credits)
- **CHEM 1450** Molecular Modeling and Graphics (3 credits)
- **CHEM 1600** Synthesis and Characterization of Polymers (3 credits)
- **CHEM 1620** Atoms, Molecules, and Materials (3 credits)
- **ECE 0257** Analysis & Design of Electronic Circuits (3 credits)
- **ECE 1247** Semiconductor Device Theory (3 credits)
- **ECE 2295** Nanosensors (3 credits)
- **ENGR 0241** Fabrication and Design in Nanotechnology (3 credits)
- **IE 1012/2012** Manufacture of Structural Nanomaterials (3 credits)
- **MEMS 1057** Micro/NanoManufacturing (3 credits)

- **MEMS 1447** Nanocharacterization (3 credits)
- **MEMS 1469** Materials Science of Nanostructures (3 credits)
- **MEMS 1477** Thin Film Processes and Characterization (3 credits)
- **MEMS 1478** Nanoparticles: Science and Technology (3 credits)
- **MEMS 1480** Introduction to Microelectromechanical Systems (3 credits)
- **PHYS 0520** Modern Physics Measurements (3 credits)
- **PHYS 1361** Wave Motion and Optics (3 credits)
- **PHYS 1370** Quantum Mechanics 1 (3 credits) or **PHYS 1371** Quantum Mechanics 2 (3 credits)
- **PHYS 1374** Introduction to Solid State Physics (3 credits)

Two of the five courses can be used to satisfy the Bioengineering 2-course, 6-credit advanced engineering/science/technical elective requirement. The other three courses are in addition to Bioengineering major requirements.

Sustainability Certificate

The aim of the Undergraduate Certificate in Sustainability is to provide undergraduates the opportunity to enhance their education by including sustainability in their course of study. This new certificate program in "Sustainability" transcends existing Schools and Departments at the University of Pittsburgh, capitalizes on ongoing Sustainability-growth opportunities in teaching and research at the University of Pittsburgh, and utilizes the framework of the Mascaro Center for Sustainable Innovation (MCSI) to execute the certificate.

For details, please visit the **Sustainability Certificate** webpage.

Undergraduate Global Health Certificate

The Undergraduate Certificate in Global Health is for students wanting to get equipped with the analytical tools and professional skills necessary to address our world's most compelling issues. Students with a CERTIFICATE IN GLOBAL HEALTH will explore the transnational processes underpinning the global burden of disease and the social determinants of health, as well as related inequalities in access to high quality medical care.

For details, please visit the **Global Health Certificate** webpage.

Public Communication of Science and Technology Certificate

The Public Communication of Science and Technology certificate focuses on how writing can function in science and technical contexts.

For details, please visit the **Public Communication of Science and Technology Certificate** webpage.

Engineering Data Analytics Certificate

The Engineering Data Analytics undergraduate certificate prepares future Swanson School of Engineering students to take on the challenge of advancing and innovating engineering applications using the systematic acquisition, management, and analysis of data.

For details, please visit the **Engineering Data Analytics Certificate** webpage.

Engineering Science Minor

The **Engineering Science Minor** provides students in engineering or the sciences to broaden their education in various areas. The four minor options align with the four tracks in the Engineering Science major and allow students to choose topical areas and courses they are most interested in.

For details, please visit the **Engineering Science Minor** webpage.

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Academic Regulations, Procedures, and Guidelines

The Department of Bioengineering endorses and abides by the academic integrity policies of the Swanson School of Engineering and the University of Pittsburgh:

The integrity of the academic process requires fair and impartial evaluation on the part of faculty and honest academic conduct on the part of students. Students are expected to conduct themselves with a high level of responsibility in the fulfillment of their course of study. The faculty have a corresponding responsibility to make clear to students those standards by which the student will be evaluated and the resources permissible for use by students during their course of study. The educational process is perceived as a joint faculty-student enterprise that involves professional judgment by faculty and may involve, without penalty, reasoned exception by students to the data or views offered by faculty. Consistent with these considerations (and without limiting the scope and application in entirety to the academic programs of the University), faculty and students are directed to observe established guidelines on academic integrity.

For more information, please refer to the University of Pittsburgh **Guidelines on Academic Integrity**.

Admissions

Undergraduate Admissions

Any Freshman in the Swanson School of Engineering (SSoE) in good academic standing (cumulative grade point average (GPA) ≥ 2.00) and who has completed the Freshman Engineering Program courses **MATH 0220**: Analytical Geometry and Calculus 1 and **MATH 0230**: Analytical Geometry and Calculus 2, **PHYS 0174**: Basic Physics for Science and Engineering 1 and **PHYS 0175**: Basic Physics for Science and Engineering 2, **CHEM 0960**: General Chemistry for Engineers 1 and **CHEM 0970**: General Chemistry for Engineers 2, **ENGR 0011**: Introduction to Engineering Analysis and **ENGR 0012**: Introduction to Engineering Computing, or the honors versions of those courses, can elect to matriculate to the Department of Bioengineering as a sophomore.

Please contact the **SSoE First Year Program** for information on applying to the Swanson School of Engineering.

Transfer Students

Students seeking to transfer to the Department of Bioengineering from any program within the University of Pittsburgh (e.g., Arts & Sciences or another SSoE department), any branch campus of the University of Pittsburgh, or any other two-year or four-year college or university must have completed physics, chemistry, and math equivalent to the Freshman Program (see above) and have a GPA ≥ 3.50 at the time of application and transfer into the Department of Bioengineering.

Non-SSoE students interested in transferring to the Department of Bioengineering should visit the **SSoE Transfer Students** web site for more information on the application process.

Current SSoE undergraduate students in another department should contact the Department of Bioengineering directly.

AP/IB/Transfer Credits

Freshmen students accepted into the Swanson School of Engineering may earn advanced standing credit by taking Advanced Placement or International Baccalaureate classes in their high schools. Students must have their AP or IB scores sent directly to the University of Pittsburgh for review by the Freshman Program for determination of the appropriate course and credits awarded. Likewise, Freshman students can transfer credits earned from another two-year or four-year college or university by submitting an official transcript to Freshman Program for determination of the appropriate course and credits awarded. Determination of advanced standing should be made as soon as possible after admission to the Freshman Engineering Program. For more information, visit **Advanced Standing** to determine your eligibility.

Note. The Department of Bioengineering accepts AP/IB credits certified by the Swanson School of Engineering with the exceptions of **BIOSC 0060**, **BIOSC 0150**, and **BIOSC 0160** and the restriction that only two AP/IB courses can be used to satisfy the Humanities/Social Science requirement. The Department of Bioengineering **does accept** AP/IB credit for **BIOSC 0050**.

The academic record of **SSoE Transfer Students** will be reviewed for advanced-standing credit by the SSoE Transfer Student Office after acceptance for admission to the Department of Bioengineering. The determination of advanced standing will be made in conjunction with the Bioengineering Associate Chair for Undergraduate Education according to Swanson School of Engineering policy and criteria established by ABET, the engineering accrediting organization. In general, advanced standing for engineering or engineering science courses will be given only if the courses were taken at an ABET-approved engineering program. Advanced standing for mathematics, science, humanities, and social science courses will be awarded to the extent that such courses match specific University of Pittsburgh Arts and Sciences courses that are acceptable by the Swanson School of Engineering. In particular, humanities and social science courses must adhere to the **Swanson School of Engineering Guidelines and Requirements**.

Academic Regulations

Graduation Requirements

To receive a Bachelor of Science in Bioengineering, students must:

1. Either complete the Bioengineering curriculum in effect at the time of matriculation to the Department of Bioengineering or any subsequent, revised Bioengineering curriculum;
2. Have an overall, cumulative GPA of at least 2.00 for all courses taken at the University of Pittsburgh and GPA of at least 2.00 for all BIOENG departmental courses;
3. Have a grade of D- or better (or S) in every course used to satisfy Bioengineering curriculum requirements (courses with F, G, I, NC, U, or W grades cannot be used);

4. Have at least one course with a **W**-designation (writing) taken at the University of Pittsburgh;
5. Complete the senior year while in residence at the University of Pittsburgh;
6. Apply for graduation at the SSoE Office of Administration before the deadline for the term of graduation (application for engineering minors and certificates should be made at the same time).

Honors Lists

At the end of each term, the academic records of all undergraduate degree students in the Swanson School of Engineering are reviewed to determine eligibility for the Term Honor List and the Dean's Honor List. Students who qualify for both honor lists will appear only on the Dean's Honor List. Please refer to **University of Pittsburgh Undergraduate Catalog** > **Swanson School of Engineering** > **Honors Lists** for details.

Academic Standing

To be considered in good academic standing, a student's cumulative GPA must be at least 2.00, **and** the student **must be making satisfactory progress** toward earning an engineering degree. The policy for students determined to be in jeopardy of not maintaining good academic standing can be found at **University of Pittsburgh Undergraduate Catalog** > **Swanson School of Engineering** > **Academic Standing**.

Repeating Courses

Course repeat policies can be found at **University of Pittsburgh Undergraduate Catalog** > **Swanson School of Engineering** > **Repeating Courses**. **Students are highly encouraged to check these policies with the Bioengineering Associate Chair for Undergraduate Education prior to repeating a course**.

Note. D- is the minimum *passing* grade in any course. Generally, students do not need to repeat any course in which a passing grade has been earned. Students may want to consider retaking a course in which a C- or lower was earned if:

1. the student did not grasp (master) information that the student really wanted to master,
2. if better mastery will be required in an advanced course, or
3. a C or better is required (e.g., MATH requires that students have a C or better in a course before taking a higher-level course).

Retaking a course simply to improve one's GPA is not really effective since the difference in cumulative GPA between repeating the course and not repeating the course is typically less than 0.02 at the time of graduation.

Academic Course Credit

Transfer Course Credits

Students in the Department of Bioengineering may take courses at other universities to satisfy graduation requirements **only with advance approval by the Bioengineering Associate Chair for Undergraduate Education**. Courses for transfer credit must be taken at colleges or universities that offer full four-year degree programs. Engineering and engineering science courses must be taken at an ABET-approved engineering program. When completing the **Bioengineering (Bioengineering) Transfer Credit Preapproval Form**, students are responsible for identifying the specific University of Pittsburgh course that matches the outside course description. Students must earn a grade of C or higher for the course to be accepted for transfer credit. Students must arrange for their transcript to be sent to their Bioengineering Associate Chair for Undergraduate Education. Note that once a student is enrolled in the Swanson School of Engineering, he or she is no longer permitted to take courses at a two-year or community college for transfer credit. Further details can be found at **University of Pittsburgh Undergraduate Catalog** > **Swanson School of Engineering** > **Advanced Standing for Courses Taken Outside the University**.

On-Line Course Policy

Students in the Swanson School of Engineering may take one Humanities/Social Science elective and one Engineering/Engineering Science/Mathematics/Science course on-line. The conditions that on-line courses are subjected to can be found at **University of Pittsburgh Undergraduate Catalog** > **Swanson School of Engineering** > **Online Courses**.

Graduate Courses

Students may take graduate-level courses to satisfy undergraduate degree requirements as jointly determined by the student and the student's academic advisor. Obtaining appropriate permission to enroll in the graduate course is the student's responsibility. A Swanson School of Engineering undergraduate student requiring fewer than 15 credits to complete the requirements for the baccalaureate degree and who intends to continue study toward an advanced degree may be permitted during their final term to register for graduate courses that will later apply toward a graduate degree. The student must obtain written permission from the school of proposed graduate study that the courses may count when and if the student is admitted into the graduate program. Although these credits will appear on the undergraduate transcript, they will not count toward fulfilling undergraduate degree requirements. They will be posted as advanced standing credits on the graduate record.

Carnegie Mellon University Cross Registration

Cross registration is a program through the **Pittsburgh Council on Higher Education (PCHE)** that provides an opportunity for enriched educational programs by permitting students to attend courses at any of ten participating colleges and universities. Carnegie Mellon University (CMU) is the primary institution at which bioengineering students take classes. Students can cross-register for a maximum of one course per semester.

Students who want to cross-register for **CMU courses** need to:

- Complete a **cross-registration form** according to the **instructions**;
- Have the form signed by the Bioengineering Associate Chair for Undergraduate Education;
- Submit the completed form to the SSoE Office of Administration.

Notes. Students must be full-time (12 or more credits) to cross-register; 3 CMU credits/units correspond to 1 Pitt credit; check your cross-registration after acceptance to be sure you have been registered for the correct course with the correct number of credits.

Over 18 Credits

Students who want to take more than 18 credits in a semester should complete the **Over 18 Credits form** and bring it to the Bioengineering Associate Chair for Undergraduate Education for approval. The approved form is then submitted to the SSoE Office of Administration for approval by the Associate Dean for Academic Affairs.

Additional Certifications

Dual Degrees

Bioengineering students can obtain a dual undergraduate degree with another Swanson School of Engineering department or a department within the College of Arts and Sciences (Further information can be found at **University of Pittsburgh Undergraduate Catalog** > **Swanson School of Engineering** > **Arts and Sciences-Engineering Dual Degree Program**). The basic rules are that (1) degree requirements for each degree must be satisfied and (2) each degree must have at least 30 credits not used for the other degree. The second rule implies that many courses can be used to satisfy requirements for both degrees.

Bioengineering students interested in a dual degree should contact the Bioengineering Associate Chair for Undergraduate Education (who may already have examples of dual degree curricula for the intended dual degree). Students will be asked to:

1. Fill out the **Bioengineering Degree Progress Worksheet** with estimated semesters in which all courses required for the Bioengineering degree will be taken. **Note**: Students can contact the Bioengineering Associate Chair for Undergraduate Education to determine whether any courses required for the dual degree can be used to satisfy a corresponding Bioengineering degree requirement (e.g., **ECE 0031** for **BIOENG 1310**).
2. Identify all course requirements for the second degree.
3. Identify overlapping courses for both curricula.
    - Identify all required courses in the Bioengineering curriculum that can be used to satisfy the second-degree requirements.

  - Identify all elective courses in the Bioengineering curriculum that can be used to satisfy the second-degree requirements.
  - Color code the background for courses that can be used to satisfy both curricula.

4. List all courses required for the dual degree that cannot be counted toward both degrees in the lower left section of the degree progress worksheet with estimated term of completion.

   Note. At least 30 credits of coursework should be listed.

After completion of above steps, students should review their proposed dual degree program with the Bioengineering Associate Chair for Undergraduate Education. Once approved, students are responsible for seeking approval from the appropriate administrator for the second degree.

Minors and Certificates

A minor and/or certificate on your transcript and resume distinguishes you as someone who has gone beyond the minimum requirements to get your degree. The minor (certificate) identifies additional skills, knowledge, and abilities that you have acquired.

Obtaining a minor or certificate generally requires completing a focused series of five to seven courses. With proper planning, one or more courses can be used to satisfy both major and minor or certificate requirements. Early planning can maximize your educational experience. See **Chapter 4** > **Minors and Certificates** for detailed information on requirements for various minors. Additional information can also be found at University of Pittsburgh Undergraduate Catalog > **Swanson School of Engineering**.

Mentoring and Advising

Advising/Mentoring Rationale

The purpose of undergraduate advising is to help each student achieve his/her post-graduate goals, which is very individualistic and requires serious reflection on the part of the student about why he/she is in the Bioengineering Program and how Bioengineering will help the student realize post-graduate goals. Reflection on post-graduate goals is an ongoing process. Goals may change as a result of new course that illuminates an area of bioengineering that the student finds interesting **or** as a result of a research experience in a previously unexplored area **or** as a result of an extracurricular experience, e.g., Cooperative Education, or interactions with professors and other students that provide new avenues to explore.

Advising **is not** about putting together a minimal set of courses that will meet the Bioengineering Program requirements. Rather, advising is an ongoing mentoring process that provides a focal point for the student to discuss evolving career aspirations with a knowledgeable faculty member who acts as a mentor to the student. Mentors are a resource who know a lot about: The university; how the university works; options available to you; and, how you can accomplish your goals. Mentors can help you understand your choices and explain options when you need more information than is available from other sources. Mentors can help connect you with other resources. While meeting with your mentor is required once a semester to approve course selections for the following semester (registration holds will not be lifted until the meeting is documented by your mentor), students are encouraged to interact on a more frequent basis.

Mentor Assignment

A Bioengineering student matriculating to the department from the Swanson School of Engineering **First Year Program** or as a **Transfer Student** from another program (internal or external to SSoE), is assigned a faculty mentor who will help guide him/her through the program in preparation for his/her individual post-graduate goals. In order to distribute advising and mentoring responsibilities equitably among faculty mentors, students are assigned to mentors without regard to their intended track of study (which can change as the student progresses through the program and develops new interests, choosing a different track). All mentors are familiar with the undergraduate curriculum and interested in helping their advisees to successfully achieve the advisees post-graduate goals.

Student/Mentor Responsibilities

Student Responsibilities. Students are responsible for maintaining an up-to-date Degree Progress Workbook (DPW) that documents their progress through the Bioengineering Program course requirements. Students are also responsible for maintaining an up-to-date Comprehensive Electives Plan (CEP) that documents their post-graduate goals and how their six track and two advanced engineering/science electives are directed toward helping them achieve their goals. An **up-to-date DPW and CEP must be brought** to any meeting with mentors to discuss course selections for the following semester. Without those documents, mentors are free to cancel the meeting.

Students should consult the **University Course Descriptions** website and PeopleSoft listings for course availability when making course selections. Although courses are fairly stable in terms of semester offered and days/time in a semester, changes are made without notice.

Note. Students, and only students, are responsible for ensuring that all courses listed on the DPW are following degree requirements as posted in the Undergraduate Bioengineering Program description. In other words, students, and only students, are responsible for ensuring that degree requirements have been met.

Mentor Responsibilities. Students and their respective mentors will discuss academic progress as recorded on the DPW, the post-graduate goals as elucidated in the CEP, and how current course selections are directed toward meeting Bioengineering degree requirements and post-graduate goals. In addition, students should expect their mentors to inquire about other actions on their part (e.g., **Cooperative Education**, **Study Abroad**, leadership in student organizations, and research activities) that are important to helping students reach their goals.

Mentors will document approval of discussed course selections, and other pertinent matters, after the meeting. The student’s university registration hold for the following semester will be lifted *only after* the mentor has complete this process.

General Mentoring Process

Students should feel free to consult with their mentor outside of the registration process. Mentors are knowledgeable and have been through the education process and can help students through also. Mentors are willing to help students reflect on what appropriate career aspirations might be and effective routes to realizing the aspirations.

Graduation Checkup

Bioengineering Seniors are required to complete the **Graduation Checkup** procedure the semester before expected graduation. The graduation checkup will compare courses listed on the student's DPW (which corresponds with Bioengineering Program requirements as posted in the Undergraduate Bioengineering Program) and student's official university course record to assure that all requirements for graduation are met. Discrepancies between the DPW and the Bioengineering Program requirements will be noted in time for the student to correct them the following semester.

The graduation checkup procedure consists of completing and submitting, either through a submission portal or email (the mode depends on when, that is, April, August, or December, Bioengineering Seniors plan to graduate), the latest version of the DPW reflecting current and past courses and courses the student is planning on taking during the subsequent semester. After the document is perused by the Bioengineering Associate Chair for Undergraduate Education, the student will receive a response by email whether his/her intended course schedule as stated in their DPW satisfies graduation requirements or whether the DPW has deficiencies in satisfying graduation requirements.

Cooperative Education

Cooperative Education, a.k.a. Co-op, is the single best educational experience an undergraduate can have. Co-op provides a unique opportunity for undergraduate students to connect directly with industry for *real-world* experience in bioengineering. By complementing and expanding upon the classroom curriculum, Co-op enriches the undergraduate experience. The Department highly encourages all undergraduates, including transfer students, regardless of future career aspirations (industry, graduate school, medical school, etc.) to participate in Co-op. Experience gained through the Co-op program will pay dividends in future endeavors, whatever they may be.

Some of the reasons to participate in Co-op include:

- Gain practical experience with engineering tools and equipment used in bioengineering practice.
- Gain experience and knowledge that will help you make a more informed decision about your post-graduation plans (industry, graduate school, health-related professions). Do you really want to...?
- Gain maturity that appeals to those who control your entry into industry, graduate school, or a health- related profession.

- Improve post-graduation placement prospects, regardless of intended destination.
- Due to salaries earned during Co-op cycles, many students can forgo part-time employment while on school rotations, providing more time to devote to academics or extracurricular activities.
- Grade point averages increase significantly for over two-thirds of Co-op participants.
- Academic credit. Co-op participants register for the 1-credit **ENGR 1090P** for each rotation. Satisfactory completion of three **ENGR 1090P** rotations can be used as a technical elective.

Process

Students typically spend three rotations of four months each (a semester) employed by one of the participating Co-op companies. Students gain appreciation for the application of their academic skills in solution of real-world problems and greater understanding in their field of interest. The Co-op experience is a mutually beneficial undertaking between the Co-op employer and the student. Hence, students typically start the Co-op experience anytime between completion of the Spring semester, Sophomore year (when students have gained sufficient engineering skills to offer the Co-op employer) and the start of Fall semester, Senior year (when the required two-semester senior design sequence commences).

Note. The process for Bioengineering students differs slightly from that in the Co-op Office brochure:

1. Register with the **Co-Op Program**.

   Note. You do not need to have an approved Co-op schedule to register or search for a position. Co-op schedules are individually tailored to the student, depending upon which semester one starts and the rotation cycle (three Co-op semesters in a row, alternating Co-op/school semesters, or some other sequence). Contact the Associate Chair for Undergraduate Education for possible Bioengineering Co-op schedules. Please note that the Department of Bioengineering will provide you an approved schedule **only after** you have a co-op offer.
2. Start searching for a position.

   Please note that this is student's responsibility. The Co-op Office can help, but do not expect them to do all the work.
3. Notify both the Co-op Office and the Bioengineering Associate Chair for Undergraduate Education when you have an offer. The Bioengineering Associate Chair for Undergraduate Education will prepare an individualized (and approved) Co-op schedule based upon your educational process and the semesters you will Co-op.
4. The Co-op Office will register you for **ENGR 1090P** for each semester that you Co-op.
5. Inform the Co-op Office and the Bioengineering Associate Chair for Undergraduate Education immediately about any changes to your Co-op plans.

The wonderful staff in the Co-op Program Office work individually with each student applicant to provide resume and interviewing assistance, as well as specialized job development. When requested, the Co-op Program Office will help find a suitable Co-op position, which can be local, national, or even international in location. Bioengineering students work with the Bioengineering Associate Chair for Undergraduate Education upon receipt of an offer from a participating Co-op employer to develop a personalized Co-op rotation/academic schedule to assure timely progression to graduation. The Co-op Program has the support of key university offices including registration, financial aid, and housing.

Interested students should explore opportunities with the Co-op Program staff. Follow up by discussing your interests with your advisor and the Bioengineering Associate Chair for Undergraduate Education.

Academic Credit

Students participating in the Co-op Program register for the 1-credit course **ENGR 1090P** for each rotation. Students will receive a grade of **S** for satisfactory completion of the rotation. Bioengineering students who satisfactorily complete **three** Co-op rotations (grade of **S** in each of the three **ENGR 1090P** courses) can use the credits to satisfy a 3-credit advanced engineering/science/technical elective in the undergraduate program by submitting a professional report documenting their experience to the Bioengineering Associate Chair for Undergraduate Education. The report format is as follows:

1. A cover page which includes:
   - A title - based on the main topics of your Co-op assignment
   - Your name
   - The company/companies at which you worked
   - The semesters when you worked
2. An abstract of no more than 200 words that conveys the summary of the foremost results/conclusions of your Co-op assignment. **Do not** include comments on the Co-op program itself or the effect of your assignment on your academic performance in this section.
3. The report should be divided into three main sections:
   - The Co-op program itself – include all comments, including unfavorable ones and suggestions for improvement, on our Co-op program, how it influenced you, how it affected your academic performance, whether it had any bearing on your career choices or opportunities, how it helped/hurt your finances, whether the program is a benefit to our department, etc. **Please be honest** - this part of your report will be used to improve the program. Please suggest ways to improve the program for new students. (3-4 pages suggested.)
   - The assignment(s) that you had; describe the problem(s) on which you worked. Give the reader a sense of the problem as it was presented to you. If you had several assignments, make note of them all, but emphasize the one on which you spent the most time or made the most significant contributions. **Do not** include any data or information that is confidential. The summary should provide an informative set of conclusions you made on a specific task or contributions that you made to a task involving many people. (3-5 pages suggested.)

   - Clearly describe the relationships between your assignment(s) and your academic program. Indicate specific courses that were particularly useful. (2-3 pages suggested.)
4. Submit an electronic copy of your report to the Bioengineering Associate Chair for Undergraduate Education as soon as practicable after your last Co-op rotation.

International Study

Most companies that employ bioengineers are engaged in multinational activities with a multinational workforce. Bioengineers must develop skills that allow them to work effectively in a global context. The Department of Bioengineering believes that the most effective way for undergraduates to develop such skills is through an international experience that provides cultural as well as educational context and that every undergraduate student should have an international experience. International experiences (i.e., study abroad) take many forms:

- Short programs (two to four weeks abroad);
- Full semester programs;
- Research internships;
- Co-op internships.

Bioengineering students have studied engineering in Brazil, Chile, Peru, Costa Rica, Viet Nam, China, Singapore, Germany, Netherlands, France, Spain, Turkey, and other locations. The Department of Bioengineering works closely with the Swanson School of Engineering's International Program Office to tailor individual experiences for our students.

Visit **Engineering International Programs** to learn more about what it means to practice engineering on a global scale. Many programs and options are available. Don't hesitate to ask questions about how you can craft your own international experience at Pitt!

Clinical Site Certification

Certain courses that involve student participation in an UPMC clinical setting may require that students obtain Clinical Site Student Certification prior to enrollment. Students are required to submit the following original documents to the Course Instructor who will deliver them to the Bioengineering Associate Chair for Undergraduate or Graduate Education for processing. Documents will be inspected prior to making two sets of photocopies. One set of photocopies will be placed in the student’s departmental record and one set will be provided to the Associate Dean for Academic Affairs. The Associate Dean will issue the student a certificate of compliance, copies of which will be retained by the Associate Dean’s office and by the Department of Bioengineering. The original documents will be returned to the student, who should keep them for presentation, as needed, to meet the requirements for entering other clinical sites.

1. Copy of HIPAA Certification – **UPMC Information Privacy and Security Awareness Training for Physicians, Mid-Level Providers, Dentists, Staff, and Students Who Are**

Not Employed by UPMC but Who Encounter Protected Health Information in UPMC Facilities. (Submit only once.)

2. Copies of the following **PA DHS Certifications**
    - Pennsylvania Child Abuse History Clearance (ACT 33)
    - Pennsylvania Criminal Record Check Clearance (ACT 34)
    - FBI Fingerprint Criminal Background Check Clearance (ACT 73)
3. Copy of immunization record/history and health screening record.
4. Copy of TB screening results (required annually).
5. Certification that you have attended an overview seminar on clinical site conduct.

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Post-Graduation Planning

Bioengineering Career Planning Guide

In your second year, you start setting in motion the events and opportunities that will make it possible for you to achieve your goals after graduation. Please feel free to contact the Bioengineering Associate Chair for Undergraduate Education to request a **Bioengineering Career Planning Guide** to help you make informed decisions at the right times, given the three common career paths for Bioengineering students.

As part of your post-graduation preparation, incorporating personal financial planning is a key component. **The College of Business Administration** offers a 1-credit undergraduate course (**BUS 1392**: Personal Financial Planning) in personal finance that the Bioengineering Department highly recommends Bioengineering students enroll in if their schedules permit. The course specifically deals with the basics of personal financial planning and focuses on near term planning with emphasis on paying off student debt, initial savings, investing for short- and long-term goals, etc.

Medical Career Preparation

An undergraduate degree in Bioengineering provides an excellent background for pursuing graduate studies in many medical health-related fields:

- Doctor of Medicine (MD)
- Doctor of Osteopathic Medicine (DO)
- Doctor of Dental Surgery (DDS)
- Doctor of Dental Medicine (DMD)
- Physician Assistant (PA)
- Physical Therapist (PT)
- Doctor of Veterinary Medicine (DVM).

While many course requirements for these graduate studies are satisfied by the Bioengineering curriculum, students interested in pursuing health-related graduate studies need to consult appropriate guides to ensure that they have met all of the course requirements for entry into the school of their choice. More information can be found at:

- **MD & DO**
- **DDS & DMD**
- **PA**
- **PT**
- **DVM**

Courses not in the Bioengineering curriculum that are typically required by medical schools include:

1. **BIOSC 0160**: Biology Laboratory 2 (or equivalent)
2. **CHEM 0310**/**CHEM 0330**: Organic Chemistry 1 plus Laboratory
3. **CHEM 0320**/**CHEM 0340**: Organic Chemistry 2 plus Laboratory
4. **PHYS 0219** (2-credits physics laboratory)

CHEM 0310 and **CHEM 0320** (but not the labs) are accepted electives within the Bioengineering program. Many medical schools will accept our engineering labs in lieu of the physics laboratory.

Biochemistry, genetics, microbiology, psychology, and sociology are not actually required courses by most schools. However, because questions on these subjects are likely to be on the **MCAT**, students should consider adding them to their course of studies.

The **Honors College** provides excellent advising for students interested in the health professions, helping to plan a curriculum that maximizes chances for acceptance by a medical school. **AAMC** (American Association of Medical Colleges) is another source of information for those considering a career in medicine, as well as the location for finding relevant forms and making application to medical schools (AMCAS page within the AAMC site).

The Medical College Admission Test (**MCAT**) is offered several times a year from January through September. Plan on taking the exam in spring of your junior year. While many students take commercially-available courses directed toward helping improve the MCAT score, the secret to success is practice, practice, practice. The MCAT is a multiple-guess exam unlike any other.

Plan to do volunteer work at least the summer before your senior year. You can volunteer any time before this but you must do some volunteer work to show your interest in the field. Contact any hospital Volunteer Office to get more information. If you are going to volunteer at any of the UPMC hospitals during the school year, make contact the summer before because spots fill up quickly.

Register with **Health Professions Advising** in the Honors College for help in preparing your dossier for the Preprofessional Health Committee. The committee reviews medical school applications in the summer, so have the forms filled out at the end of the spring term junior year or at the beginning of the summer. Letters of recommendation are required for the committee review. Ask your recommenders at least six weeks before the letters are due to provide sufficient time to prepare a thoughtful letter of recommendation.

A

Appendix A – Example Bioengineering Undergraduate Curriculum

Non-Pre-Med Version

EXAMPLE BIOENGINEERING UNDERGRADUATE CURRICULUM
(For students entering the program Fall 2014 through Fall 2023)

One possible four-year path through the curriculum
BOLDFACED courses are Bioengineering Core or Track Elective courses

FRESHMAN YEAR

FALL SEMESTER	Credits	SPRING SEMESTER	Credits
MATH 0220: Analytical Geometry & Calculus 1	4	MATH 0230: Analytical Geometry & Calculus 2	4
PHYS 0174: Basic Physics for Science & Engineering 1	4	PHYS 0175: Basic Physics for Science & Engineering 2	4
CHEM 0960: General Chemistry for Engineers 1	3	CHEM 0970: General Chemistry for Engineers 2	3
ENGR 0011: Introduction to Engineering Analysis	3	ENGR 0012: Introduction to Engineering Computing	3
Humanities/Social Science Elective	3	Humanities/Social Science Elective	3
ENGR 0081: Freshman Engineering Seminar 1	0	ENGR 0082: Freshman Engineering Seminar 2	0
	17		17

SOPHOMORE YEAR

FALL SEMESTER	Credits	SPRING SEMESTER	Credits
BIOENG 1070: Introductory Cell Biology 1	3	**BIOENG 1071**: Introductory Cell Biology 2	3
BIOSC 005x: Foundations of Biology Lab 1	1	**BIOENG 1210**: Biothermodynamics	3
MATH 0240: Analytical Geometry & Calculus 3	4	**BIOENG 1310**: Bioinstrumentation	3
MATH 0290: Differential Equations	3	**BIOENG 1630**: Biomechanics 1	3
ENGR 0135: Statics & Mechanics of Materials 1	3	BIOENG 1000: Statistics for Bioengineering [b,c]	4
Track Elective [a]	3	or **Track Elective** (**CHEM 0320** only)	[3]
BIOENG 1085: Introduction to Bioengineering (Seminar)	0	**BIOENG 1085**: Introduction to Bioengineering (Seminar)	0
	17		16

[a] Pre-med and CE Track students should take **CHEM 0310** (Organic Chemistry sequence) as a Track Elective
[b] Pre-med and CE Track students should take **CHEM 0320** (Organic Chemistry sequence) as a Track Elective. BIOENG 1000 moves to Spring Semester, Junior Year
[c] Effective Fall 2018, only BIOENG 1000 satisfies the statistics requirement regardless of year of matriculation to the program

JUNIOR YEAR

FALL SEMESTER	Credits	SPRING SEMESTER	Credits
BIOENG 1002: Intramural Internship [d]	3	**BIOENG 1150**: Bioengineering Methods & Applications	3
BIOENG 1220: Biotransport Phenomena	3	Biosignals Application Course (**BIOENG 1580** or **1680**) [e] or **Track Elective**	4 or 3
BIOENG 1320: Biological Signals & Systems	3		
BIOSC 1250: Human Physiology	3	**Track Elective** [f]	3
MATH 0280: Introduction to Matrices & Linear Algebra	3	**Track** or **Imaging Elective**	3
BIOENG 1241: Bio-Ethics [d]	3	Humanities/Social Science Elective	3
BIOENG 1085: Introduction to Bioengineering (Seminar)	0	**BIOENG 1085**: Introduction to Bioengineering (Seminar)	0
	18		16 or 15

[d] **BIOENG 1002** & **BIOENG 1241** may be taken Fall or Spring Semester, Junior or Senior Year
[e] The Biosignals Application Course (**BIOENG 1255**) can be taken Fall of Senior Year
[f] Students who took **CHEM 0320** Spring Semester Sophomore Year must take BIOENG 1000

SENIOR YEAR

FALL SEMESTER	Credits	SPRING SEMESTER	Credits
BIOENG 1160: Bioengineering Design 1	3	**BIOENG 1161**: Bioengineering Design 2	3
Track Elective or **Biosignals Application Course**	3 or 4	**Track Elective** or **Biosignals Application Course**	3 or 4
Track or **Imaging Elective**	3	**Track** or **Imaging Elective**	3
Advanced (Free) Engineering/Science Elective	3	Advanced (Free) Engineering/Science Elective	3
Humanities/Social Science Elective	3	Humanities/Social Science Elective	3
BIOENG 1085: Introduction to Bioengineering (Seminar)	0	**BIOENG 1085**: Introduction to Bioengineering (Seminar)	0
	15 or 16		15 or 16

NOTE: All students must have an imaging course that is on the approved list of imaging courses
NOTE: Four (4) of the 8 Advanced Engineering/Science Electives (6 Track plus 2 Advanced (Free) Engineering/Science Electives) **must be** engineering courses (any department)
NOTE: Humanities/Social Science Electives must be taken from the approved School of Engineering list
NOTE: At least one course must have a **W** (writing) designation

Pre-Med Version

EXAMPLE BIOENGINEERING UNDERGRADUATE CURRICULUM
(For students entering the program Fall 2014 through Fall 2023)

One possible four-year path for pre-med students through the curriculum
BOLDFACED courses are Bioengineering Core or Track Elective courses
Italicized courses/text are prerequisites/requirements for medical/dental school

FRESHMAN YEAR

FALL SEMESTER	Credits	SPRING SEMESTER	Credits
MATH 0220: Analytical Geometry & Calculus 1	4	MATH 0230: Analytical Geometry & Calculus 2	4
PHYS 0174: Basic Physics for Science & Engineering 1	4	*PHYS 0175: Basic Physics for Science & Engineering 2*	4
CHEM 0110: General Chemistry 1	4	*CHEM 0120: General Chemistry 2*	4
ENGR 0011: Introduction to Engineering Analysis	3	ENGR 0012: Introduction to Engineering Computing	3
Humanities/Social Science Elective[(a)]	3	Humanities/Social Science Elective[(a)]	3
ENGR 0081: Freshman Engineering Seminar 1	0	ENGR 0082: Freshman Engineering Seminar 2	0
	18		18
Other semester activities: Volunteer (V)/Clubs		*Other semester activities: V/Clubs*	

SUMMER SEMESTER: *V and/or Research (R) and/or Shadow (S) and/or Fellowships (F)*

[(a)] *Psychology is required for medical/dental school. Students can take, e.g., PSY 0010 or PSY 1205 to meet this requirement*

SOPHOMORE YEAR

FALL SEMESTER	Credits	SPRING SEMESTER	Credits
***BIOENG 1070** : Introductory Cell Biology 1*	3	***BIOENG 1071** : Introductory Cell Biology 2*	3
BIOSC 005x: Foundations of Biology Lab 1	1	**BIOENG 1210**: Biothermodynamics	3
MATH 0240: Analytical Geometry & Calculus 3	4	**BIOENG 1310**: Bioinstrumentation	3
MATH 0290: Differential Equations	3	**BIOENG 1630**: Biomechanics 1	3
ENGR 0135: Statics & Mechanics of Materials 1	3	*BIOSC 0067: Foundations of Biology Research Lab*	1
***CHEM 0310** : Organic Chemistry 1*	3	***CHEM 0320** : Organic Chemistry 2*	3
BIOENG 1085: Introduction to Bioengineering (Seminar)	0	*CHEM 0345: Organic Laboratory*	2
	17	**BIOENG 1085**: Introduction to Bioengineering (Seminar)	0
			18
Other semester activities: V/R/Leadership (L)		*Other semester activities: V/R/L*	

SUMMER SEMESTER: *V and/or R and/or S and/or F or Study Abroad. Start MCAT preparation*

JUNIOR YEAR

FALL SEMESTER	Credits	SPRING SEMESTER	Credits
BIOENG 1000: Statistics for Bioengineering	4	**BIOENG 1002**: Intramural Internship	3
BIOENG 1220: Biotransport Phenomena	3	**BIOENG 1150**: Bioengineering Methods & Applications	3
BIOENG 1320: Biological Signals & Systems	3	Biosignals App Course (**BIOENG 1580/1680**) or **Track Elective**[(b)]	4 or 3
BIOSC 1250: Human Physiology	3	**Track Elective**[(b)] if not selecting Biosignals Application	3
MATH 0280: Introduction to Matrices & Linear Algebra	3	**Track Elective**[(b)] or **Imaging Elective**	3
BIOENG 1085: Introduction to Bioengineering (Seminar)	0	Humanities/Social Science Elective	3
	16	**BIOENG 1085**: Introduction to Bioengineering (Seminar)	0
			16 or 18
Other semester activities: V/R/L; MCAT preparation		*Other semester activities: V/R/L; MCAT preparation*	

SUMMER SEMESTER: *R/F; Take MCAT in May or June; Apply to Health Professions Committee; Apply to AMCAS, AACOMAS, or AADSAS; Study Abroad*

[(b)] *Biochemistry/chemical biology is required for medical/dental school. Students can take **BIOSC 1000** / **CHEM 1810** to meet this requirement*

SENIOR YEAR

FALL SEMESTER	Credits	SPRING SEMESTER	Credits
BIOENG 1160: Bioengineering Design 1	3	**BIOENG 1161**: Bioengineering Design 2	3
Biosignals Application Course (**BIOENG 1255**) or **Track Elective**	4 or 3	Biosignals Application Course (**BIOENG 1255**) or **Track Elective** [(c)]	4 or 3
Track Elective [(c)] if Biosignals Application already selected	3	**Track Elective** [(c)] or **Imaging Elective** if Biosignals already selected	3
Track Elective [(c)] or **Imaging Elective**	3	BIOENG 1241: Bio-Ethics	3
Advanced (Free) Engineering/Science Elective	3	Advanced (Free) Engineering/Science Elective	3
Humanities/Social Science Elective	3	Humanities/Social Science Elective	3
BIOENG 1085: Introduction to Bioengineering (Seminar)	0	**BIOENG 1085**: Introduction to Bioengineering (Seminar)	0
	16 or 18		16 or 18
Other semester activities: V/R/Interview		*Other semester activities: V/R/Interview*	

[(c)] *Microbology is required for some dental schools. Students can take **BIOSC 1850** to meet this requirement*

NOTE: All students must have an imaging course that is on the approved list of imaging courses
NOTE: Four (4) of the 8 Advanced Engineering/Science Electives (6 Track plus 2 Advanced (Free) Engineering/Science Electives) **must be** engineering courses (any department)
NOTE: Humanities/Social Science Electives must be taken from the approved School of Engineering list
NOTE: At least one course must have a **W** (writing) designation
NOTE: *Medical/dental schools require 2 English courses (not film)*

B

Appendix B – Senior Design (BIOENG 1160/1161)

While aspects of engineering design are incorporated in several of the Bioengineering Program core and elective courses, the keystone design experience is captured in our full-year, two-semester senior design course sequence, BIOENG 1160 and BIOENG 1161. The design experience employs a team-based approach to the *biodesign* process, combining the common core skills of all team members with particular knowledge of individual members gained through their area of concentration. Student teams select their design projects and mentors through an extensive unmet-needs identification process in various clinical settings. Students design, fabricate, and evaluate iterative prototypes in context of the FDA's Quality System Regulation (QSR) (and the Design Controls portion in particular) that are subsequently tested to determine whether functional requirements are met (Verification and Validation).

Numerous considerations are addressed in teaching the design process, including: **(1)** needs assessment coupled with use a modified Osterwalder business model canvas to identify, refine, update, and challenge the proposed value proposition and customer archetype(s) for the design project; **(2)** introduction to the unique requirements of the medical design process as required by the FDA's Quality System Regulation, the Centers for Medicaid and Medicare Services (CMS) reimbursement requirements, and Institutional Review Board (IRB) oversight of human subjects investigations; **(3)** introduction to state-of-the-art tools in computer-aided design (SolidWorks), computational fluid dynamics, finite element analysis and statistical design of experiments (DesignExpert); **(4)** assessment/prediction of component and product reliability; and **(5)** introduction to and use of low-, medium-, and high-resolution prototyping, fabrication, and production techniques used in the medical product industry. Design prototypes are twice presented to faculty, students, industrial representatives, and the general public at the Swanson School of Engineering (SSoE) Design Expo: initial design concepts and preliminary prototypes are presented at the Fall Expo and final prototypes, including results of verification and validation testing, are presented at the Spring Expo.

A schematic overview of the design course structure is presented in Figure B1. The overarching goal for the BIOENG 1160/1161 sequence is medical product design in context of the FDA QSR. The first semester, BIOENG 1160, introduces unmet identification techniques in the clinical setting as the basis to ultimately identify and define the design project and then proceeds into the *learning* phase in which students are introduced to methodology and standards to develop the comprehensive risk-based design history file. Emphasis is placed on engineering design tools that are commonly employed in industry. The expected design product from the first semester is a preliminary physical prototype that captures the essence of their design approach. The second semester, BIOENG 1161, *extends* and refines student design experience through introduction to additional engineering design tools, experimental methodology to test and validate their design, and creation of a functional prototype of their design.

Figure B1. Overview of the topics covered within the BIOENG 1160/1161 two-semester design course sequence.

Project Identification and Bioengineering Economics

The Senior Design course has been instructing students in innovative design methodology (as recently promoted by Yock *et al.* (2010) *Biodesign*. Cambridge University Press) for 16 years. The cornerstone of the methodology is needs assessment for identification of unmet needs coupled with development of a *project canvas* (Ostwalder) that focuses on value proposition, customer archetype, and minimum viable prototypes.

Following preliminary instruction on ethnography and clinical unmet needs assessment and prior art assessment, students are tasked with identifying potential design projects and any prior art associated with the potential project. Instruction on estimation of market sizes using both direct (interpretation of market reports such as those from Frost and Sullivan) and indirect methodologies (calculation based on series of assumptions) is provided in BIOENG 1160. The concepts are used and extended throughout the two-semester course sequence. *Ad hoc* presentations throughout the two-semester are designed to amplify the students' appreciation of unique economic considerations particular to medical technology development such as an introduction to angel investing, venture capital, strategic partnerships, licensing, and other forms of financing typically experienced in medical technology companies.

An individual deliverable required from each student is a needs and market-size analysis for each of the possible project topics under consideration. The purpose of this assignment is twofold:

first to provide students with the tools and skills necessary to estimate market-size and second to provide an additional objective assessment to help design groups refine the potential of Senior Design topics under consideration.

Students then actualize the process through unmet needs identification in the clinical setting to begin verifying or disproving underlying assumptions and to continually reevaluate their project canvas categories. Presentation and interpretation of basic financial statements are taught with the goal to provide student groups the background necessary to routinely (quarterly at least) prepare a balance sheet reflecting the assets and liabilities of their project effort.

FDA, Regulatory Affairs, and Standards

The medical design process focuses on the requirements of FDA 21 CFR Part 820.30 (Design Controls portion of the Quality System Regulation (QSR)), the reimbursement requirements of (CMS) Institutional Review Board (IRB) oversight of human subjects investigations, and particular Standards (e.g., ISO, ANSI, IEEE, ASTM, OSHA) and FDA Guidances associated with a product.

FDA 21 CFR Part 820.30 (Design Controls). Students are instructed in, and expected to apply to their design project, the components of FDA's QSR focusing on Design Controls (human factors evaluation, design brief, product design specification, hazard analysis, fault tree analysis, failure mode and effects analysis), device master record and device history record, validation and verification planning, protocol development, and test report creation, and post-marketing surveillance. Students are expected to substantiate a probable regulatory classification (Class I, Class II, Class III) and regulatory pathway to market (e.g., 510(k) or PMA) for their prototype. Deliverables documenting execution of their design projects include validation and verification plans, protocols, and test reports are due periodically throughout the two-semester sequence.

Institutional Review Board (IRB). Students are introduced to the role of the IRB in medical product development and instructed in how to submit a study proposal for IRB approval. As part of the process, students are asked to develop human factors plans and human subjects testing protocols for their design project. Students are required to obtain IRB certification in Responsible Conduct of Research and Human Subject Research prior to submitting their study proposal for IRB approval.

Industry Standards and FDA Guidances. Because senior design projects vary widely scope with concomitant wide variation in particular manufacturing/product specification standards, students are provided generic instruction in how to use the library to find Standards (e.g., ISO, ANSI, IEEE, ASTM, OSHA) and FDA Guidances applicable to their project (which they are expected to incorporate into their verification and validation testing). They are expected to determine those standards and use them in verification and validation of their final product prototype.

Fabrication

Fabrication consequences of design decisions are a central theme throughout the BIOENG 1160/1161 course sequence. In BIOENG 1160, several weeks are devoted to computer-aided engineering software instruction (SolidWorks). SolidWorks is widely used in the medical product as well as many other industries. Introduction to low- and medium-resolution fabrication techniques (e.g., 3D printing) follows naturally from the SolidWorks instruction. Additionally, students are introduced to plastic injection molding, the most common fabrication technique used in medical device manufacture, is presented as part of SolidWorks and Design of Experiments (DOX) class modules. For example, students are asked, *based on your knowledge of injection molding, how would you need to modify a particular design to ensure success with the molding process?*

BIOENG 1161 extends discussion of fabrication and evaluation of the students' senior design projects. For example, BIOENG 1161 is generally the semester that the students begin iteration and evaluation of prototypes associated with their project efforts. Fabrication techniques have historically utilized the spectrum of rapid prototyping and both manual and CNC machining tools; e.g., stereolithography and CNC turning and milling. Within the context of each project, basic manufacturing techniques are presented and discussed. The students are asked to consider what changes might be required to mass manufacture the product (i.e., transfer to manufacturing) and what types of costs would be associated with the necessary design changes and manufacturing processes.

Verification and Validation (V&V)

Great emphasis is placed on verification and validation of the project prototype. After an initial assignment to create a verification and validation plans, several assignments throughout the two semesters revisions these plans and begin detailed test protocols to support V&V activities. Instruction in statistical design of experiments (DesignExpert) is used to illustrate the impact of good experimental design in reducing the amount of testing actually needed verify and validate. Students are expected to incorporate DOX, where appropriate, in their V&V test protocols.

Sustainability

The environmental impacts of design decisions are presented to the students for consideration. For example, the students are asked to consider the disposal consequences of materials typically chosen for medical technology applications. Students are asked to consider disposal aspects associated with an estimated 16,600 tons of waste per day generated by hospitals in the US (2010; **https://practicegreenhealth.org/**) and the fact this amount probably continues to increase due to increased use of disposable products.

Other issues, such as the impact of incineration of medical waste containing, for example those containing chlorinated materials, such as PVC, is discussed as relevant. Students are asked to consider the impact of PVC use in a wide array of medical products from disposable intravenous (IV) bags and tubing to bedpans and the availability of PVC-free devices. Finally, students are required to consider the likely ultimate disposal method as a basis for the material choices made during formulation of technical specifications. For example, if incineration is the final disposal method, what materials might be unsuitable?

Health and Safety

Health and safety issues are discussed on an ad hoc basis in the context of design groups. For example, if a design group is using manual machining as part of prototype fabrication, common OSHA requirements are discussed and those aspects most relevant to safety emphasized. The importance of universal precautions is a recurring theme woven throughout the BIOENG 1160/1161 course sequence and is illustrated with “real world” examples from the instructor’s career.

Ethical Considerations. BIOENG 1160 and 1161 focus on the challenging aspects of medical product design and how they differ from design issues associated with non-medical applications such as common consumer products. For example, an in-class case study based on a video of a national news report (60 Minutes) is presented on the Sulzer knee- and hip- recall that occurred in 2003. This 30-minute video presents how unethical behavior in the design and manufacturing directly impacted the health and safety of the lives of patients receiving the medical product.

Presentation of informal, *case studies* from the instructor’s career on an *ad hoc* basis occur when relevant to particular class discussion throughout the BIOENG 1160/1161 course sequence.

List of Design Projects

2022-2023 Academic Year

- *IV Shower Guard* (**The Jane and Jerome Schultz Outstanding Senior Design Award winner**)
- *Redesigning Nasal Cannula Routing*
- *Resolving the Endoscopic’s Thumb*
- *IV Pole for Wheelchair/Beds*
- *Ankle-Foot Orthosis (AFO) Shoe Donning Assist Device* (**The Jane and Jerome Schultz Outstanding Senior Design Award winner**)
- *Improved Infusion Pump*
- *Improved Urine Specimen Collection*
- *Hands-Free Teeth Brushing*
- *EDS Shoulder Reduction Trainer*
- *Instructional Swaddling Blanket*
- *Special Needs Dentistry Trainer*

2021-2022 Academic Year

- *Eye Gaze Call Bell*
- *Baby Stroller for Wheelchair*
- *Portable Wheelchair Transfer Board*
- *Improved Patient Controlled Analgesia (PCA) Controller* (**The Jane and Jerome Schultz Outstanding Senior Design Award winner**)
- *Improved Speculum for Obese Patients*
- *Improving the Overbed Tray Table for Clinical Use*
- *Ambulatory External Female Urinary Catheter*
- *Improved Accessibility for Pediatric Peripheral Lines*
- *The Design of a Bariatric Ultrasound Trainer for the Subxiphoid Cardiac View* (**The Jane and Jerome Schultz Outstanding Senior Design Award winner**)
- *Redesigned Bag Valve Mask*
- *Pediatric IV Site Stabilization Device*
- *IV Stabilization for Elbow Joint*

2020-2021 Academic Year

- *Stepped Tension Achilles Tendonitis Brace*
- *Foregut Surgery Simulator*
- *Patient Repositioning Device*
- *Addressing Self Harm in Patients with ASD*
- *System to Improve Glove Donning*
- *Quantifying Tau Update*
- *Alarm Fatigue Mitigation with Supplemental Notification Device*
- *Abdominal Shaker*
- *Speculum Redesign to Reduce Trauma Induction* (**The Jane and Jerome Schultz Outstanding Senior Design Award winner**)
- *Compact Spacer Design for Inhaler Compliance*
- *Stoke Patient Aphasia Communication Easel*
- *PulseAid* (**The Jane and Jerome Schultz Outstanding Senior Design Award winner**)

2019-2020 Academic Year

- *Depth-Perception Module with Direct Feedback for Laparoscopic Skills Training*
- *Monitoring Blood Loss during Surgery*
- *Nurse-assistive Patient Rotation Mechanism for Pressure Sore Examination*
- *The Inspirometer: A Pediatric Respiratory Therapy Device*
- *Low cost infant transporter*
- *DAPHNE: Dynamic & Accessible Postpartum Hemorrhage Novice Education*
- *Patient-Specific Endovascular Surgical Trainer*
- *Head Support for ALS Patients*
- *Reinforced Local Anesthetic Needle Sleeve*
- *Sharps Safety Kit*
- *Independent Transfer Tool for Wheelchair-Bound Patients*
- *Foot-Operated Blood Pressure Cuff for LVAD Patients*
- *Mechanical Suction Tube Bender for Endoscopic Surgery*
- *Needle Recovery in Inside-Out Meniscal Repair*
- *Multifunctional IV pole attachment*

2018-2019 Academic Year

- *Ultrasound Tray Redesign*
- *Improved Pelvic Exam Wedge*
- *Device to Secure Nasal Cannula and Prevent Skin Breakdown*
- *Ventricoperitoneal Shunt Clog Detection System*
- *Arterial Line Leveling System*
- *Improved Neonatal Nasal Cannula*
- *Manual Wheelchair Backpack*
- *Improved ICU Mitten Restraints*
- *HIPEC Chemotherapy Device*
- *Zipper Assist Device for Paraplegics*
- *IV Line Organization System For OR/ICU Applications*
- *Patient Migration Prevention System (Device to Reduce Patient Migration in Bed)*
- *Open Syringe Feeding Tube System for Neonates*

- *Postpartum Hemorrhage Pad*
- *Expandable Cannula Sheath For ECMO/CPB*

2017-2018 Academic Year

- *System to Monitor Patient Compliance*
- *Alert System for Dislodgment of Neonatal PIV Catheters*
- *Pediatric PCA Pump Redesign*
- *Automated Fundal Massage Device*
- *Safe Sleep Hospital Crib*
- *Spinal Decompression Attachment for a Chiropractic Table*
- *Stabilizing Head Support for Neck Atrophy Patients*
- *Damping Ambulatory Vibrations During Emergency Neo-Natal Transport*
- *Intrinsic Hand Rehabilitation Device*
- *Device to Prevent Falling During Scoliosis Series X-rays*
- *Jackson Pratt Drain Seal and Support System*
- *Output-Measuring Bedpad for Incontinent Patients*
- *A Tool for Natural Sleep Endoscopy*
- *Improved Cerebral Spinal Fluid Management Device*

2016-2017 Academic Year

- *VAD Proximity Alert System*
- *Brace Buddy – Prevention of Knee Brace Migration and Rotation*
- *Improved Intubation Device*
- *Anti-Tamper Injection Port*
- *Rheumatoid Arthritis Handgrip*
- *ACL Graft Prep Device*
- *Adjustable Prosthetic Foot*
- *External Fixator for Calcaneal Fracture Reduction Surgery*
- *Infant Sleep Positioner*
- *Key Lock Assist Device*
- *Prosthetic Caliper*
- *HeelFlex-Pro – Device to Reposition Feet and Prevent Heel Ulcer Formation*

- *Developmental Hip Dysplasia Harness*

2015-2016 Academic Year

- *Non-Disruptive Length Acquisition Device for Incubated Neonates*
- *Force Sensor for Tele-rehabilitation*
- *Cranial Ultrasound Support Device*
- *Pressure Sensing Insole for Diabetic/Neuropathic Patients*
- *Prolonged Field Care: An Improved Tourniquet for Military Use*
- *Dynamic Head Support*
- *Anti-Gravity Leg Exercise Assist Device*
- *ICU Ulcer Prevention Mat*
- *Shoulder Anti-Subluxation Tray*
- *Endoscopic Carpal Tunnel Release*
- *Positive Reinforcement Device to Encourage Vocalization in Autistic Individuals*
- *Adjustable Ankle-Foot Orthotic for Children with Cerebral Palsy*

C

Appendix C – Undergraduate Research

The Department of Bioengineering is proud of the many research accomplishments of our undergraduates. We encourage our students to participate in research opportunities that can be found with our extensive affiliated faculty and throughout the University of Pittsburgh and University of Pittsburgh Medical Center (UPMC). The extensive breadth of interest and depth of knowledge displayed by our undergraduates is reflected in *presentations at professional conferences*, *publications in professional journals*, and the *Intramural Internship (BIOENG 1002) program*.

Presentations and Publications

Biomedical Engineering Society (BMES) Annual Conference

The professional society for biomedical engineering and bioengineering.
2023 | **2022** | **2021** | **2020** | **2019** | **2018** | **2017**

Science20XX

The University of Pittsburgh's annual celebration of science and technology.
2019 | **2018** | **2017**

Bioengineering (Bioengineering) Day

Bioengineering Day serves as a showcase for the research taking place within the Pittsburgh bioengineering community. The goal of the event is to bring together faculty, alumni, friends, and industry partners from the Greater Pittsburgh Area in a joint celebration of the bioengineering innovation and advancements taking place in our community.
2023 | **2022** | **2020** | **2019** | **2018**

Miscellaneous Conferences

2023 | **2022** | **2021** | **2020** | **2019** | **2018** | **2017**

INGENiUM

Undergraduate Research at the Swanson School of Engineering.
2023 | **2022** | **2021** | **2020** | **2019** | **2018**

Professional Journal Publications

2023 | **2022** | **2021** | **2020** | **2019** | **2018** | **2017** | **2016** | **2015**

Intramural Internship Presentations

Our undergraduates are actively involved in many research projects that span the Schools of Engineering, Medicine, Dental Medicine, and others. Research mentors welcome our students into their labs, where the students make valuable contributions to the mentors' research efforts.

Perusal of the presented topics reveals the wide scope of research activities available to our students. Prospective undergraduate researchers can identify potential areas of research interest and potential lab mentors through these topics.

2024 Spring Technical Symposium | **2023 Fall Technical Symposium**
2023 Spring Technical Symposium | **2022 Fall Technical Symposium**
2022 Spring Technical Symposium | **2021 Fall Technical Symposium**
2021 Spring Technical Symposium | **2020 Fall Technical Symposium**
2020 Spring Technical Symposium | **2019 Fall Technical Symposium**
2019 Spring Technical Symposium | **2018 Fall Technical Symposium**
2018 Spring Technical Symposium | **2017 Fall Technical Symposium**

D

Appendix D – Course Pre-Requisites

The following tables provide pre-requisites (extracted directly from PeopleSoft) for required courses in the curriculum. The courses within each table are categorized based on the pedagogical components described in Figure 1 (see section 1.2).

Please note that course pre-requisites are subject to change and it is highly recommended that PeopleSoft be utilized in order to verify course requirements prior to any planning.

MATHEMATICS	
Course	**Pre-requisite**
MATH 0220	C or better in **MATH 0200** or math placement score at least 76
MATH 0230	C or better in **MATH 0220**
MATH 0240	C or better in **MATH 0230**
MATH 0290	C or better in **MATH 0230** or **MATH 0235**
MATH 1270	**MATH 0280**, **MATH 1180**, or **MATH 1185**
MATH 0280	C or better in **MATH 0220** or **MATH 0235**
MATH 1180	**MATH 0240** | **MATH 0413** (check with Mathematics Dept.)
MATH 1185	Consent of instructor/department
BIOENG 1000	**MATH 0230** or **MATH 0235**

BASIC SCIENCES	
Course	**Pre-requisite**
PHYS 0174	Co-requisite: **MATH 0220**
PHYS 0475	Min cum. QPA of 3.25 | Co-requisite: **MATH 0230** or **MATH 0235**
PHYS 0175	C or better in **PHYS 0174** & **MATH 0235** | Co-requisite: **MATH 0230**
PHYS 0476	Min cum. QPA of 3.25 | C or better in **PHYS 0475** or B or better in **PHYS 0174** | Co-requisite: **MATH 0240**
CHEM 0110	N/A
CHEM 0410	Department consent required
CHEM 0710	N/A
CHEM 0760	N/A
CHEM 0960	N/A
CHEM 0120	(**CHEM 0110** or **CHEM 0710** or **CHEM 0760** or **CHEM 0960** or **CHEM 0101**) or (**CHEM 0410** and **CHEM 0430**) or (**CHEM 0111** and **CHEM 0113**)
CHEM 0420	Department consent required
CHEM 0720	(**CHEM 0110** or **CHEM 0710** or **CHEM 0760** or **CHEM 0960** or **CHEM 0101**) or (**CHEM 0410** and **CHEM 0430**) or (**CHEM 0111** and **CHEM 0113**)
CHEM 0770	(**CHEM 0110** or **CHEM 0710** or **CHEM 0760** or **CHEM 0960** or **CHEM 0101**) or (**CHEM 0410** and **CHEM 0430**) or (**CHEM 0111** and **CHEM 0113**)
CHEM 0970	(**CHEM 0110** or **CHEM 0710** or **CHEM 0760** or **CHEM 0960** or **CHEM 0101**) or (**CHEM 0410** and **CHEM 0430**) or (**CHEM 0111** and **CHEM 0113**)

BASIC SCIENCES	
Course	**Pre-requisite**
BIOENG 1070	**ENGR 0012** and **CHEM 0120** and **PHYS 0175** | Co-requisite: **ENGR 0016**
BIOENG 1071	**BIOENG 1070**
BIOENG 1072	**BIOENG 1070** and min GPA of 3.25 or instructor permission
BIOSC 0057	C or better in (**BIOSC 0150** or **BIOSC 0170** or **BIOSC 0715** or **BIOSC 0190**) or (**BIOL 0101** or **BIOL 0110**) | Co-requisite: **BIOENG 1070**
BIOSC 0058	First year & Sophomore only
BIOSC 0067	C or better in (**BIOSC 0050** or **BIOSC 0057** or **BIOSC 0058** or **BIOSC 0070** or **BIOSC 0190** or **BIOL 0101** or **BIOL 0111**) and (**BIOSC 0160** or **BIOSC 0180** or **BIOSC 0716** or **BIOL 0102** or **BIOL 0120**)
BIOSC 0068	C or better in **BIOSC 0058**
BIOSC 1250 NROSCI 1250	C or better in (**BIOSC 0160** or **BIOSC 0716** or **BIOSC 0191** or **BIOSC 0180** or **BIOENG 1071** or **BIOENG 1072** or **BIOL 0102** or **BIOL 0120**) and (**CHEM** 0120 or **CHEM** 0720 or **CHEM** 0770 or **CHEM** 0970 or **CHEM** 0102 or (**CHEM** 0112 and **CHEM** 0114)
BIOSC 1070 NROSCI 1070	Department consent required

HUMANITIES/SOCIAL SCIENCES	
Course	**Pre-requisite**
BIOENG 1241	Juniors & Seniors only
Other electives	Please refer to PeopleSoft for details

BASIC ENGINEERING	
Course	**Pre-requisite**
ENGR 0011	N/A
ENGR 0015	N/A
ENGR 0711	Min GPA of 3.25
ENGR 0012	**ENGR 0011**
ENGR 0016	**ENGR 0011** or **ENGR 0015**
ENGR 0712	**ENGR 0711**
ENGR 0716	**ENGR 0711**
ENGR 0135	(**MATH 0150** or **MATH 0230** or **MATH 0231** or **MATH 0235**) and (**PHYS 0150** or **PHYS 0174** or **PHYS 0201** or **PHYS 0475**)

CORE BIOENGINEERING	
Course	**Pre-requisite**
BIOENG 1002	**BIOENG 1000** or **ENGR 0020** or **ENGR 0021**
BIOENG 1085	N/A
BIOENG 1150	(**BIOENG 1071** or **BIOENG 1072**) and **BIOENG 1220** and **BIOENG 1310** and **BIOENG 1320** and **BIOENG 1630**

CORE BIOENGINEERING	
Course	**Pre-requisite**
BIOENG 1160	Seniors only
BIOENG 1161	**BIOENG 1160**
BIOENG 1210	**MATH 0290** and (**PHYS 0175** or **PHYS 0476**) and (**CHEM 0960** or **CHEM 0120** or **CHEM 0720**)
BIOENG 1211	**MATH 0290** and (**PHYS 0175** or **PHYS 0476**) and (**CHEM 0960** or **CHEM 0120** or **CHEM 0720**) and min GPA of 3.25 or instructor permission
BIOENG 1220	**MATH 0240** and (**BIOENG 1210** or **BIOENG 1211**)
BIOENG 1310	**MATH 0240** and (**PHYS 0175** or **PHYS 0476**)
BIOENG 1320	**BIOENG 1310** and **MATH 0240** and **MATH 0290**
Signals Application	
BIOENG 1255	**BIOENG 1320** and (**BIOSC 1250** or **NROSCI 1250** or **BIOSC 1070** or **NROSCI 1070** or **NUR 0012**)
BIOENG 1580	**BIOENG 1320** and (**ENGR 0012** or **ENGR 0712** or **ENGR 0716**)
BIOENG 1680	**BIOENG 1320**
BIOENG 1630	**ENGR 0135**
BIOENG 1680	**BIOENG 1320**
Imaging Electives	
BIOENG 1005	**BIOENG 1310** | Co-requisite: **BIOENG 1320**
BIOENG 1330	**BIOENG 1320**
BIOENG 1340	**BIOENG 1320** and **MATH 0240** and **MATH 0290**
BIOENG 1383	**BIOENG 1075** or (**PHYS 0102** or **PHYS 0111** or **PHYS 0175** or **PHYS 0476** or **PHYS 1306** or **PHYS 1361**)
BIOENG 2385	Instructor permission required
BIOENG 2505	Instructor permission required
ECE 1390	Seniors only
PSY 1471	Please check with Department of Psychology

BIOENGINEERING TRACK	
Course	**Pre-requisite**
Electives	Please refer to PeopleSoft for details

ADVANCED ENGINEERING/SCIENCE/TECHNICAL	
Course	**Pre-requisite**
Electives	Please refer to PeopleSoft for details

OTHER BIOENGINEERING COURSES	
Course	**Pre-requisite**
BIOENG 0050	Instructor permission required
BIOENG 0051	Instructor permission required
BIOENG 0052	Instructor permission required
BIOENG 0053	**BIOENG 1000** or **ENGR 0020** or **ENGR 0021**

OTHER BIOENGINEERING COURSES	
Course	**Pre-requisite**
BIOENG 0052	Instructor permission required
BIOENG 0053	**BIOENG 1000** or **ENGR 0020** or **ENGR 0021**
BIOENG 0054	(**BIOENG 0050** and **BIOENG 1024**) or **MEMS 0024**
BIOENG 1024	**ENGR 0011** or **ENGR 0015** or **ENGR 0711** or **ET 0011**
BIOENG 1050	**BIOENG 1220**
BIOENG 1051	**BIOENG 1220**
BIOENG 1052	**BIOENG 1220**
BIOENG 1075	**BIOENG 1070**
BIOENG 1086	N/A
BIOENG 1095	Department consent required
BIOENG 1096	Department consent required
BIOENG 1218	**BIOENG 1210**
BIOENG 1351	**CS 0441** or (**ENGR 0012** or **ENGR 0712** or **ENGR 0716**) and **BIOENG 1310**
BIOENG 1355	N/A
BIOENG 1370	**BIOENG 1630**
BIOENG 1533	**BIOENG 1220** and (**BIOSC 1000** or **BIOSC 1810** or **CHEM 1810**)
BIOENG 1586	(**BIOENG 1071** or **BIOENG 1072**) and **BIOENG 1320**
BIOENG 1615	Juniors and Seniors only
BIOENG 1620	**BIOENG 1810**
BIOENG 1631	**BIOENG 1630**
BIOENG 1632	**BIOENG 1631** and **MATH 0280** and (**ENGR 0012** or **ENGR 0712** or **ENGR 0716**)
BIOENG 1633	**BIOENG 1631** and **MATH 0280**
BIOENG 1810	**CHEM 0320** and (**BIOSC 1000** or **BIOSC 1810** or **CHEM 1810** or **CHEM 1880**)

E

Appendix E – Bioengineering Course Classifications for Medical School

The following tables provide Bioengineering course classifications for medical school. Please consult the **Association of American Medical Colleges** (AAMC) website as well as the American Medical College Application Service (AMCAS) application guide for details about course classification. Pre-med students in the department are highly encouraged to consult with a pre-health professions advisor at the **Pre-Health Resource Center** for Health Careers to explore career paths related to the medical field.

Biology, Chemistry, Physics, and Math Courses

AMCAS uses course classification to calculate applicant GPAs. Classifications that are in the biology, chemistry, physics, and math (BCPM) category indicate that such courses will be included in the calculation of the applicant's BCPM GPA. Note that the department offering the course is typically not a factor in the course classification; in fact, classifications are based on the primary content of the course.

BIOLOGY (BIOL)	
Course	**Title**
BIOENG 1070	INTRODUCTORY CELL BIOLOGY 1
BIOENG 1071	INTRODUCTORY CELL BIOLOGY 2
BIOENG 1072	HONORS INTRODUCTORY CELL BIOLOGY 2
BIOENG 1075	INTRODUCTION TO CELL AND MOLECULAR BIOLOGY LABORATORY TECHNIQUES
BIOENG 1218	EMERGING BIOMEDICAL TECHNOLOGIES (HONORS)
BIOENG 1586	QUANTITATIVE SYSTEMS NEUROSCIENCE
BIOENG 1615	INTRODUCTION TO NEURAL ENGINEERING
BIOSC 0050	FOUNDATIONS OF BIOLOGY LABORATORY 1
BIOSC 0057	FOUNDATIONS OF BIOLOGY RESEARCH LABORATORY 1
BIOSC 0058	FOUNDATIONS OF BIOLOGY SEA-PHAGES LABORATORY 1
BIOSC 1070	HONORS HUMAN PHYSIOLOGY
BIOSC 1250	HUMAN PHYSIOLOGY
NROSCI 1070	HONORS HUMAN PHYSIOLOGY
NROSCI 1250	HUMAN PHYSIOLOGY

CHEMISTRY (CHEM)	
Course	**Title**
BIOSC 1000	INTRODUCTION TO BIOCHEMISTRY
BIOENG 1210	BIOENGINEERING THERMODYNAMICS
BIOENG 1211	HONORS BIOENGINEERING THERMODYNAMICS
BIOSC 1810	MACROMOLECULAR STRUCTURE AND FUNCTION
CHEM 0110	GENERAL CHEMISTRY 1
CHEM 0120	GENERAL CHEMISTRY 2
CHEM 0410	GENERAL CHEMISTRY 1
CHEM 0420	GENERAL CHEMISTRY 2
CHEM 0710	HONORS GENERAL CHEMISTRY 1
CHEM 0720	HONORS GENERAL CHEMISTRY 2

CHEMISTRY (CHEM)	
Course	**Title**
CHEM 0760	HONORS GENERAL CHEMISTRY FOR ENGINEERS 1
CHEM 0770	HONORS GENERAL CHEMISTRY FOR ENGINEERS 2
CHEM 0960	GENERAL CHEMISTRY FOR ENGINEERS 1
CHEM 0970	GENERAL CHEMISTRY FOR ENGINEERS 2
CHEM 1810	CHEMICAL BIOLOGY
CHEM 1880	CHEMICAL BIOLOGY FOR ENGINEERS

PHYSICS (PHYS)	
Course	**Title**
BIOENG 1310	LINEAR SYSTEMS AND ELECTRONICS 1 (BIOINSTRUMENTATION)
ENGR 0135	STATICS AND MECHANICS OF MATERIALS 1
PHYS 0174	BASIC PHYSICS FOR SCIENCE AND ENGINEERING 1
PHYS 0175	BASIC PHYSICS FOR SCIENCE AND ENGINEERING 2
PHYS 0475	HONORS BASIC PHYSICS FOR SCIENCE AND ENGINEERING 1
PHYS 0476	HONORS BASIC PHYSICS FOR SCIENCE AND ENGINEERING 2

MATHEMATICS (MATHS)	
Course	**Title**
BIOENG 1000	STATISTICS FOR BIOENGINEERING
ENGR 0020 or ENGR 0021	PROBABILITY AND STATISTICS FOR ENGINEERS 1 PROBABILITY AND STATISTICS FOR ENGINEERS
MATH 0220	ANALYTIC GEOMETRY AND CALCULUS 1
MATH 0230	ANALYTIC GEOMETRY AND CALCULUS 2
MATH 0240	ANALYTIC GEOMETRY AND CALCULUS 3
MATH 0280	INTRO TO MATRICES AND LINEAR ALGEBRA
MATH 0290	APPLIED DIFFERENTIAL EQUATIONS
MATH 1180	LINEAR ALGEBRA
MATH 1185	HONORS LINEAR ALGEBRA
MATH 1270	ORDINARY DIFFERENTIAL EQUATIONS 1

All Other Courses

Classifications that are not grouped in BCPM category indicate courses that will be included in the calculation of the applicant's all other (AO) GPA.

ENGINEERING (ENGI)	
Course	**Title**
BIOENG 1005	RF (RADIOFREQUENCY) MEDICAL DEVICES AND APPLICATIONS OF ELECTROMAGNETICS IN MEDICINE
BIOENG 1024	MEDICAL PRODUCT DESIGN
BIOENG 1050	ARTIFICIAL ORGANS (LUNG AND VASCULAR)

Appendix E

ENGINEERING (ENGI)	
Course	**Title**
BIOENG 1051	ARTIFICIAL ORGANS 2 (BLOOD AND HEART)
BIOENG 1052	ARTIFICIAL ORGANS 3 (KIDNEY AND LIVER)
BIOENG 1160	BIOENGINEERING DESIGN 1
BIOENG 1161	BIOENGINEERING DESIGN 2
BIOENG 1220	BIOTRANSPORT PHENOMENA
BIOENG 1255	DYNAMIC SYSTEMS: A PHYSIOLOGICAL PERSPECTIVE
BIOENG 1320	BIOLOGICAL SIGNALS AND SYSTEMS
BIOENG 1330	BIOMEDICAL IMAGING
BIOENG 1340	INTRODUCTION TO MEDICAL IMAGING AND IMAGE ANALYSIS
BIOENG 1351	BIOSIGNAL ACQUISITION AND ANALYSIS
BIOENG 1355	MEDICAL PRODUCT REGULATION AND REIMBURSEMENT
BIOENG 1383	BIOMEDICAL OPTICAL MICROSCOPY
BIOENG 1580	BIOMEDICAL APPLICATIONS OF SIGNAL PROCESSING
BIOENG 1620	INTRODUCTION TO TISSUE ENGINEERING
BIOENG 1630	BIOMECHANICS 1: MECHANICAL PRINCIPLES APPLIED TO BIOLOGICAL SYSTEMS
BIOENG 1631	BIOMECHANICS 2 – INTRODUCTION TO BIODYNAMICS AND BIOSOLID MECHANICS
BIOENG 1632	BIOMECHANICS 3 – BIODYNAMICS OF MOVEMENT
BIOENG 1633	BIOMECHANICS 4 – BIOMECHANICS OF ORGANS, TISSUES AND CELLS
BIOENG 1680	BIOMEDICAL APPLICATIONS OF CONTROL
BIOENG 1810	BIOMATERIALS AND BIOCOMPATIBILITY
BIOENG 2385	ENGINEERING MEDICAL DEVICES FOR QUANTITATIVE IMAGE ANALYSIS AND VISUALIZATION
BIOENG 2505	MULTI-MODAL BIOMEDICAL IMAGING TECHNOLOGIES
BIOENG 2630	METHODS IN MEDICAL IMAGE ANALYSIS
ENGR 0011	INTRODUCTION TO ENGINEERING ANALYSIS 1
ENGR 0012	INTRODUCTION TO ENGINEERING ANALYSIS 2
ENGR 0016	INTRODUCTION TO ENGINEERING ANALYSIS 2
ENGR 0711	HONORS ENGINEERING ANALYSIS AND COMPUTING
ENGR 0712	ADVANCE ENGINEERING APPLICATIONS FOR FRESHMAN
ENGR 0715	ENGINEERING APPLICATIONS FOR SOCIETY
ENGR 0716	THE ART OF MAKING: ART OF HANDS-ON SYSTEM DESIGN AND ENGINEERING

COMMUNICATIONS (COMM)	
Course	**Title**
BIOENG 1002	INTRAMURAL INTERNSHIP
BIOENG 1150	BIOENGINEERING METHODS AND APPLICATIONS

OTHER (OTHR)

Course	Pre-requisite
BIOENG 0050	WORKSHOP IN BIOENGINEERING DESIGN
BIOENG 0051	WORKSHOP IN MEDICAL DEVICES – THE BASICS
BIOENG 0052	WORKSHOP IN OPENSIM
BIOENG 0053	WORKSHOP IN STATISTICAL DESIGN OF EXPERIMENTS
BIOENG 0054	WORKSHOP IN DESIGN FOR MANUFACTURABILITY
BIOENG 1085	INTRODUCTION TO BIOENGINEERING SEMINAR
BIOENG 1095	SPECIAL PROJECTS
BIOENG 1096	UNDERGRADUATE TEACHING EXPERIENCE
BIOENG 1241	SOCIETAL, POLITICAL AND ETHICAL ISSUES IN BIOTECHNOLOGY (**Could also be classified as PHIL**)
BIOENG 1355	MEDICAL PRODUCT REGULATION AND REIMBURSEMENT
BIOENG 1370	COMPUTATIONAL SIMULATION IN MEDICAL DEVICE DESIGN
BIOENG 1533	CONTROLLED DRUG DELIVERY
PSY 1471	MAPPING BRAIN CONNECTIVITY

F

Appendix F – Study Abroad Full Semester Planning

If you are interested in a full semester study abroad program, then the following flowchart should assist you with your planning endeavors. This chart was created by Mr. Juan (Sebastian) Correa, one of our magnificent bioengineering students, who completed a semester abroad at the Technical University of Denmark (DTU).

Pre-Requisites	Several things that should be known prior to starting the process of planning to study abroad: - **Department (ex. BIOE)** - **Desired Program (ex. Semester exchange)**
What universities offer courses in desired area?	Important to find universities that not only have your exact major, but the area in which your classes are. Many schools may have different department names for relatively the same academic area.
Information on specific courses available?	It can be challenging navigating each university's system to find information on courses being taught and what material they cover.
Location Preferences	Is there a specific region or country in mind? This can help narrow down the list of schools to a more manageable number.
Semester Schedule	Some universities may run their semesters at times which may not work well with the Pitt semester schedule.
Do I meet the GPA requirements?	In some cases, there is a GPA requirement necessary to be accepted by the university abroad.
Which semester?	The intended semester abroad is important to know to help determine which courses may need to be taken abroad. It can also help to have no preference of which semester.

Which courses?

Very important step- must determine which courses need to be taken during the proposed semester and which courses are a bit more flexible in terms of timing.

Which courses does the school offer?

Must navigate through each university's system to find possible classes that may correspond to the intended courses of the proposed semester. This step is the most time consuming of any.

Does the Undergraduate Program Director approve?

Crucial step- must get all courses that one intends to take abroad confirmed by the department Undergraduate Program Director to verify if the courses will transfer back to Pitt as intended.

Course Language

Note which language courses are taught in and if there are any alternatives (may be on a course-by-course basis). Most universities will offer courses in English, but not all.

Course Timing

Also, important to note when intended courses are being offered to check if they align with the proposed semester. Some schools may not offer this on their website.

Does the university and location interest me?

There may not be a chance to be picky here, but important to determine if the university and location of the university is exciting and intriguing as one will spend several months living there.

Are there alternative courses?

Not required but very helpful; finding more courses that can be transferred back to Pitt for credit can be a big help as one may only find out if they can 100% take intended courses once the semester is starting.

G

Appendix G – Student Chapters

Pitt BMES

The University of Pittsburgh (Pitt) Biomedical Engineering Society (**BMES**) is proud to be a resource and liaison for fellow undergraduates in the Department of Bioengineering, professionals in industry, faculty at the University, and surrounding community. The chapter works diligently to supplement the traditional engineering curriculum with a variety of activities to enrich and stimulate their members' academic and professional experience. Biomedical

industry tours, networking events, presentations of undergraduate student research, clinical and industrial panel presentations, and social activities are the highlights of their program.

The Pitt community is highly encouraged to visit the chapter's **website** for upcoming events and other pertinent information.

Accessible Prosthetics Initiative (API) @Pitt

What is our mission? Focus on increasing accessibility to prosthetic devices, especially in underserved communities. We do this through *device development*, *education*, and *networking*.

1. **Learn more about manufacturing 3D-printed prosthetics**
    - Using and exploring open-source devices
    - Innovating novel uses for 3D printing in the field of prostheses
2. **Develop educational resources for students**
    - Creating curriculum for students, professionals, and amputees
3. **Network with surrounding amputees and healthcare professional**
    - Outreach and work with groups in the local Pittsburgh community

Want to learn more? **pittchapterapi@gmail.com** | Follow us on social media: **@api_pitt** (Facebook, Twitter, Instagram)

H

Appendix H – Mental Health Tips and Resources

If you require assistance beyond the resources provided below, please contact **Ms. Cheryl Paul** (412-624-4042), Swanson School of Engineering Director of Student Services, for confidential support.

How to Connect to Support

- **Article**: *How to find a therapist for the first time*
- If you are experiencing a crisis that requires immediate attention you may speak with a counselor at any time 24 hours a day, 7 days a week.
- Any student requiring support for an urgent, or crisis, situation may call the **University Counseling Center** (UCC) at **412-648-7930** at any time to speak directly with a clinician.
- **Thriving Campus** is an online directory that allows Pitt students to access a list of off-campus, licensed mental health clinicians, many of whom specialize in working with students. The website includes various guides and resources that assist students through the process of securing off-campus outpatient care.
- **re:solve Crisis Network** is the Allegheny County crisis agency staffed with professional mental health clinicians 24/7. Call **1-888-796-8226** or visit their facility at 333 North Braddock Ave, Pittsburgh, PA 15208.
- The National Suicide Prevention Lifeline provides free and confidential emotional support to people in suicidal crisis or emotional distress 24/7. Call **1-800-273-8255**. (TTY, dial **800-799-4889**. Voice/Caption Phone, dial **800-273-8255**).

How Do You Know When it is Time to Think Beyond Self-Care?

Consider using a screening tool:

- **Therapy Assistance Online** (TAO): This screening will ask you a few questions in each area & provide you some feedback along with some ideas about next steps you can take
- **Article**: *Should I start therapy? 10 signs you could benefit from working with a therapist or counselor*

Managing Stress & Anxiety

Options to consider:

- **Article**: *5 self-case practices for every area of your life*
- **Article**: *Building your resilience*
- **COLOR**! Coloring can relax the fear center of your brain, the amygdala. It induces the same state as meditating by reducing the thoughts of a restless mind. This generates mindfulness and quietness, which allows your mind to get some rest after a long day at work. Here are some examples of University of Pittsburgh themed coloring books:

- SSoE Coloring Book
- Nationality Rooms Coloring Book
- Color Within the … Flu Virus?

- **Racial trauma & self-care resources**
  - **Article**: *5 self-care practices black people can use while coping with trauma*
  - **Article**: *The four bodies: A holistic toolkit for coping with racial trauma*
  - **Article**: *4 BIPOC women on the power of saying 'no' – and why it's essential for self care*
- **LGBTQIA+ resources**
  - **SisTers PGH**: A black and trans led non-profit organization that serves POC, trans, & non-binary people within Southwestern PA.
  - **The TREVOR Project**: A support center where LGBTQ youth and their allies can go for support and find answers to frequently asked questions.
  - **Central Outreach Wellness Center**: Inclusive healthcare with dignity and respect.
- **Asian Pacific Islander community resources**
  - **Article**: *Speaking up against racism around the coronavirus*
  - **Hollaback** is a non-profit working to end all forms of harassment
  - **National Alliance on Metal Health**: Refer to the section titled **How to Seek Culturally Competent Care** for details
- **Substance use resources**
  - The University of Pittsburgh's **Collegiate Recovery Program** (CRP) provides a safe, nurturing, and affirming environment where students in recovery from substance use can receive the assistance and support they need to achieve academic success and personal goals while in college.
  - **Drug & Alcohol Rehab Centers, Counseling, & Support** in Pittsburgh, PA

Meditation/Mindfulness Apps & Activities

Options to consider:

- **Calm – College Connection**: Meditations to help students ride the rollercoaster of **college** life
  - Full list of **more apps**
- Pitt's Stress-Free-Zone (SFZ): Evidence-based, mind/body stress reduction skills. SFZ mindfulness services teach skills for working with the mind/body system in ways that not only help us feel better in the moment but also help increase awareness of mental habits that keep us locked into reactive, unhelpful behaviors. With increased awareness we can begin to break those habits and experience some freedom from them.
  - **Classes and workshops**

Help for Someone Else

If you believe someone has a plan to hurt or kill themselves and you fear they are in imminent danger, stay with that person and call **Pitt Police** (**412-624-2121**) or **911** immediately. If you are not with them, keep the conversation going until you can connect them with help.

Do's & Don'ts	
Do	**Don't**
Let the person talk and listen to them without judgement	Try to minimize problems or shame a person into changing their mind
Reassure them that treatment is available and suicidal feelings are temporary	Preach about suicide being wrong
Ask direct questions: • Do you ever think about suicide? • Do you have a plan to attempt suicide or take your life? • Have you attempted suicide before? • Have you thought about when you would do it? • Have you thought about what method you would use?	Leave the person alone or end the phone call until help arrives

I

Appendix I – Undergraduate Forms, Resources, and Guidelines

Undergraduate Forms

Bioengineering Degree Progress Workbook (DPW) and Comprehensive Electives Plan (CEP) **Note.** DPW and CEP are required components of the Bioengineering advising process.
BIOENG 1002 Intramural Internship Application **Note.** Students must complete this form to be enrolled in BIOENG 1002.
BIOENG 1024 Medical Product Design Application **Note.** Students must complete this form to be enrolled in BIOENG 1024.
BIOENG 1095 Special Projects Application **Note.** Students must complete this form to be enrolled in BIOENG 1095.
BIOENG 1096 Undergraduate Teaching Assistant Application **Note.** Students must complete this form to be enrolled in BIOENG 1096. **Bioengineering Undergraduate Teaching Assistant and Grader Policy**
Bioengineering Research Practicum Application **Note.** Certain UPMC laboratories may require completion of this form.
Bioengineering Transfer Credit Preapproval Form **Note.** Students must complete this form to seek approval prior to transferring credits from another college or university.
Over 18 Credits Application **Note.** Students who want to take more than 18 credits in a semester must complete this form and seek approval from the Bioengineering Associate Chair for Undergraduate Education.
CMU Cross Registration **Form** & **Instructions** **Note.** Students who want to cross-register for CMU courses need to complete this form and have the form signed by the Bioengineering Associate Chair for Undergraduate Education.
Declare SSoE Minor(s) / Certificate(s) **Note.** Complete this form to **add**, **change**, or **remove** a minor or certificate in SSoE.
Declare DSAS Minor(s) / Certificate(s) **Note.** Complete this form to **add** a minor or certificate in DSAS.
Bioengineering Minor Checklist **Note.** Students interested in obtaining a Bioengineering Minor must complete this form and submit it to the **Bioengineering Undergraduate Administrator**.

Undergraduate Resources

Swanson School of Engineering Undergraduate Catalog
Note. Students should consult the catalog for pertinent Swanson School of Engineering academic regulations, procedures, and guidelines, such as *repeating courses*, *Humanities and Social Science requirement*, etc. To access the **approved Humanities and Social Science electives**, click on the link above, then select: Swanson School of Engineering (under Schools and Academic Programs) > Humanities and Social Science Requirement > Approved Electives — First Year Students.

Matriculating Sophomore Bioengineers
Note. Matriculating sophomore bioengineers should consult this document for Fall Term planning purposes.

Report a Publication
Note. Please use this form to provide pertinent information when you have publications to report.

Bioengineering Registration Issues & Procedures

The Department of Bioengineering has created several survey sites to help facilitate issues that can arise with the registration process. In particular:

- **BIOENG 1085**: If you are unable to register for seminar for any reason (waitlist full, conflict, etc.), fill out the **Seminar Registration Issue** for assistance.
- **BIOENG 1024**: Students cannot enroll in BIOENG 1024 directly and must fill out the **BIOENG 1024 Application** form. The Undergraduate Administrator will begin enrolling students on the second Wednesday after registration opens (MPE Track students first followed by other cohorts).
- **BIOENG 1241**: Students cannot enroll in BIOENG 1241 directly and must fill out the **BioEthics Registration** form. The Undergraduate Administrator will begin enrolling students on the second Wednesday after registration opens (seniors first followed by juniors).
- **BIOENG 1002**: For planning purposes, we request that students interested in taking BIOENG 1002 fill out the **Intramural Internship** survey along with the **BIOENG 1002 Intramural Internship Application** form.
- **NUR 0012/NUR 0002 – Human Anatomy & Physiology**: The School of Nursing has limited number of seats for Bioengineering students in this course. We ask that you facilitate registration through the Undergraduate Administrator. If you want to take **NUR 0012/NUR 0002**, please fill out the **Nursing 0012 and 0002** survey.

Guidelines: Tips and Best Practices for Requesting Assistance

Emailing. When emailing the Undergraduate Academic Administrator, please be sure to include your **full name** and more importantly, your **student ID number** (7-digit PeopleSoft number). Be clear and detailed in your request – we cannot help with what we cannot decipher!

When requesting assistance with enrollment, include full class name(s), and course, section, and class numbers. If the class includes a lab or recitation, include your choice (if there is more than one), by section and class number. In addition, it would be very helpful if the time of the class were included as well for clarity.

Example:

BIOENG 1070: INTRODUCTORY CELL BIOLOGY 1		
Class	**Section**	**Day & Time**
13067	1030-LEC	TuTh 11:00AM-12:15PM
13068	1040-REC	Mo 8:00AM-8:50AM
18696	1045-REC	Mo 9:00AM-9:50AM

For the course:
Full class name: INTRODUCTORY CELL BIOLOGY 1
Course number: 1070 (please note that this number is part of the title)
Section number: 1030
Class number: 13067
Day & Time: TuTh 11:00AM-12:15PM

For the recitation:
Section number: 1045
Class number: 18696
Day & Time: Mo 9:00AM-9:50AM

PeopleSoft Class Search Tip. When searching for classes in PeopleSoft, it is highly recommended that you search for all available courses, not just open courses. This is applicable, for example, in the case of BIOENG 1085, which often appears as closed even though all bioengineering students must be enrolled.

BIOENG vs. Non-BIOENG Course Enrollment. Please be advised that the Department can only assist with BIOENG and ENGR (ENGR 1000, ENGR 0501, and ENGR 1770) course enrollment. For assistance with non-BIOENG courses (e.g., BIOSC, MATH, CHEM, etc.), contact those respective departments.

Transfer Credits, Add/Drop, Over 18 Credits, Monitored Withdrawal Processing. For assistance with these items, it is recommended that you submit forms as far in advance of the deadline as possible. Last minute requests cannot be guaranteed to be submitted to administrative offices in time. Additionally, for non-SSoE courses, the Undergraduate Program can assist with preparation of add/drop and withdrawal forms; however, it is your responsibility to submit and have the forms processed by respective departments by the deadlines.

Graduation Application Form for Seniors. Graduation Applications must be submitted to the SSoE Dean's Office within the deadline dates specified. Please coordinate with the Undergraduate Administrator accordingly.