The University of Connecticut
School of Engineering

BIOMEDICAL ENGINEERING
GUIDE TO COURSE SELECTION
AY 2008-2009

for
Biomedical Engineering (BME) Majors
in the School of Engineering
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1. INTRODUCTION

The purpose of this document is to guide students in designing a plan of study for the Biomedical Engineering Program at the University of Connecticut (UConn). Any such plan must be consistent with the Biomedical Engineering Program Educational Objectives. The Program Educational Objectives have been developed to satisfy the requirements of ABET and the general education requirements of UConn. For Biomedical Engineering, ABET curricular requirements are given as:

“The structure of the curriculum must provide both breadth and depth across the range of engineering topics implied by the title of the program.

The program must demonstrate that graduates have: an understanding of biology and physiology, and the capability to apply advanced mathematics (including differential equations and statistics), science, and engineering to solve the problems at the interface of engineering and biology; the ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living materials and systems.”

The Biomedical Engineering curriculum allows for the choice of several senior-level courses. This makes it possible for students to specialize in one of the following tracks: Biochemical Engineering, Biofluid Biomechanics, Bioinformatics, Bioinstrumentation, Biomaterials, and Biosolid Biomechanics. This Guide is intended to be used in conjunction with the University of Connecticut General Catalog as a source of information regarding degree requirements in Biomedical Engineering.

1.1 Preparation of Plans of Study

Prior to registration during the first semester of the Junior year, or for transfer students in the second semester at the University of Connecticut, whichever is later, each student must complete a Plan of Study form documenting the program he or she intends to follow. The BME Program Director is available to help students in developing a suitable Plan of Study form which is consistent with the Biomedical Engineering Program Educational Objectives.

2. BIOMEDICAL ENGINEERING PROGRAM

The Biomedical Engineering Program at the University of Connecticut is continuously evolving and improving in response to feedback from our constituents and program assessment results. We have developed a set of Program Educational Objectives which are periodically reviewed by all constituents (BME students, BME faculty, alumni, and employers). The feedback provided by our constituents is used to continuously refine and improve the Program Educational Objectives.
We have determined a set of Program Outcomes which are necessary for the achievement of the Program Educational Objectives. We use several assessment tools (employer surveys, alumni surveys, exit interviews, senior surveys, and course assessment surveys) to measure our success with respect to the Program Outcomes. The assessment results are reviewed periodically and used for the continuous improvement of the program and our courses.

The two-loop process involving the definition of the Program Educational Objectives (loop one) and the assessment / program improvement (loop two) is shown below.

![The Two Loops of EC2000](image)

**2.1 Biomedical Engineering Program Educational Objectives**

Following the mission of the University and the School, the Biomedical Engineering program is committed to excel in teaching and research. The BME Program Educational Objectives and Program Outcomes are listed below:

**Educational Objectives**

Educational Objectives describe the performance of our alumni. The BME undergraduate Program Educational Objectives are that our alumni:
are equipped with an up-to-date technical and hands-on education in biomedical engineering emphasizing analysis, synthesis and design, allowing them to successfully work in industry, or attend graduate, medical, dental, business or law schools.

- possess a desire for life-long learning and a curiosity about the world.
- Possess the quantitative and analytic skills necessary to embrace emerging technologies and the ability to look at traditional textbook learning with a fresh perspective.
- possess excellent written and oral communication skills necessary to interact with health care professionals, engineers and scientists.
- possess the ability to work effectively in teams.
- possess the sense of responsibility of a professional engineer.
- will become global leaders in the biomedical engineering professions.

Program Outcomes

Program Outcomes describe the performance of our students at the time of graduation. The BME program has demonstrated that our students have attained:

A. an ability to apply knowledge of mathematics, science, and engineering in the solution of biomedical engineering problems

B. an ability to design and conduct experiments, as well as to analyze and interpret data

C. an ability to design a biomedical engineering system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

D. an ability to function on multi-disciplinary teams including working on a biomedical engineering senior design project

E. an ability to identify, formulate, and solve engineering problems

F. an understanding of professional and ethical responsibility

G. an ability to communicate effectively

H. the broad education necessary to understand the impact of engineering solutions in a global and societal context

I. a recognition of the need for, and an ability to engage in life-long learning

J. a knowledge of contemporary issues

K. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

L. an understanding of biology and physiology, and the capability to apply advanced mathematics (including differential equations and statistics), science, and engineering to solve the problems at the interface of engineering and biology
M. an ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living materials and systems

N. a knowledge of a culture outside the US and basic familiarity of another language (if applicable)

The Biomedical Engineering Curriculum described in section 3 has been designed to achieve the Program Educational Objectives and Program Outcomes.

3. BIOMEDICAL ENGINEERING CURRICULUM

The basic level curriculum has been designed to achieve the Program Educational Objectives and Program Outcomes, and to meet the University General Education Requirements. Section 3.1 describes the University General Education Requirements. Section 3.2 describes the basic-level Biomedical Engineering Curriculum, and Section 3.3 describes areas of specialization within Biomedical Engineering.

3.1 General Education Requirements (University Core Curriculum)

As part of all baccalaureate degree programs at the University, students are required to satisfy a common core of coursework known as the General Education Requirements. All students are required to take ENGL 1010 or 1011 or 3800 (plus two “W” Courses). In addition, there is a second language requirement.

Second Languages

The minimum requirement is met if the student is admitted to the University with three years of a single foreign language in high school, or the equivalent. With anything less than that, the student must pass the second semester course in the first year sequence of college level study in a single language.

The General Education Requirements comprise four Content Areas. The Content Area courses in Groups One, Two, and Three must be taken in six different academic units. Content Area Three is automatically satisfied in the basic BME program of study. The others are summarized as follows:

Content Area One. Arts and Humanities. Six Credits

Arts and Humanities courses provide a broad vision of artistic and humanist themes. These courses enable students themselves to study and understand the artistic, cultural and historical processes of humanity. They encourage students to explore their own traditions and their places within the larger world so that they, as informed citizens, may participate more fully in the rich diversity of human languages and cultures.

Content Area Two. Social Sciences. Six Credits

The social sciences examine how individuals, groups, institutions, and societies behave and influence one another and the natural environment. Courses in this group enable students to
analyze and understand interactions of the numerous social factors that influence behavior at the individual, cultural, societal, national, or international level. They use the methods and theories of social science inquiry to develop critical thought about current social issues and problems.

**Content Area Four. Diversity and Multiculturalism. Six Credits**

In this interconnected global community, individuals of any profession need to be able to understand, appreciate, and function in cultures other than their own. Diversity and multiculturalism in the university curriculum contribute to this essential aspect of education by bringing to the fore the historical truths about different cultural perspectives, especially those of groups that traditionally have been under-represented. These groups might be characterized by such features as race, ethnicity, gender, sexual identities, political systems, or religious traditions, or by persons with disabilities. By studying the ideas, history, values, and creative expressions of diverse groups, students gain appreciation for differences as well as commonalities among people.

Subject matter alone cannot define multicultural education. A key element is to examine the subject from the perspective of the group that generates the culture. The inquiry needs to be structured by the concepts, ideas, beliefs, and/or values of the culture under study. A variety of approaches can be used, including comparative or interdisciplinary methodologies. Regardless of the approach, courses should view the studied group(s) as authors and agents in the making of history.

**3.2 Overview of the Curriculum**

The lower division or freshman and sophomore years of the Biomedical Engineering curriculum are similar to the other engineering curricula with the addition of Biology 1107 in the second semester. The entire program of professional requirements is selected by the student, subject to approval by his/her advisor, the Department Head and final approval by the SoE Dean of Undergraduate Education. The recommended sequence of courses is as follows.

**Biomedical Engineering - Required Courses**

**BME 3100 (211)**

*Physiological Modeling*

Three credits. Pre- or Co-requisite: MATH 1132Q (116Q). Recommended Preparation: BIOL 1107 (107). Open to Sophomores.

Techniques for analysis and modeling of biomedical systems. Application of advanced mathematics (including Differential Equations, Laplace Transforms and Statistics) and computer-aided methods to study the problems at the interface of engineering and biology. Elements of physiological modeling and the solution of the transient and forced response for a variety of biomechanical, biomaterial, bioelectrical and biochemical systems.

**BME 3120 (New)**

*LabVIEW Basics for Biomedical Engineers*

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1 Previous 3-digit catalog course numbers in parentheses
One credit. Prerequisite: CSE1100C (123C) or CSE 1010. Cannot be taken for credit after passing BME 3130. One 3-hour laboratory period.
The LabVIEW Basics course introduces the LabVIEW programming environment. The fundamentals of using graphical programming to collect, analyze, display and store data are covered. Learn techniques for designing stand alone applications, creating interactive user interfaces and optimizing data flow.

**BME 3130 (New) LabVIEW Intermediate for Biomedical Engineers**
One credit. Prerequisite: BME 3120. One 3-hour laboratory period.
The LabVIEW Intermediate course introduces structured practices to design, test, and use LabVIEW applications. Recommended development techniques for hierarchical VI development, event-based architectures, user-interface design, error handling and documentation are covered. Learn to extend application functionality and reduce development time by using connectivity technologies such as DLLs, ActiveX, and the Internet.

**BME 3150 (New) Statics and Dynamics for Biomedical Engineers**
Three credits. Co-requisite: MATH 2110Q (210Q) or MATH 2130Q (230Q).
Fundamentals of statics and dynamics using vector methods on physiological systems. Resolution and composition of forces; equilibrium of force systems; rectilinear and curvilinear motion, translation, rotation, plane motion, work, energy and power.

**BME 3300 (220) Biochemical Engineering for Biomedical Engineers**
Three credits. Open to juniors or higher. Prerequisite: BME 3100 (211). Co-requisite: CHEM 2443 (243).
Introduction to chemical reaction kinetics; enzyme and fermentation technology; microbiology, biochemistry, and cellular concepts; biomass production; organ analysis; viral dynamics. Replaces BME 3301 (221).

**BME 3400 (251) Biosystem Analysis**
Four credits. Prerequisite: BME 3100 (211). This course and ECE 3101 (202) may not both be taken for credit.
A lecture and laboratory course that covers Fourier analysis, Laplace analysis and Z-transforms. Techniques for generating quantitative mathematical models of physiological control systems; the behavior of physiological control systems using both time and frequency domain methods.

**BME 3500 (252) Biomedical Engineering Measurements**
Four credits. Prerequisite: BME 3400 (251) and ECE 2001W (210W).

**BME 3600W (261W) Biomechanics**
Four credits. Prerequisite: BME 3100 (211) and 3150; ENGL 1010 (110) or ENGL 1011 (111) or ENGL 3800 (250)


**BME 3700 (271) Biomaterials**

Four credits. Prerequisite: MSE 2101 (MMAT 201) or MSE 2001 (MMAT 243) and BME 3100 (211).

A lecture and laboratory course that introduces a series of implant materials, including metals, ceramics, glass ceramics, polymers, and composites. These materials are compared with the natural materials, with consideration given to issues of mechanical properties, biocompatibility, degradation of materials by biological systems, and biological response to artificial materials. Particular attention is given to materials for the total hip prosthesis, dental restoration, and implantable medical devices.

**BME 4900 (290) Biomedical Engineering Design I**

Three credits. Prerequisite: This course is taken by seniors in the semester before BME 4910 (291).

Discussion of the design process; project statement, specifications, project planning, scheduling and division of responsibility, ethics in engineering design, safety, environmental considerations, economic constraints, liability, manufacturing, and marketing. Projects are carried out using a team-based approach. Selection and analysis of a design project to be undertaken in BME 4910 (291) is carried out. Written progress reports, a proposal, an interim project report, a final report, and oral presentations are required.

**BME 4910 (291) Biomedical Engineering Design II**

Three credits. Prerequisite: BME 4900 (290).

Design of a device, circuit, system, process, or algorithm. Team solution to an engineering design problem as formulated in BME 4900 (290), from first concepts through evaluation and documentation. Written progress reports, a final report, and oral presentation are required.
Bachelor of Science in Engineering in Biomedical Engineering

Freshman Year (Total credits: 33)

First Semester
CHEM 1127Q – General Chemistry (4 credits)
MATH 1131Q - Calculus I (4 credits)
CSE 1100C - Introduction to Computing (2 credits)
ENGL 1010 or 1011 – Seminar in Academic Writing or Seminar in Writing Through Literature (4 credits)
ENGR 1000 - Orientation to Engineering (1 credit)
Content Area 1 (Not in PHIL) (3 credits)

Second Semester
CHEM 1128Q - General Chemistry (4 credits)
MATH 1132Q - Calculus II (4 credits)
BIOL 1107 - Principles of Biology (4 credits)
ENGR 1166 - Foundations Of Engineering - BME Section (3 credits)

Sophomore Year (Total credits: 32)

First Semester
PHYS 1501Q - Physics for Engineers I (4 credits)
MATH 2110Q - Multivariable Calculus (4 credits)
BME 3150 Statics & Dynamics for Biomedical Engineers (3 credits)
BME 3100 - Physiological Modeling (3 credits)
Content Area 2 (Social Sciences) (3 credits)

Second Semester
STAT 3025Q - Statistical Methods (Calculus Level) (3 credits)
BME 3120 - LabVIEW Basics for Biomedical Engineers (1 credit)
BME 3400 - Biosystem Analysis (4 credits)
ECE 2001W – Electric Circuits (4 credits)
PHIL 1104 - Philosophy & Ethics (3 credits)

Junior Year (Total credits: 33)

First Semester
BME3600W - Biomechanics (4 credits)
PNB 2264 - Human Physiology and Anatomy (4 credits)
CHEM 2443 - Organic Chemistry (3 credits)
MSE 2101 - Material Science & Engineering I or MSE 2001 - Sruc, Prop, & Proc Mater I (3 credits)
BME 3500 - Biomedical Engineering Measurements (4 credits)

Second Semester
BME 3700 - Biomaterials (4 credits)
Engineering Elective (3 credits)
BME 3130 - LabVIEW Intermediate for Biomedical Engineers (1 credit)
Life Science Elective (3 credits)
Math Science Elective (4 credits)

Senior Year (Total credits: 30)

First Semester
BME 4900 - Biomedical Engineering Design I (3 credits)
BME 3300 - Biochemical Engineering for Biomedical Engineers (3 credits)
Biomedical Engineering Elective (3 credits)
Engineering Elective (3 credits)
Content Area 2 (Social Sciences; not same department as in Sophomore Year) (3 credits)

Second Semester
BME 4910 - Biomedical Engineering Design II (3 credits)
Biomedical Engineering Elective (3 credits)
Engineering Elective (3 credits)
Content Area 4 (Diversity) (3 credits)
Content Area 4 (Multiculturalism) (3 credits)

TOTAL CREDITS FOR DEGREE: 128
4. TRACKS IN BME

In order to provide guidance for those students seeking to specialize in a subfield within Biomedical Engineering, six tracks of specialization associated with Biomedical Engineering have been identified which accommodate most student interests. These are:

1. Biochemical Engineering/Tissue Engineering/Biotechnology
2. Biofluid Biomechanics
3. Bioinformatics
4. Bioinstrumentation/Medical Imaging/Biosignal Processing
5. Biomaterials

Suggested courses for the unspecified Engineering Elective courses are presented in section 4.1. For information about tracks within Biomedical Engineering, the student may wish to examine the textbook Introduction to Biomedical Engineering used in BME 3100, or issues of the EMB Magazine or view the UConn BME Program website, or the websites of the Biomedical Engineering professional societies IEEE Engineering in Medicine and Biology Society (http://www.ewh.ieee.org/soc/embs/) and http://EMB-Magazine.bme.uconn.edu or the Biomedical Engineering Society (http://www.bmes.org). In addition to the required BME courses, students also must two BME elective courses described in section 4.2. In addition to the required life science courses, one elective life science course is also required from the approved list in section 4.3.

4.1 Engineering Elective Courses

Must be a series of courses within a track. The purpose of the course selection is to develop an expertise within a traditional engineering program. A minimum total of 9 credit hours is required.

Biochemical Engineering/Tissue Engineering/Biotechnology Track

Biochemical engineering involves biotechnology and processes that convert natural materials such as sugars into molecules such as therapeutic proteins, and harnessing the synthetic capabilities of cells and genetic engineering. Tissue engineering is the study of tissue dynamics that coordinate tissue repair, replacement, and reconstruction. Biotechnology involves the production of medicaments and vaccines, as well as in the emergence of stem-cell and gene therapies. Examples include antibiotics produced by specially designed organisms and genetic cures engineered through genomic manipulation.

CHEG 2103 (203) Introduction to Chemical Engineering

First semester. Three credits. Recommended preparation: CHEM 1128Q (128Q) or both CHEM 1125Q (125Q) and 1126Q (126Q); MATH 1122Q (114Q) or 1132Q (116Q) or CSE 1100C (123C). Open to sophomores.

Application of the principles of chemistry and physics to chemical processes; units, dimensions, and process variables; material balances; equations of state (ideal and real); single
component equilibria; energy balances; non-reactive and reactive processes; combined mass and energy balances.

CHEG 2111 (211) Chemical Engineering Thermodynamics I
Either semester. Three Credits. Three class periods and one discussion period. Recommended Preparation: MATH 2110Q (210Q), CHEM 1128Q (128Q), and CHEG 2103 (203), or consent of Chemical Engineering Program Director. This course and ME 2233 (233) may not both be taken for credit.
First and second law of thermodynamics; thermal and PVT properties of matter; exact differentials and thermodynamic identities; design and analysis of power cycles; analysis of refrigeration and liquefaction processes.

CHEG 3112 (214) Chemical Engineering Thermodynamics II
Either semester. Four Credits. Three class periods and one discussion period. Prerequisite: MATH 2410Q (211Q), CHEG 2111 (211), or consent of Chemical Engineering Program Director.
Properties and phase equilibria for ideal and non-ideal mixtures; design of equilibrium flash separators; phase equilibria using equations of state; chemical equilibria; optimum conditions for chemical reactions; applications include chemical, electrochemical and biochemical systems.

CHEG 3123 (223) Transfer Operations I
Either semester. Three credits. Three class periods and one discussion period. Recommended preparation: MATH 2110Q (210Q) and 2410Q (211Q), CHEM 1128Q (128Q), and CHEG 2103 (203), or consent of Chemical Engineering Program Director.
Overall mass, energy, and momentum balances; fluid flow phenomena; theoretical and empirical relationships for design of incompressible fluid-flow systems; conductive heat transfer; heat transfer coefficients and design of heat exchange systems.

CHEG 3151 (251) Process Kinetics
Theory of chemical reaction rate; homogeneous, heterogeneous and catalytic systems. Analysis and design of batch and flow reaction systems; analysis of rate data; temperature and catalytic effects in reactor design; mass transport effects; non-ideal reactor design.

Biofluid Biomechanics Track
Biofluid biomechanics deals with the properties and movement of fluids under the influence of a force. A typical focus is the cardiovascular system and blood’s flow properties. Biomechanical engineers also study the flow of fluids in the body and the transfer of chemical substances across membranes and synthetic materials.

ME 2233 (233) Thermodynamic Principles
Both semesters. Three credits. Prerequisite: CHEM 1127Q (127Q) or both CHEM 1124Q (124Q) and 1125Q (125Q); PHYS 1501Q (151Q); MATH 2110Q (210Q), which may be taken
concurrently. Cannot be taken for credit after ME 3242 (242) or 3250 (250). Open to sophomores or higher.

Introduction to the First and Second Laws of Thermodynamics. Thermodynamic properties of pure substances and ideal gases. Analysis of ideal and real processes - including turbines, pumps, heat exchangers, and compressors.

**ME 2234 (234) Applied Thermodynamics**
First semester. Three credits. Prerequisite: ME 2233 (233) or CHEG 2111 (211). Open to sophomores or higher.
Thermodynamic first and second law analysis of vapor and gas cycles, property relations for simple pure substances, properties of ideal gas mixtures, psychrometry, fundamentals of combustion thermodynamics, application of thermodynamics in the design of thermal engineering systems.

**ME 3242 (242) Heat Transfer**
Second semester. Three credits. Prerequisite: ME 2233 (233) and 3250 (250).
Fundamentals of conduction, convection, and radiation heat transfer. Application of the general laws of heat transfer, and heat exchange to a wide variety of practical problems. The analytical, numerical, and graphical solution of one, two, and three dimensional problems.

**ME 3250 (250) Fluid Dynamics I**
First semester. Three credits. Prerequisite: ME 2233 (233); MATH 2110Q (210Q) and 2410Q (211Q). Cannot be taken for credit after passing ME 240, 3242 (242), 245, 3251 (251), 263, 4972 (272) or CE 3120 (297).
Laws of conservation of mass, momentum, and energy in fluid systems, fluid statics, dimensional analysis, incompressible, inviscid and viscous flows, steady and unsteady flows, internal and external flows.

**ME 3251 (251) Fluid Dynamics II**
Either semester. Three credits. Prerequisite: ME 3250 (250) or CE 3120 (297).

**ME 3275 Introduction to Computational Fluid Dynamics**
Either semester. Three credits. Prerequisite: ME 3242 and ME 3250.
Introductory course on computational fluid dynamics (CFD) based on pressure-based finite volume methods. Topics covered include: integral derivations of governing equations of fluid flow, finite volume discretization of diffusion and convection equations, pressure-velocity coupling algorithms based on SIMPLE method for flow field solutions and finite volume solutions of unsteady problems. The course also covers iterative and non-iterative solution methods for large systems of linear equations, as well as methods for verification and validation of computational solutions.
**Bioinformatics Track**

Bioinformatics involves developing and using computer tools to collect and analyze data related to medicine and biology. Work in bioinformatics may involve using sophisticated techniques to manage and search databases of gene sequences that contain many millions of entries.

**CSE 1102 (133) Object Oriented Design and Programming**
Second semester. Three credits. Three class periods of lecture and one 75 minute laboratory period per week. Prerequisite: CSE 1100C (123C). Not open to students who have passed CSE 124.


**CSE 2100 (134) Data Structures and Introduction to Algorithms**
First semester. Three credits. Three class periods of lecture. Prerequisite: CSE 1102 (133).

Students who have passed CSE 124 will receive only 2 credits for CSE 2100.

Fundamental concepts of data structures and the algorithms that proceed from them. Implementation and use of linked lists, stacks, queues, trees, priority queues, heaps and graphs. Emphasis on recursion, abstract data types, object oriented design, and associated algorithms and complexity issues. Design using specifications and requirements. Basic computer organizations, including memory organizations and allocations issues. Programming assignments.

**CSE 2300W (210W) Digital Logic Design**
First semester. Four credits. Three class periods and one 2-hour laboratory period.

Prerequisite: CSE 1100C (123C) or 1102 (133); PHYS 1010Q (101Q) or 1501Q (151Q) or high school physics; ENGL 1010 (110) or 1011 (111) or 3800 (250). Cannot be taken after passing CSE 207 or 208W. Open to sophomores or higher.

Representation of digital information. Analysis, design, and evaluation of combinational and sequential logic circuits. Debugging techniques. Use of computer facilities for circuit simulation, CAD, and report preparation and presentation. Introduction to structure and operation of digital computers. Design projects. Written reports with revisions are required for each project.

**CSE 2500 (254) Introduction to Discrete Systems**
Either semester. Three credits. Prerequisite: CSE 1102 (133). Not open for credit to students who have passed MATH 214Q. Open to sophomores or higher.

Mathematical methods for characterizing and analyzing discrete systems. Modern algebraic concepts, logic theory, set theory, grammars and formal languages, and graph theory. Application to the analysis of computer systems and computational structures.
CSE 3300 (245) Computer Networks and Data Communication
Semester by arrangement. Three credits. Prerequisite: CSE 2304 (201) or 3666 (220); STAT 3025Q (220Q) or 3345Q (224Q) or 3375Q (230Q) or MATH 3160 (231).
Introduction to computer networks and data communications. Network types, components and topology, protocol architecture, routing algorithms, and performance. Case studies including LAN and other architectures.

CSE 3504 (221) Probabilistic Performance Analysis of Computer Systems
Either semester. Three credits. Prerequisite: CSE 2100 (134); CSE 2500 (254); STAT 3025Q (220Q) or 3375Q (230Q) or MATH 3160 (231).
Introduction to the probabilistic techniques which can be used to represent random processes in computer systems. Markov processes, generating functions and their application to performance analysis. Models which can be used to describe the probabilistic performance of digital systems.

CSE 3666 (220) Introduction to Computer Architecture
Either semester. Three credits. Three 1-hour lectures and one 1-hour laboratory period. Prerequisite: CSE 2100 (134) and 2300W (210W). Not open after passing CSE 4302 (249) or 4901 (261). CSE 3666 and either CSE 2304 (201) or 243 may not both be taken for credit.
Structure and operation of digital systems and computers. Fundamentals of digital logic. Machine organization, control and data paths, instruction sets, and addressing modes. Integer and floating-point arithmetic, the memory hierarchy, the I/O subsystem. Assembly language and basic program organization, interrupts, I/O, and memory allocation.

CSE 4302 (249) Computer Organization and Architecture
Either semester. Three credits. Three one-hour lectures. Prerequisite: CSE 2300W (210W) and 3666 (220). Cannot be taken after passing CSE 243 or CSE 4901 (261).
Organization and architecture of modern computer systems. Emphasis is on alternatives and advances to the basic Von Neumann architecture: topics such as pipelining, memory hierarchy and management, multiprocessor and alternative architectures, reconfigurable hardware, and other techniques for performance enhancement.

**Bioinstrumentation/Medical Imaging/Biosignal Processing Track**
Bioinstrumentation uses electronics, measurement principles and techniques, and innovative biosensors to develop devices for monitoring, diagnosing, and treating diseases. Computers have become increasingly important in this area. They monitor the condition of patients during surgery or in intensive care. Computers also monitor healthy people in unusual environments, such as astronauts in space or underwater divers at great depths. Bioinstrumentation engineers develop and investigate many tools to detect, diagnose, and study biological conditions. For example, medical imaging systems apply energy, such as X rays, or sound waves, to the body to create detailed pictures of internal structures. Biosignal processing is used to detect, classify and analyze signals produced by the body, and are used in medical devices. Other devices, such as an implantable defibrillator act as a personal physician if a heart attack occurs, restoring normal heart function. Biomedical engineers have developed certain lasers and other devices to help treat disorders. Lasers, which produce
narrow, powerful beams of light, make possible bloodless surgery on blood vessels, nerve fibers, retinas and corneas. Automated infusion pumps continuously deliver the drug insulin to diabetic patients.

**CSE 2300W (210W) Digital Logic Design**
First semester. Four credits. Three class periods and one 2-hour laboratory period. Prerequisite: CSE 1100C (123C) or 1102 (133); PHYS 1010Q (101Q) or 1501Q (151Q) or high school physics; ENGL 1010 (110) or 1011 (111) or 3800 (250). Cannot be taken after passing CSE 207 or 208W. Open to sophomores or higher. Representation of digital information. Analysis, design, and evaluation of combinational and sequential logic circuits. Debugging techniques. Use of computer facilities for circuit simulation, CAD, and report preparation and presentation. Introduction to structure and operation of digital computers. Design projects. Written reports with revisions are required for each project.

**ECE 3001 (205) Electromagnetic Fields and Waves**
First semester. Three credits. Prerequisite: PHYS 1502Q (152Q); MATH 2110Q (210Q) and 2410Q (211Q). Not open to students who have received credit for ECE 4141 (227) or ECE 206. Application of electric and magnetic field theory to engineering problems involving conductors, dielectrics, semiconductors, magnetic materials, the motion of charged particles, and wave propagation. Relationship between fields and circuit parameters in the context of transmission lines and radiation.

**ECE 3201 (212) Electronic Circuit Design and Analysis**
Either semester. Four credits. Prerequisite: ECE 2001 (210W) or both ECE 2608 (201) and 2609W (209W). This course and ECE 3608 (204) or ECE 3609 (261) may not both be taken for credit. Three 1-hour lectures and one 2-hour laboratory. Physical electronics underlying the operation of electronic devices. Diodes, diode models, and diode circuits. Transistors, transistor models, and transistor circuits. DC, small signal, and frequency analysis of transistor amplifiers. Compound transistor configurations. Computer analysis tools. Design projects are implemented and tested in the laboratory. Laboratory reports with revisions are required for each project.

**ECE 3221 (215) Digital Integrated Circuits**
Second semester. Three credits. Prerequisite: ECE 3201 (212) or 3608 (204); CSE 2300W (210W). This course and ECE 3222 (213) cannot both be taken for credit. Switching, timing, wave shaping, and logic circuits to generate waveforms and functions used in pulse systems, instrumentation and computers. Emphasis is on integrated circuits.

**ECE 3223 Optical Engineering**
First semester. Three credits. Prerequisites: ECE 3001 or PHYS 3201. Not open to students who have passed ECE 4231. Principles and techniques of optical engineering, including geometrical optics, optical fibers and systems, sources and detectors, measurements, imaging, lenses, wave optics, polarization,
interference, diffraction, optical Fourier transforms, holography, interferometry, integrated optics, frequency conversion, interaction of light and matter.

**ECE 3411 (266) Microprocessor Applications Laboratory**
Either semester. Three credits. One class period and one 4-hour laboratory.
Design of software and interface hardware to use a microcomputer as an on-line, real-time element in data acquisition, filtering and control systems. Use of clocks, DAC's, ADC's, speech synthesis modules, and movement generators. Design project. Written and oral presentations of laboratory results.

**ECE 3608 (EE204) Electronic Devices and Circuits**
Semester by arrangement. Three credits. Prerequisite: ECE 2608 (201). This course and ECE 239 may not both be taken for credit.
Physical electronics underlying the operation of modern solid-state devices. Diodes and diode circuits. The bipolar junction transistor and field-effect transistors. Models of transistors. Applications of transistors to integrated circuits such as operational amplifiers and logic gates.

**ECE 4095 Special Topics in Electrical and Computer Engineering**
Semester, credits, and hours by arrangement or as announced. Instructor consent required. Classroom and/or laboratory course in special topics as announced in advance for each semester. With a change in content, this course may be repeated for credit.

**ECE 4099 Independent Study in Electrical and Computer Engineering**
Semester by arrangement. Credits and hours by arrangement. Prerequisite: Consent of instructor.
Individual exploration of special topics as arranged by the student with an instructor of his or her choice. With a change in content, this course may be repeated for credit.

**ECE 4111 (241) Communication Systems**
First semester. Three credits. Prerequisite: ECE 3101 (202) or BME 3400 (251); STAT 3345Q (224Q).

**ECE 4201 (240) Electronic Circuits and Applications**
Second semester. Three credits. Prerequisite: ECE 3201 (212) or 3608 (204). Recommended preparation: ECE 3111 (232).
Analysis and design of linear amplifiers. The effects of feedback in tuned, video, and operational amplifiers. Noise, stability, and frequency compensation. Applications encompass active filters, oscillators, phase lock loops and nonlinear operations such as multiplication, modulation, sampling, and analog-to-digital conversion.
ECE 4211 (245) Semiconductor Devices and Nanostructures (formerly Micro/Opto-Electronic Devices)
Second semester. Three credits. Prerequisite: ECE 3201 (212) or 3608 (204).
Principles and applications of contemporary solid state devices such as light-emitting diodes, injection lasers, solar cells, p-n-p-n diodes, SCR and Triacs, IMPATT diodes, Schottky devices, bipolar and MOS transistors, MESFETs and MODFETs, and fundamentals of integrated circuits.

ECE 4231 (228) Fiber Optics
Semester by arrangement. Three credits. Prerequisite: ECE 207 or 3001 (205) or PHYS 3201 (255).
Application of Maxwell's equations and geometric optics first to two-dimensional dielectric waveguides and then to cylindrical fibers. Ray and mode theory, eigenvalues, Goos-Haenchenschift. Step-index, graded-index, and single-mode fibers. Splicers, couplers, sources, detectors and optical design. Fiber manufacturing techniques.

ECE 4242 Micro/Opto-Electronic Devices and Circuits Fabrication Lab
First semester. Three credits. Prerequisites: ECE 3221 and 4211.
Semiconductor wafer preparation and characterization including: determination of carrier concentration, mobility, and lifetime; oxidation, diffusion, metallization, mask layouts, and photolithographic techniques as employed in the realization of discrete devices (e.g., bipolar and MOS transistors, solar cells) and integrated circuits; design of basic IC components such as transistors, resistors, and capacitors; monolithic fabrication of simple digital/analog circuits. Design project. Written and oral presentations of laboratory results.

ECE 4243 Nanoscience & Nanotechnology I
First semester. Three credits. Prerequisites: ECE 4211 or PHYS 2300 or 3401 or MSE 4001, and CHEM 1127 or equivalent.
Fundamentals of electron and hole confinement in quantum well, wire and dot heterostructures, confinement of photons in photonic band gap structures, density of states in quantum wires; transport in quantum wires and dots, and single wells(SWNT) and multi-wall carbon nanotubes; operation of nano field-effect transistors; absorption and emission in quantum wires and dot structures; fabrication methodology to grow and assemble quantum wires and dots including self-assembly techniques for light-emitting diodes, transistors, lasers, and nanoelectromechanical (NEM) structures.

ECE 4244 Nanotechnology II
Second semester. Three credits. Prerequisites: ECE 4211 or ENGR 4243; open to Seniors only.
Growth and characterization of carbon nanotube using vapor phase nucleation; growth of CdSe quantum dots using liquid phase precipitation and vapor phase MOCVD reactor; characterization using AFM and TEM and dynamic scattering techniques; device processing highlighting nanolithography (E-Beam), and self assembly techniques; project work involving fabrication of devices such as LEDs, carbon nanotube based FETs, and sensors using self-assembled quantum dots hosted in inorganic or organic/polymer layers.
**Biomaterials Track**

Biomaterials concern the development and selection of appropriate materials to place inside the human body. Such selection ranks among the most difficult tasks faced by biomedical engineers. It demands an understanding of the physical and chemical properties of the living tissue that a material will assist or replace. The material to be implanted must cause no harmful effects, such as poisonous reactions or cancer. In turn, the body must not damage the materials of the implant. For most devices implanted for a long period of time, the materials must be chemically inactive, durable enough to withstand the repeated stresses of a lifetime, and harmless to the tissues and blood. Implantable materials include certain ceramics, metal alloys, and plastics.

**CHEG 3156 (256) Polymeric Materials**

Either semester. Three credits. Not open to students who have passed CHEM 3661 (CHEM 280). Recommended preparation: CHEM 2444 (CHEM 244).

Structure, properties, and chemistry of high polymers; solution and phase behavior; physical states, viscoelasticity and flow; production and polymer processing; design of polymers for specific applications.

**MSE 2002 (MMAT 244) Introduction to Structure, Properties, and Processing of Materials II**

Second semester. Three credits. Prerequisites: MSE 2001 (MMAT 243) or 2101 (MMAT 201). Open to sophomores.

Structures, properties, and processing of ceramics; structure, properties and processing of polymers and composites; electrical, thermal, magnetic and optical properties of solids; and corrosion.

**MSE 2053 (MMAT 284) Materials Characterization and Processing Laboratory**


Principles of materials properties, processing and microstructure will be illustrated by experiments with qualitative and quantitative microscopy, mechanical testing, thermal processing, plastic deformation and corrosion. Materials design and selection criteria will be introduced by studying case histories from industry and reverse engineering analyses.

**MSE 3003 (MMAT 265) Phase Transformation Kinetics and Applications**

First semester. Three credits. Prerequisite: MSE 2001 (MMAT 243) or 2101 (MMAT 201).

Principles and applications of phase transformations to control microstructure and materials properties. In depth, quantitative coverage will include vacancies, solid structures, phase diagrams, diffusion, solidification of metals, nucleation and growth kinetics, and thermal treatments to control microstructure.

**MSE 3004 (MMAT 266) Mechanical Behavior of Materials**

Second semester. Three credits. Prerequisite: MSE 2001 (MMAT 243) or 2101 (MMAT 201).

Elements of elastic plastic deformation of materials and the role of crystal structure. Strengthening and toughening mechanisms. Fracture; including fatigue, stress corrosion and creep rupture. Test methods.
MSE 3055 (MMAT 286) Materials Processing and Microstructures Laboratory
First semester. One credit. Prerequisite: MSE 2053 (MMAT 284); MSE 3003 (MMAT 265), which may be taken concurrently. One 3-hour laboratory period.

MSE 3152 (MMAT 202) Materials Science & Engineering Lab
Both semesters. One credit. One 3-hour laboratory period. Prerequisite: MSE 2101 (MMAT 201), which may be taken concurrently.
Experiments will illustrate the relationships between processing, properties and microstructure for common industrial materials. Topics include sample preparation techniques, quantitative metallography, x-ray diffraction, light and electron microscopy, tensile and fatigue testing, phase transformations, heat treatment, corrosion.

MSE 4001 (MMAT 267) Electrical and Magnetic Properties of Materials
First semester. 3 credits. Prerequisites: MSE 2101 or both PHYS 1502 and MSE 2001.
Principles underlying electrical and magnetic behavior will be applied to the selection and design of materials. Topics covered will include: thermoelectricity, photoelectricity, conductors, semiconductors, superconductors, dielectrics, ferroelectrics, piezoelectricity, pyroelectricity, and magnetism. Device applications.

MSE 4003 (MMAT 236) Materials Characterization
Semester by arrangement. Three credits. Two class periods and, every other week, a 3-hour laboratory period. Laboratory sections in addition to those initially listed will be arranged. Prerequisite: MSE 2001 (MMAT 243) or 2101 (MMAT 201).
Principles and experimental methods of optical, electron, and x-ray examination of engineering materials. Emphasis on use of x-ray analysis, with introduction to electron microscopy, Auger spectroscopy, scanning electron microscopy, and microanalysis.

MSE 4034 (MMAT 234) Corrosion and Materials Protection
Semester by arrangement. Three credits. Prerequisite: MSE 2001 (MMAT 243) or 2101 (MMAT 201).

MSE 4240 (MMAT 260) Nanomaterials Synthesis and Design
Either semester. 3 credits. Prerequisite: MSE 2002.
Introduces synthesis and design of materials in the nanoscale. Typical synthesis strategies of low dimensional materials including nanoparticles, nanowires, nanotubes and hierarchical nanostructures are presented and discussed. The reasons behind growth mechanisms are interpreted and the nanoscale structure-properties relations are described. Design strategies of
multifunctional nanomaterials will be addressed as well. Readings from modern scientific literature are assigned weekly for in-class discussions.

MSE 4241 (MMAT 261) Nanomaterials Characterization and Application
Either semester. 3 credits. Prerequisite: MSE 2002.
Introduces materials characterization and applications at the nanoscale. Standard and advanced methods in Scanning Probe Microscopy, Electron Microscopy, and Focused Ion Beams are presented. Self-Assembled and Lithographically defined structures are treated. Nanoscale particles, tubes, films, and structures are discussed. Applications for enhanced mechanical, electronic, magnetic, optical, and biological properties are described. Societal implications including performance, costs, environmental impacts, and health issues are addressed. Readings from modern scientific literature are assigned weekly for in-class discussions.

MSE 4095 Special Topics in Materials Engineering
Both semesters. 3 credits. Prerequisite: Instructor Consent Required.

Biosolid Biomechanics Track
Biomechanics is mechanics applied to biology. This includes the study of motion, material deformation, and fluid flow. For example, studies of the fluid dynamics involved in blood circulation have contributed to the development of artificial hearts, while an understanding of joint mechanics has contributed to the design of prosthetic limbs.

ME 3214 Dynamics of Particles and Rigid Bodies
Second semester. Three credits. Prerequisite: CE 2120.
Kinematics and dynamics of particles. Motion relative to translating and rotating observers; inertial reference systems; central forces and orbits. Kinematics and dynamics of groups of particles and rigid bodies. Lagrangian description of motion.

ME 3225 Computer-Aided Design, Modeling, and Graphics
Both semesters. Three credits. Prerequisites: CSE 1100; CE 3110; MATH 2110 and Instructor Consent Required.
Introduction to computer-aided graphics, modeling and design. Applications of graphics software and hardware with mini- and micro-computer systems. Interactive computer graphic techniques. Extensive laboratory study of wire-frame and raster computer graphics. Static and dynamic graphic presentation methods.

ME 3227 Design of Machine Elements
First semester. Three credits. Prerequisite: CE 3110.
Application of the fundamentals of engineering mechanics, materials and manufacturing to the design and analysis of machine elements.

ME 3229 Machine Design
Second semester. Three credits. Prerequisite: CE 3110.

**ME 3253 Linear Systems Theory**
First semester. Three credits. Prerequisite: CE 2120; MATH 2410Q.
Review of ODE Solutions, mathematical modeling of dynamic systems, linearization of nonlinear behavior, Laplace domain representation of dynamics, transfer functions, block diagram algebra, signal-flow graphs, Mason's rule, transient analysis of system response, convolution integral, Duhamel's integral, Green's function, stability of linear systems, Routh-Hurwitz method, root locus, frequency response, Bode and polar representations, introduction to feedback systems.

**ME 3255 Computational Mechanics**
First semester. Three credits. Prerequisites: MATH 2410 and CE 3110.
Topics include elementary numerical analysis, finite differences, initial value problems, ordinary and partial differential equations and finite element techniques. Applications include structural analysis, heat transfer, and fluid flow.

**ME 3260 Measurement Techniques**
Second semester. Three credits. Prerequisite: ECE 3002.
Theory and practice of measurement including analysis and application of electromechanical transducers. Methods of measuring length, area, time, pressure, temperature, force and strain. The determination of the phase relation between a driving potential and the response of a system. The application of statistical methods to analysis of experimental data.

### 4.2 Biomedical Engineering Elective Courses
A total of two different 3-credit courses is required and must be selected from the following:

**BME 3810 Computational Genomics**
Three credits. Prerequisite: BIOL 1107, CSE 1100 or CSE 1010, and either STAT 3025Q or STAT 3345Q.
Computational methods for genomic data analysis. Topics covered include statistical modeling of biological sequences, probabilistic models of DNA and protein evolution, expectation maximization and Gibbs sampling algorithms, genomic sequence variation, and applications in genomics and genetic epidemiology. Cross-listed with CSE 3810.

**BME 4300 (253) Physiological Control Systems**
Three credits. Prerequisite: BME 3400 (251) or ECE 3111 (232).
Analysis of human physiological control systems and regulators through the use of mathematical models. Identification and linearization of system components. Systems interactions, stability, noise, and the relation of system malfunction to disease. The analysis and design of feedback systems to control physiological states through the automatic administration of drugs.
**BME 4500 (255) Bioinstrumentation**  
Three credits. Prerequisite: BME 3500 (252).  
Modeling, analysis, design, and operation of transducers, sensors, and electrodes, for physiological systems; operational and instrumentation amplifiers for bioelectric event signal conditioning, interfacing and processing; A/D converters and hardware and software principles as related to sampling, storing, processing, and display of biosignals and digital computers.

**BME 4600 (262) Biosolid Mechanics**  
Three credits. Prerequisite: BME 3600W (261W) or consent of instructor.  
Mechanical behavior of biological solids. Applications of the theories of elasticity, viscoelasticity, and poroelasticity to bones, ligaments and tendons, skeletal muscle, and articular cartilage. Axial, bending, shearing and torsional loadings. Bone morphology and growth. Biphasic theory. Failure theories. Topics may be modified slightly to accommodate student interests.

**BME 4701 (273) Advanced Biomaterials**  
Three credits. Prerequisite: BME 3700 (271).  
Offers opportunity to gain in-depth knowledge of a series of biomaterials for various applications. Topics include calcium phosphates and composites for hard tissue replacement, drug delivery systems, issues unique to the biomedical field, and regulations for new products and standards. Not open to students who have passed BME 272 (this course replaces BME 272).

**BME 4710 (274) Introduction to Tissue Engineering**  
Three credits. Prerequisite: BME 3700 (271).  
Presents basic principles of biological, medical, and material science as applied to implantable medical devices, drug delivery systems and artificial organs.

**BME 4800 (280) Bioinformatics**  
Three credits. Prerequisites: BIOL 1107 (107), CSE 1100 or CSE 1010, and either STAT 3025Q (220Q) or STAT 3345Q (224Q).  
Fundamental mathematical models and computational techniques in bioinformatics. Exact and approximate string matching, suffix trees, pairwise and multiple sequence alignment, Markov chains and hidden Markov models. Applications to sequence analysis, gene finding, database search, phylogenetic tree reconstruction. Cross-listed with CSE 3800 (277).

**BME 4985 (295) Special Topics in Biomedical Engineering**  
Semester, credits, and hours by arrangement or as announced. Prerequisite and/or consent: announced separately for each course.  
Classroom and/or laboratory courses in special topics as announced in advance for each semester.

**BME 4999 (299) Independent Study in Biomedical Engineering**
Semester by arrangement. Credits and hours by arrangement, not to exceed four in any semester. Prerequisite: Consent of instructor.
Individual exploration of special topics as arranged by the student with an instructor of his or her choice. With a change in content, this course may be repeated for credit.

**BME graduate courses (5000 level & above) can be substituted for BME Electives**

### 4.3 Biomedical Engineering Honors Courses

The Program offers at least one BME honors course each semester from the spring semester of the freshman year through the spring semester of the senior year. Additionally, the BME senior design project can count as the Honors Thesis. In addition, the BME Program offers the following Honors Core course to satisfy the Honors program requirements.

**BME 1401 (120) Honors Core: Computational Molecular Biology**

Three credits.
Introduction to research in computational biology through lectures, computer lab exercises, and mentored research projects. Topics include gene and genome structure, gene regulation, mechanisms of inheritance, biological databases, sequence alignment, motif finding, human genetics, forensic genetics, stem cell development, comparative genomics, early evolution, and modeling complex systems. (Cross-listed with MCB 1401 and CSE 1401).

### 4.4 Life Science Elective

Three-credit hours are required and must be from the following courses:

**CHEM 2444 (244) Organic Chemistry**

Either semester. Three credits. Prerequisite: CHEM 2443 (243)
A continuation of CHEM 2443 (243).

**CHEM 3563 (263) Physical Chemistry**

Both semesters. Four credits each semester. Prerequisite: CHEM 1126Q (126Q) or 1128Q (128Q) or 1138Q (138Q) or 1148Q (130Q); PHYS 1230 (123) or 1402Q (132Q) or 1502Q (152Q) or 1602Q (142Q); MATH 2110Q (210Q) or 2130Q (230Q).
A study of gases, liquids, solids, solutions, and thermodynamics.

**MCB 2000 (203) Introduction to Biochemistry**

Either semester. Four credits. Three class periods and one 3-hour laboratory period. Prerequisite: CHEM 2241 (141) or 2444 (244). CHEM 2444 (244) may be taken concurrently. Not open for credit to students who have passed MCB 3010 (204).
The structure, chemistry, and metabolism of carbohydrates, lipids and proteins. Enzyme function and kinetics, energy metabolism, and structure and function of nucleic acids. A survey course for students of agriculture, general biology, medical technology, nursing, and pharmacy. Molecular and Cell Biology majors, biophysics majors, and other students desiring a more intensive introduction or considering advanced course work in biochemistry or molecular biology should take MCB 3010 (204). A fee of $20 is charged for this course.
MCB 2610 (229) Fundamentals of Microbiology
Either semester. Four credits. Three lecture periods and one 2-1/2-hour laboratory period. Prerequisite or Co-requisite: CHEM 2241 (141) or 2443 (243). Cannot be taken for credit after MCB 3246 (246), 3617 (217), 3633 (233), 3635 (235), 3636 (236), 3640W (240W), 4624 (224) or 230. Recommended preparation: BIOL 1107 (107) or equivalent. Biology of microorganisms, especially bacteria. Cellular structure, physiology, genetics, and interactions with higher forms of life. Laboratory familiarizes students with methodology of microbiology and aseptic techniques. A fee of $20 is charged for this course.

MCB 3010 (204) Biochemistry
First semester. Five credits. Four class periods and one 3-hour laboratory. Prerequisite or Co-requisite: CHEM 2444 (244). Recommended preparation MCB 2210 (210) or 2610 (229). Not open for credit to students who have passed MCB 2000 (203). The structure and function of biological macromolecules. The metabolism of carbohydrates, lipids, amino acids, proteins and nucleic acids. The regulation of metabolism and biosynthesis of biological macromolecules. An in-depth introduction intended for students planning to take advanced coursework in biochemistry, biophysics or other areas of molecular biology. A fee of $20 is charged for this course.

MCB 3832C (232C) Microcomputer Applications in Molecular & Cell Biology
First semester. Three credits. One 1-hour lecture and two 3-hour laboratories. Recommended preparation: MCB 2210 (210) or 2410 (200) or 2413 (213) or 2610 (229) or 3010 (204). Introduction to the use of microcomputers in molecular biology, emphasizing commercially available applications software, both general (spreadsheet, word processing, database, graphics) and specialized (DNA and protein sequence database manipulation, molecular modeling, data acquisition, others).

PNB 2265 (265) Human Physiology & Anatomy II
Second semester. Four credits. Three class periods and one 3-hour laboratory. Prerequisite: PNB 2264 (264). Not open to students who have passed PNB 2275 (275). PNB 2264 and 2265 must be taken in sequence to obtain credit, and may not be counted toward the Biological Sciences or Physiology and Neurobiology majors. Fundamentals of human anatomy and physiology for students in medical technology, physical therapy, nursing, and education (Sport Science). A fee of $20 is charged for this course.

4.5 Math Science Elective
Four-credit hours are required and must be from the following courses. For students in the Bioinstrumentation track, PHYS 1502Q (152Q) is recommended.

BIOL 1108 (108) Principles of Biology II
Either semester. Four credits. Three class periods and one 3-hour laboratory period. Students may not receive more than 12 credits for courses in biology at the 1000’s level.
A course designed to provide a foundation for more advanced courses in Biology and related sciences. Topics covered include plant biology, genetics, ecology and evolution. A fee of $10 is charged for this course. CA 3-LAB.

CHEM 2446 Organic Chemistry Laboratory
Either semester. One credit. One 4-hour laboratory period. Not open for credit to students who have passed CHEM 2445. Prerequisite: CHEM 2443. This course is open only to Chemical Engineering or Biomedical Engineering majors or by consent of instructor. Introduction to techniques, manipulations, calculations and spectroscopy. A fee of $20 is charged for this course.

ECE 1101 Electrical and Computer Engineering Tools
Second semester. One credit. Not open for credit to students who have passed ECE 3101. An introduction to the modern computer tools used for circuit analysis, signal and system analysis, control, and data acquisition.

MATH 2210Q (227Q) Applied Linear Algebra
Either semester. Three credits. Prerequisites: MATH 1132Q or 1152Q or 2142Q. Recommended prep: grade of C- or better in MATH 1132Q. Not open after passing MATH 3210 or 2144. Cannot be taken after passing MATH 3710, 255, 3510. Systems of equations, matrices, determinants, linear transformations on vector spaces, characteristic values and vectors, from a computational point of view. The course is an introduction to the techniques of linear algebra with elementary applications.

MATH 2410Q (211Q) Elementary Differential Equations
Either semester. Three credits. Prerequisite: MATH 1132Q (116Q) or 1152Q (136Q) or 2142Q (244Q). Recommended preparation: A grade of C- or better in MATH 1132Q (116Q) and MATH 2110Q (210Q) or 220 or 2130Q (230Q). Not open to students who have passed MATH 2420 (221Q) or 2144Q (246Q). Cannot be taken after MATH 2720W (242W), 3146 (252), 3150 (273), 3370 (225), 3410 (272), 3412 (279), 3510 (281), 3710 (204). Introduction to ordinary differential equations and their applications, linear differential equations, systems of first order linear equations, numerical methods.

MATH 2420Q (221Q) Honors Differential Equations
Either semester. Three credits. Prerequisite: MATH 1152Q (136Q) or instructor consent. Not open to students who have passed MATH 2410Q (211Q) or 2144Q (246Q). MATH 2420Q satisfies any requirement met by MATH 2410Q, and provides superior preparation for prospective mathematics, science, and engineering majors. The subject matter of MATH 2410Q in greater depth, with emphasis on the underlying mathematical concepts.

MATH 3146 (252) Introduction to Complex Variables
Either semester. Three credits. Prerequisites: MATH 2110 and 2410, or MATH 2420 or MATH 2144. Not open for credit to students who have passed MATH 5046. Functions of a complex variable, integration in the complex plane, conformal mappings.
MATH 3794 Problem Seminar
Either semester. One credit. One class period. Prerequisite: MATH 1122, 1132, or 1152. This course, with a change of topic, may be repeated for credit. Problem sequences selected from algebra, geometry, calculus, combinatorics, and other branches of mathematics, designed to introduce mathematical concepts and to give experience in problem solving.

PHYS 1502Q (152Q) Physics for Engineers II
Either semester. Four credits. Three class periods and one 3-hour laboratory period. Prerequisite: PHYS 1501Q (151Q). Not open for credit to students who have passed PHYS 1402Q (132Q) or 1602Q (142Q). PHYS 1502Q may be taken for not more than 2 credits, with the permission of the instructor, by students who have received credit for PHYS 1202Q (122Q). Electric and magnetic fields, electromagnetic waves, quantum effects, introduction to atomic physics. CA 3-LAB.

4.6 Double Majors, Minors and Additional Degrees
Opportunities exist to pursue a double major program in Biomedical Engineering and one of the other undergraduate engineering curricula, to pursue a minor degree program in conjunction with the BME degree, or to pursue an additional degree within the University.

Double Major with another Engineering program
Opportunities exist to pursue a double major program in Biomedical Engineering and one of the other undergraduate engineering curricula. If a student wishes to be a double major within Engineering, he or she should notify the Dean of Undergraduate Education. Careful planning of course selection should be done each semester in consultation with the student's advisor. A separate Plan of Study form for each major must be prepared and submitted for approval.

Minors
Several minors are available within the University that may be attractive to students pursuing the Biomedical Engineering degree. These are listed in the General Catalog.

Additional Degree with another major outside of Engineering
From time to time students wish to obtain an additional degree in a field outside of the School of Engineering. One example of an additional degree would be that found in the EUROTECH program in which the completion of a degree in German Studies within the College of Liberal Arts & Sciences is achieved at the same time the student completes the primary degree in a major within the School of Engineering. In addition, a student may pursue a double major in BME other foreign languages. This is an excellent combination with study abroad in biomedical engineering. Students who have such an interest should discuss the procedure for pursuing the additional degree with the Director of Undergraduate Advising, (486-5462), Undergraduate Programs Office.
5. FILLING OUT THE PLAN OF STUDY FORM

All students in the first semester of their Junior year in the Engineering curriculum must prepare a written Plan of Study form. These students should work with their advisors to determine a Plan of Study which meets the degree requirements of the School of Engineering and the University.

After an initial consultation with the advisor, the student should prepare two (2) original copies of the Plan of Study form (available from the BME Program Director's office) by following the guidelines given below. Once the two original copies are prepared, the student should make an appointment with his or her advisor to have him/her review and approve the form. Both the advisor and the student should check his or her transcript to be sure that all Lower Division (freshman/sophomore) requirements have been met and should check that the proposed Upper Division (junior/senior) plan satisfies Department, School and University requirements. After the form is approved by the advisor, the two originals should be forwarded to the BME Program Director, Prof. John Enderle, for approval, prior to being forwarded to the Director of Undergraduate Advising, Prof. David Jordan. Note: the student should check back with his or her advisor to see if any corrections must be made after the form has been reviewed by the BME Program Director.

The BME Program Director will evaluate and indicate approval of the Plan of Study, and then will send the two originals to the Director of Undergraduate Advising. The Director of Undergraduate Advising will evaluate the Plan and indicate his approval of it. In the event that approval is not given, the difference of opinion must be worked out among the advisor, the student and the Director of Undergraduate Advising or BME Program Director, as appropriate.

The Dean's Office will return two copies of the approved tentative Plan of Study form to the advisor: one of the two "originals" which is to be kept in the student's counseling folder, the other being a photocopy to be given to the student.

Note that an approved Plan of Study form can be modified at any time if course offerings and student objectives warrant it. However, no modification that jeopardizes the meeting of requirements will be approved. Modification must be made in consultation with the student's advisor and will usually involve the submission of a "revised" Plan of Study form for approval, in the same manner as the "original" form was prepared and submitted. Although not required until the last semester, it is suggested that a "revised" form be submitted each semester rather than waiting until the final semester. This way any problems can be caught as early as possible. This "revised" Plan of Study form may be created as done initially by forming two new originals, or by marking the changes on the approved "original" and having this "revised" form circulated for approval. Alterations to the courses listed should be made by crossing out the course(s) not taken, writing in those that were, and having the advisor initial and date each change. If extensive changes are to be made, or if a second revision is necessary, a new "original" Plan of Study form must be submitted.
The Plan of Study form should be reviewed at each subsequent registration period. In the student's last semester, he or she is required to file a "final" Plan of Study form which accurately lists all the courses that were taken to satisfy degree requirements. Any modifications to an already approved Plan of Study form should then be submitted for final approval following the above procedure.

The BME Office will generate a Plan of Study for you, or you can fill it out neatly in ink. All approval initials and signatures should also be in ink and dated. Expected date of graduation and year of catalog requirements must be clearly shown. The following guidelines should be adhered to:

**Catalog year and date of graduation:** It is extremely important that you accurately list what catalog year you are filing under and your intended date of graduation. Both items are needed for use by the Registrar so that completion of your degree requirements may be certified by your graduation date. The catalog year may be any year to the most recent continuous period of registration as an engineering student.

**Courses taken:** The Plan of Study form must show exactly the courses being used to satisfy degree requirements. Exemption from specific School of Engineering course requirements or substitution of alternative courses must be clearly indicated on the Plan of Study form, explained in the "Comments" section and/or with an attachment, and may require approval via petition by the Director of Undergraduate Advising (see "Exemption and Substitution" below).

**Content Area Groups**

**Content Area One:** Six credit hours are required in Content Area One. One of the courses is PHIL 104. The other one must be in a different department from the approved list.

**Content Area Two:** Six credit hours in different departments from the approved list are required in Content Area Two, from different departments than in Content Area One.

**Content Area Three:** Students in BME are required to take CHEM 1127Q, 1128Q; PHYS 150IQ; BIOL 1107, which automatically satisfy Content Area Three.

**Content Area Four:** Six credit hours from the approved list are required in Content Area Four. One Content Area 4 course must be an international course. One course may count as both Content Area 4 and Content Area 1 or 2.

**Competencies**

**Second Language Requirement:** The Second Language requirement calls for three years of a single foreign language in High School or the student must pass the second semester course in the first year sequence of college level study in a single language. The words "High School" should be circled if the student has met this requirement in High School or by certification of
English as a second language. If not, the appropriate courses should be listed with the credit by category columns modified accordingly (see "Credit Summary" below). Elementary levels of a foreign language should fall under the "Other" category, while more advanced language courses may be counted as "Humanities" credits in the ABET categories.

**Information Literacy Requirement:** Information literacy involves a general understanding of how information is created, disseminated and organized, and an ability to access, evaluate, synthesize and incorporate information into written, oral, or media presentations. Basic information literacy is taught to all freshmen as an integral part of ENGL 1010/1011, in collaboration with the staff of the University Libraries. Each major program has considered the information literacy competencies required of its graduates and built those expectations into the upper-level research and writing requirements in the major.

**Quantitative Requirement:** Students in Engineering are required to complete MATH 1131Q, 1132Q, 2110Q, and PHYS 1501Q which also satisfy the General Education Requirement for quantitative (Q) courses. (Note that MATH 1120Q-1121Q may be used to meet the freshman fall semester calculus requirement.)

**Computer Technology:** Entering students are expected to have the basic computer technology skills required to begin university study. CSE 1100C satisfies this requirement.

**Writing (W) Competency:** All students must take either ENGL 1010 or 1011. Students passing ENGL 3800 are considered to have met the ENGL 1010 or 1011 requirement. Additionally, all students must take two writing-intensive (W) courses, which may also satisfy Content Area requirements. One of these must be at the 2000-level and associated with the student's major. Approved courses for each major are listed in their sections of this catalog. (Note: ENGL 1010 or 1011 is a prerequisite to all writing-intensive courses.) ECE 2001W and BME 3600W, required courses in the BME program, satisfy this requirement.

**Required courses:** Required courses are shown on the form. If there are alternatives listed, the course(s) that the student has taken or intends to take should be circled. The credit by category columns should be modified as needed (see "Credit Summary" below).

**Professional Requirements:** The Professional Requirements which are not specified on the Plan of Study form are chosen in consultation with the student’s advisor.

**Restrictions:** The following courses may not be counted for credit toward graduation: MATH 1120Q and 1110Q along with other mathematics courses numbered below 110Q; PHYS 1010Q, 1030Q; CSE 1000C; STAT 100; and courses labeled "independent study" or "special topics" (e.g. courses numbered 4999 and 4985) taken in departments outside of the School of Engineering. No course taken on a Pass/Fail basis may be counted for credit toward graduation or used to meet any course requirement of the School of Engineering. Many general University restrictions are shown in the Academic Regulations and Procedures section of the University Catalog. Some examples include: Not more than 12 credits of biology at the 1000-level may be counted toward graduation; Not more than 2 credits of ESLE 160 may be
counted toward graduation; Not more than 6 credits from PHIL 1101, 1102, 1103, 1104, 1105 may be counted toward graduation; and no credit for a course prerequisite to a second course in the same department may be counted for credit toward graduation after the student has passed the second course.

**Exemption and Substitution:** Students who desire to be excused from any of the requirements, or to substitute other courses for those prescribed, must do so by submitting a petition to the Director of Undergraduate Advising. Some examples of this type of departure from a published regulation are as follows: exemption from MATH 1131Q for a student who had Calculus in high school and started in our MATH 1132Q or substitution of PHYS 1201Q, 1202Q, 1530Q for PHYS 1501Q, 1502Q. Note that a substitution of three courses for two (as in the Physics example) results in only the credits for the two being counted for graduation, i.e. you are making a substitution for the equivalent work. Note that substitutions for courses taken as departmental Professional Requirements usually do not require a petition for approval by the Dean, but may be indicated on the Plan of Study form directly. Students must not write down or leave unchanged anything on the Plan of Study that they have not actually taken or plan to take.

**Transfer Courses:** Transfer courses should be listed on the Plan of Study form just as any other course, with a superscript of "TC" to indicate which courses were transferred. The credit associated with each transfer course should be noted as explained in the next section (see "Credit Summary" below). Transfer courses may be counted at their University of Connecticut equivalent credit in the category totals if the transcript does not show the number of credits granted for the particular course.

For transfer work that does not have an exact University of Connecticut equivalent; e.g., 4.25 credits of BME 1000 LEVEL, the credits should be listed as follows:

**BME 1000 LEVEL (4.25)TC**

In other words, the discipline followed by the level with an indication of how many credits is needed.

To aid students with transfer work, columns for sub-totaling "University of Connecticut Credits" and "Transfer Credits" are listed. These columns should be used to sum the credits across each row, separating those credits earned at University of Connecticut from those completed elsewhere.

The total transfer credit granted (not the sum of the University of Connecticut equivalents) less any equivalent restrictions (such as subtracting 3 credits if MATH 1040Q is listed since this course does not count for credit in the School) should be listed on the line labeled "Transfer Credits". The total of all credits taken at the University of Connecticut should be listed on the line labeled "University of Connecticut Credits". The sum of the "Transfer Credits" and the "University of Connecticut Credits" should be listed on the "Total Credits" line. The total credits must equal or exceed 128.
**Changes:** Changes to a previously submitted Plan of Study form may be made in consultation with the advisor and will require submission of a "revised" Plan of Study form for approval, in the same manner as the "original" form was prepared and submitted. This may be done by marking the changes on the previously approved original Plan of Study form, available from the advisor or the Office of the Dean, and having the advisor initial and date each change. No modifications of a photocopy will be accepted. If a second revision of an "original" is necessary, or if extensive changes are to be made, the submission of a new "original" Plan of Study form is required. In the student's last semester, he/she must submit a "final" Plan of Study form which accurately lists all the courses that were taken to satisfy degree requirements.
APPENDIX: Engineering Accreditation and ABET Engineering Criteria 2000

The Accreditation Board for Engineering and Technology (ABET) is recognized in the United States as the sole agency responsible for accreditation of educational programs leading to degrees in engineering. The first statement of the Engineers Council for Professional Development (ECPD, now ABET) relating to accreditation of engineering educational programs was proposed by the Committee on Engineering Schools and approved by the Council in 1933. The original statement, with subsequent amendments, was the basis for accreditation until 2000. The statement presented here is required of programs beginning in 2005.

All accredited engineering programs must include engineering in the program title (An exception has been granted for programs accredited prior to 1984 under the title of Naval Architecture.) To be considered for accreditation, engineering programs must prepare graduates for the practice of engineering at a professional level.

It is the responsibility of the institution seeking accreditation of an engineering program to demonstrate clearly that the program meets the following criteria.

I. GENERAL CRITERIA FOR BASIC LEVEL PROGRAMS

Criterion 1. Students

The quality and performance of the students and graduates are important considerations in the evaluation of an engineering program. The institution must evaluate student performance, advise students regarding curricular and career matters, and monitor student’s progress to foster their success in achieving program outcomes, thereby enabling them as graduates to attain program objectives.

The institution must have and enforce policies for the acceptance of transfer students and for the validation of courses taken for credit elsewhere. The institution must also have and enforce procedures to assure that all students meet all program requirements.

Criterion 2. Program Educational Objectives

Although institutions may use different terminology, for purposes of Criterion 2, program educational objectives are broad statements that describe the career and professional accomplishments that the program is preparing graduates to achieve.

Each engineering program for which an institution seeks accreditation or reaccreditation must have in place:

(a) detailed published educational objectives that are consistent with the mission of the institution and these criteria
(b) a process based on the needs of the program’s various constituencies in which the
objectives are determined and periodically evaluated

(c) an educational program, including a curriculum that prepares students to attain program outcomes and that fosters accomplishments of graduates that are consistent with these objectives

(d) a process of ongoing evaluation of the extent to which these objectives are attained, the result of which shall be used to develop and improve the program outcomes so that graduates are better prepared to attain the objectives.

**Criterion 3. Program Outcomes and Assessment**

Although institutions may use different terminology, for purposes of Criterion 3, program outcomes are statements that describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge, and behaviors that student acquire in their matriculation through the program.

Each program must formulate program outcomes that foster attainment of the program objectives articulated in satisfaction of Criterion 2 of these criteria. There must be processes to produce these outcomes and an assessment process, with documented results, that demonstrates that these program outcomes are being measured and indicates the degree to which the outcomes are achieved. There must be evidence that the results of this assessment process are applied to the further development of the program.

Engineering programs must demonstrate that their students attain:
- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

In addition, an engineering program must demonstrate that its students attain any additional outcomes articulated by the program to foster achievement of its education objectives.

**Criterion 4. Professional Component**

The professional component requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The faculty must ensure that the program curriculum
devotes adequate attention and time to each component, consistent with the outcomes and objectives of the program and institution. The professional component must include:

(a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline

(b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.

(c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives.

Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.

**Criterion 5. Faculty**

The faculty is the heart of any educational program. The faculty must be of sufficient number; and must have the competencies to cover all of the curricular areas of the program. There must be sufficient faculty to accommodate adequate levels of student-faculty interaction, student advising and counseling, university service activities, professional development, and interactions with industrial and professional practitioners, as well as employers of students.

The program faculty must have appropriate qualifications and must have and demonstrate sufficient authority to ensure the proper guidance of the program and to develop and implement processes for the evaluation, assessment, and continuing improvement of the program, its educational objectives and outcomes. The overall competence of the faculty may be judged by such factors as education, diversity of backgrounds, engineering experience, teaching experience, ability to communicate, enthusiasm for developing more effective programs, level of scholarship, participation in professional societies, and licensure as Professional Engineers.

**Criterion 6. Facilities**

Classrooms, laboratories, and associated equipment must be adequate to accomplish the program objectives and provide an atmosphere conducive to learning. Appropriate facilities must be available to foster faculty-student interaction and to create a climate that encourages professional development and professional activities. Programs must provide opportunities for students to learn the use of modern engineering tools. Computing and information
infrastructures must be in place to support the scholarly activities of the students and faculty and the educational objectives of the program and institution.

**Criterion 7. Institutional Support and Financial Resources**

Institutional support, financial resources, and constructive leadership must be adequate to assure the quality and continuity of the engineering program. Resources must be sufficient to attract, retain, and provide for the continued professional development of a well-qualified faculty. Resources also must be sufficient to acquire, maintain, and operate facilities and equipment appropriate for the engineering program. In addition, support personnel and institutional services must be adequate to meet program needs.

**Criterion 8. Program Criteria:**

Each program must satisfy applicable Program Criteria. Program Criteria provide the specificity needed for interpretation of the basic level criteria as applicable to a given discipline. Requirements stipulated in the Program Criteria are limited to the areas of curricular topics and faculty qualifications. If a program, by virtue of its title, becomes subject to two or more sets of Program Criteria, then that program must satisfy each set of Program Criteria; however, overlapping requirements need to be satisfied only once.

For Biomedical Engineering, ABET curricular requirements are given as:

“"The structure of the curriculum must provide both breadth and depth across the range of engineering topics implied by the title of the program.

The program must demonstrate that graduates have: an understanding of biology and physiology, and the capability to apply advanced mathematics (including differential equations and statistics), science, and engineering to solve the problems at the interface of engineering and biology; the ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living materials and systems.”