Biomedical Engineering

About Biomedical Engineering

Biomedical engineering is an interdisciplinary field in which the concepts, methods and techniques of engineering are applied to solving problems in biology and medicine. It applies quantitative, analytical and integrative methods from the molecular level to that of the whole organism to further our understanding of basic biological processes and to develop innovative approaches for the prevention, diagnosis and treatment of disease.

A student majoring in biomedical engineering will have the opportunity to participate in the world-class research activities of engineering and medical faculty in biomaterials and imaging, cardiovascular engineering, cell and tissue engineering, molecular cellular and systems engineering, and neural engineering. All students in biomedical engineering are encouraged to join and be active in the Biomedical Engineering Society.

Mission Statement

Our departmental mission is to serve society as a center for learning and knowledge-creation in engineering and science for the purpose of advancing biology and medicine.

Our overall educational objective is to prepare those receiving a bachelor’s degree in biomedical engineering for a variety of career paths. To that end, our undergraduate curriculum is designed to provide technical proficiency as well as communication and other professional skills so that our graduates will be able to:

- Pursue careers in the biomedical engineering industry or related fields.
- Undertake advanced study (e.g., MS, PhD) in biomedical engineering or a related field, in preparation for careers utilizing this further training.
- Complete professional degrees (e.g., in medicine, dentistry, law, business) in preparation for careers utilizing those degrees.

Academic Programs

The Bachelor of Science in Biomedical Engineering (BS–BME) is designed to prepare graduates for the practice of engineering at a professional level and is accredited by Engineering Accreditation Commission of ABET (http://www.abet.org).

The curriculum is structured around a basic core of 102 units. In addition, a complementary set of courses totaling at least 18 units completes the degree requirements. The latter courses will be elected from the sciences (biology, chemistry, physics), mathematics or engineering.

In order to satisfy ABET requirements, all professional engineering curricula at the baccalaureate level must include the equivalent of one and one-half years of engineering topics, to include engineering sciences and engineering design appropriate to biomedical engineering. The BS–BME degree at Washington University requires 48 credits of engineering topics. The basic core curriculum includes 33 to 34 engineering topics credits. Therefore, students pursuing a BS–BME degree will need 14 to 15 additional engineering topics credits beyond the basic core curriculum. They also may receive up to 6 units of academic credit for a research or design project, by registering for BME 400, BME 400A, BME 400B or BME 400C Independent Study. In addition, their course program must include sufficient laboratory experience to ensure competence in experimental design, data collection and data analysis. For more information regarding engineering topics unit requirements, please refer to the BME Undergraduate Studies Manual, available in the Biomedical Engineering Department in Whitaker Hall, Room 190.

Double Majors

An option available to students majoring in biomedical engineering is the double major, leading to a second professional Bachelor of Science degree in one of the other engineering disciplines in four years. A degree in biomedical engineering combined with a professional degree in one of the traditional engineering disciplines can be expected to enhance employment options in industry. Depending upon the second major chosen, total unit requirements may range from 140 to 148 (or less if the student enters with AP credits). Hence, some summer work may be necessary in order to complete a double major within four academic years. To determine the specific requirements to be satisfied for both degrees, students are urged to consult with an adviser in the second department as early as possible.

Please visit our website for the most current and up-to-date information.

Phone: (314) 935-7208
Departmental website: http://bme.wustl.edu

Chair

Steven C. George
Elvera and William Stuckenbelt Professor and Chair
MD, University of Missouri
PhD, University of Washington in Seattle
Tissue engineering; microphysiological systems; vascularizing engineered tissues
Endowed Professors

Rohit V. Pappu
Edwin H. Murty Professor of Engineering
PhD, Tufts University
Macromolecular self assembly and function, computational

Yoram Rudy
Fred Saigh Distinguished Professor of Engineering
PhD, Case Western Reserve University
Cardiac electrophysiology, modeling of the cardiac system

Lori A. Setton
Lucy and Stanley Lopata Distinguished Professor of Biomedical Engineering
PhD, Columbia University
Biomaterials for local drug delivery, tissue regenerations specific to the knee joints and spine

Larry A. Taber
Dennis and Barbara Kessler Professor of Biomedical Engineering
PhD, Stanford University
Mechanics of growth and development, cardiac mechanics

Lihong Wang
Gene K. Beare Distinguished Professor of Biomedical Engineering
PhD, Rice University
Biophotonics and multimodality optical imaging

Professors

Mark Anastasio
PhD, The University of Chicago
Imaging sciences, phase-contrast, x-ray imaging

Jianmin Cui
PhD, State University of New York–Stony Brook
Ion channels, channel structure-function relationship, biophysics

Daniel Moran
PhD, Arizona State University
Motor control, neural engineering, neuroprosthetics, movement biomechanics

Shelly E. Sakiyama-Elbert
PhD, California Institute of Technology
Cell adhesion, nerve regeneration, protein engineering

Associate Professors

Dennis L. Barbour
MD, PhD, Johns Hopkins University
Auditory physiology, sensory cortex neurocircuitry, functional neuronal imaging

Donald L. Elbert
PhD, University of Texas at Austin
Biomaterials, polymer chemistry, proteomics

Vitaly Klyachko
PhD, University of Wisconsin–Madison
Synaptic function and plasticity, neural circuits, information analysis, neurological disorders

Jin-Yu Shao
PhD, Duke University
Cell mechanics, receptor and ligand interactions, molecular biomechanics

Kurt A. Thoroughman
Director of Undergraduate Studies
PhD, Johns Hopkins University
Human motor control and motor learning, neural computation

Assistant Professors

Jan Bieschke
PhD, Max Planck Institute for Biophysical Chemistry/University of Braunschweig
Single molecule fluorescence and other biophysical methods to probe the mechanistic underpinnings of protein misfolding

Hong Chen
PhD, University of Washington
Physical acoustics, therapeutic ultrasound and ultrasound imaging

Kristen Naegle
PhD, Massachusetts Institute of Technology
Computational systems biology with emphasis on cellular networks involved in cancer and diabetes

Baranidharan Raman
PhD, Texas A&M University
Computational and systems neuroscience, neuromorphic engineering, pattern recognition, sensor-based machine olfaction

Jon Silva
PhD, Washington University
Ion channel biophysics

Lecturer

Patricia Widder
MS, Washington University
Majors
The Major in Biomedical Engineering

The BS in Biomedical Engineering requires completion of the courses in the Core Curriculum and five upper-level courses beyond the Core, as described below. Students must also meet all School of Engineering & Applied Science (SEAS) and WUSTL requirements (including the English Composition requirement; please see the Engineering Degree Requirements page) and, to satisfy ABET requirements for a professional degree, must accrue 48 engineering topics units over their course work.

The Basic Core

The Biomedical Engineering Core Curriculum consists of 104 units, outlined below.

<table>
<thead>
<tr>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical Sciences Units</strong></td>
<td></td>
</tr>
<tr>
<td>General Chemistry (Chem 111A, Chem 112A)</td>
<td>6</td>
</tr>
<tr>
<td>General Chemistry Laboratory I, II (Chem 151, Chem 152)</td>
<td>4</td>
</tr>
<tr>
<td>General Physics (Physics 117A, Physics 118A OR Physics 197, Physics 198)</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>18</td>
</tr>
<tr>
<td><strong>Biological Science</strong></td>
<td></td>
</tr>
<tr>
<td>Principles of Biology I (Biol 2960)</td>
<td>4</td>
</tr>
<tr>
<td>Principles of Biology II (Biol 2970)</td>
<td>4</td>
</tr>
<tr>
<td>Physiological Control Systems (Biol 3058)</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>10</td>
</tr>
<tr>
<td><strong>Mathematics</strong></td>
<td></td>
</tr>
<tr>
<td>Calculus II &amp; III (Math 132, Math 233)</td>
<td>6</td>
</tr>
<tr>
<td>Differential Equations (Math 217)</td>
<td>3</td>
</tr>
<tr>
<td>Engineering Mathematics A &amp; B (ESE 318, ESE 319)</td>
<td>6</td>
</tr>
<tr>
<td>Probability and Statistics for Engineering (ESE 326)</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>18</td>
</tr>
<tr>
<td><strong>Engineering Science</strong></td>
<td></td>
</tr>
<tr>
<td>Computer Science (CSE 131) or Engineering and Scientific Computing (CSE 200)</td>
<td>3</td>
</tr>
<tr>
<td>Introduction to Electrical and Electronic Circuits (ESE 230)</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>7</td>
</tr>
</tbody>
</table>

Students must complete five upper-level courses beyond the Core to complete the major and to prepare for particular fields of employment or education beyond the baccalaureate degree. All five of these courses need to carry 3 or more academic credits and 3 or more engineering topics units. At least two of the five courses need to be drawn from the Tier I course list below.

<table>
<thead>
<tr>
<th>Tier I</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Electromagnetics Principles (ESE 330)</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>10</td>
</tr>
</tbody>
</table>

Biomedical Engineering

<table>
<thead>
<tr>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Virtual Studio I, II, III, IV (BME 123B, BME 124B, BME 223B, BME 224B)</td>
<td>4</td>
</tr>
<tr>
<td>Introduction to Biomedical Engineering (BME 140)</td>
<td>3</td>
</tr>
<tr>
<td>Biomechanics (BME 240)</td>
<td>3</td>
</tr>
<tr>
<td>Quantitative Physiology I, II (BME 301A, BME 301B)</td>
<td>8</td>
</tr>
<tr>
<td>Bioengineering</td>
<td>3</td>
</tr>
<tr>
<td>Thermodynamics (BME 320B)</td>
<td>3</td>
</tr>
<tr>
<td>Biotransport (BME 366) or Transport Phenomena I (EECE 301)</td>
<td>3</td>
</tr>
<tr>
<td>Biomedical Engineering Design (BME 401)</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>27</td>
</tr>
</tbody>
</table>

Other

<table>
<thead>
<tr>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humanities and social sciences</td>
<td>15</td>
</tr>
<tr>
<td>Engineering Practice and Professional Values (Engr 4501, Engr 4502 and Engr 4503 — one credit each)</td>
<td>3</td>
</tr>
<tr>
<td>Technical Writing (Engr 310)</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>21</td>
</tr>
</tbody>
</table>

**Total, Basic Core**

104
BME 524  Tissue Engineering (#)  3
BME 525  Engineering Aspects of Biotechnology (#)  3
BME 527  Design of Artificial Organs (#)  3
BME 533  Biomedical Signal Processing (#)  3
BME 572  Biological Neural Computation  3
BME 573A  Applied Bioelectricity (#)  3
BME 575  Molecular Basis of Bioelectrical Excitation (#)  3
BME 589  Biological Imaging Technology  3
BME 5913  Molecular Systems Biology: Computation & Measurements for Understanding Cell Physiology and Disease  3

The remaining three courses may be earned from the Tier I list above or from the Tier II list below. Tier II consists of other 3-credit, upper-level (300-500) BME courses (see BME in WUCRSL) or from the SEAS courses listed below.

Tier II
CSE 330S  Rapid Prototype Development and Creative Programming  3
CSE 332S  Object-Oriented Software Development Laboratory  3
CSE 441T  Advanced Algorithms  3
CSE 587A  Algorithms for Computational Biology  3
EECE 302  Transport Phenomena II: Mass Transfer  3
EECE 305  Materials Science  3
EECE 551  Metabolic Engineering and Synthetic Biology  3
ESE 351  Signals and Systems  3
ESE 425  Random Processes and Kalman Filtering  3
ESE 441  Control Systems  3
ESE 444  Sensors and Actuators  3
ESE 447  Robotics Laboratory  3
ESE 455  Quantitative Methods for Systems Biology  3
ESE 482  Digital Signal Processing  3
ESE 488  Signals and Systems Laboratory  3
MEMS 3110  Machine Elements  3
MEMS 3410  Fluid Mechanics  3
MEMS 3420  Heat Transfer  3
MEMS 350  Engineering Mechanics III  3
MEMS 3601  Materials Engineering  3
MEMS 3610  Materials Science  3
MEMS 4101  Manufacturing Processes  3
MEMS 424  Introduction to Finite Element Methods in Structural Analysis  3
MEMS 4310  Dynamics and Vibrations  3

PLEASE NOTE: 1) Courses above that are marked with (#) are offered every other year or less. 2) The most up-to-date Tier lists can be found on the BME website.

Independent Study
During their course of study, students may receive up to 6 units of academic credit for BME 400, BME 400A, BME 400B, and/or BME 400C. Three units (one semester) of BME 400C may be used to fulfill one course in Tier II.

Double Majors
Students majoring in biomedical engineering may choose to double major within SEAS, leading to a second professional Bachelor of Science degree in one of the other engineering disciplines in four years. A degree in biomedical engineering combined with a professional degree in one of the traditional engineering disciplines can be expected to enhance employment options in industry. Depending upon the second major chosen, total unit requirements may range from 140 to 148 (or fewer if the student enters with AP credits). Hence, some summer work may be necessary in order to complete a double major within four academic years. To determine the specific requirements to be satisfied for both degrees, students are urged to consult with an adviser in the second department and their four-year adviser as early as possible.

Minors
There are no biomedical engineering minors. Please see the complete list of minors offered in the School of Engineering & Applied Science.

Courses
Visit https://courses.wustl.edu to view semester offerings for E62 BME.

E62 BME 123B Engineering Virtual Studio I
The goal of EVS is to integrate core material across the major and provide connection to the big picture of BME while developing student scholarly and professional identity. We hope EVS is a comfortable community for students to build connections: with peers, across studies and broader interests, building toward broad successes here at Wash U and in the world beyond. EVS I is the first semester in a four semester series to provide BME students with continued support throughout their underclassman years. EVS I focuses on drawing connections among core classes and the bigger picture of BME and getting students started on their artifact collection and reflection process.
Credit 1 unit.

E62 BME 124B Engineering Virtual Studio II
Engineering Virtual Studio (EVS) is a one-credit, pass-fail, online course to assist students with connecting core material with integrative, innovative ideas in engineering research. Students read, model and discuss these connections with peers and upperclassman mentors. The pass requires active online participation and a semester-ending reflective essay. The EVS
sequence is required for BME majors who matriculate in 2012 or later.
Credit 1 unit.

E62 BME 140 Introduction to Biomedical Engineering
An introduction to the vast and diverse field of biomedical engineering (BME), this very challenging course has two main purposes. One is to teach students — via lectures, reading assignments, homework and exams — to think on their own, to solve problems and know how engineering principles are applied to the areas of bioelectricity, biomechanics, biomolecules, biotechnology and bioimaging. The second is to introduce students — via guest lectures by school of medicine and engineering faculty — to some of the fascinating and challenging ongoing research in these areas. The course is challenging because students at this early stage, by and large, lack the knowledge base to understand either the engineering/biological aspects of the topical areas or the research being presented. Nevertheless, because future success depends on such, emphasis throughout is placed on developing self-learning as well as quantitative and analytical problem-solving skills, but at an appropriate level. By the end of the course it is hoped that students have begun to acquire the skills and approaches necessary to succeed in the engineering curriculum as well as a much more in-depth and informed perspective of BME.
Corequisites: BME major with sophomore standing. 
Prerequisites: Physics 117A OR 197, Chem 111A, and college-level calculus.
Credit 3 units. EN: TU

E62 BME 210 Clinical Applications of BME
The objective of this course is to enable BME undergraduate students to explore selected aspects of the clinical environment, primarily those involving a diagnostic procedure or treatment modality and to teach them how to identify clinical needs/new approaches in these environments. The course begins with a three-week in-class primer where students receive HIPAA training, learn proper hospital etiquette, are introduced to the clinical entities and are taught observational skills. Students then rotate in small groups in several medical entities wherein they interact directly with health care providers and observe current practices. Each rotation lasts for two weeks and finishes with a discussion section where students share their observations and potential clinical needs with the class. Students then devote additional time to further explore and research one of the clinical entities. The course concludes with oral and written presentations of each of the chosen medical entities.
Prerequisites: BME major with sophomore standing.
Credit 2 units.

E62 BME 223B Engineering Virtual Studio III
The goal of EVS is to integrate core material across the major and provide connection to the big picture of BME while developing student scholarly and professional identity. We hope EVS is a comfortable community for students to build connections: with peers, across studies and broader interests, building toward broad successes here at Wash U and in the world beyond. EVS III is the third semester of a four semester series to provide continuous support throughout the underclassman years. EVS III focuses on the development of personal scholarly identity and connection to the big picture of BME. The central goal is for students to build their own connection and presentation of linkage between foundational ideas and real-world problems and solutions.
Credit 1 unit.

E62 BME 224B Engineering Virtual Studio IV
Engineering Virtual Studio (EVS) is a one-credit, pass-fail, online course to assist students with connecting core material with integrative, innovative ideas in engineering research. Students read, model and discuss these connections with peers and upperclassman mentors. The pass requires active online participation and a semester-ending reflective essay. The EVS sequence is required for BME majors who matriculate in 2012 or later.
Credit 1 unit.

E62 BME 240 Biomechanics
Principles of static equilibrium and solid mechanics applied to the human anatomy and a variety of biological problems. Statics of rigid bodies with applications to the musculoskeletal system. Mechanics of deformable media (stress, strain; stretching, torsion and bending) with introduction to nonlinear behavior, viscoelasticity and growth in living tissue. Applications to cells, bone, muscle, arteries, the heart and the cochlea. Prerequisites: Physics 117A or 197.
Credit 3 units. EN: TU

E62 BME 301A Quantitative Physiology I
A course (lectures, recitation and supervised laboratory sections) designed to elaborate the physiological background necessary for advanced work in biomedical engineering. A quantitative model-oriented approach to physiological systems is stressed. Topics include bioinstrumentation, eye movement, muscle mechanics, action potentials, sensory systems, neuroprosthetics.
Prerequisites: BME 140, CSE 131 or 200, ESE 230, Biol 3058 (previously Biol 3050 or 3059), ESE 317 or ESE 319, or permission of instructor. Corequisites: E60 Eng 310 or permission of instructor.
Credit 4 units. EN: TU

E62 BME 301B Quantitative Physiology II
A course (lectures, recitation and supervised laboratory sections) designed to elaborate the physiological background necessary for advanced work in biomedical engineering. A quantitative model-oriented approach to physiological systems is stressed. Topics include electrocardiography; heart contractility and molecular bases; cell signaling, pulse wave propagation in arteries; pulmonary function; renal function; imaging, and systems biology, immune system; drug delivery. Prerequisites: BME 140, CSE 131 or 200, ESE 230, ESE 317, Biol 3058, or permission of instructor. Corequisites: Eng 310 or permission of the instructor.
Credit 4 units. EN: TU

E62 BME 320B Bioengineering Thermodynamics
This course teaches the foundations of thermodynamics with strong emphasis on concepts, problem solving, and applications in bioengineering and biophysics. The course covers classical thermodynamics as well as statistical mechanics, and the statistical underpinnings of thermodynamic functions are emphasized. Applications of thermodynamic control in biomolecular and cellular systems are discussed. The target audience for this course is sophomores or juniors majoring in Biomedical Engineering. Students have to enroll in recitation section. Recommended prerequisites: Chem 112A, Physics 118A or 198, Math 132, Math 233, Math 217.
Credit 3 units. EN: TU
**E62 BME 329 Biothermodynamics in Practice**
This course includes hands-on, laboratory experiments in topics relevant to bioengineering thermodynamics, such as heat transfer, relationships involving temperature and pressure, equilibria, mixing, and solution chemistry. A focus of the course is extending fundamental scientific principles to biological applications. Students have the opportunity to design their own experiments, explore topics of special interest, and present their findings. Prerequisites: Chem 111A and 151; Physics 117A, 118A.
Credit 3 units. EN: TU

**E62 BME 366 Transport Phenomena in Biomedical Engineering**
Many processes of importance in biology and medicine involve the transfer of mass, heat or momentum. Through the use of the differential control volume approach, the fundamental transport equations are derived. Systematic derivation of differential equations appropriate for different types of transport problems are explored. Solutions of the resulting differential equations for simple chemical/biological systems are then sought. Macroscopic descriptions of fluid flow are applied to the design of blood pumps for the heart. Unsteady mass transfer with diffusion, advection and chemical reactions also are applied to the transport of proteins, metabolites and therapeutics throughout the body. Prerequisites: BME 240, Math 217, ESE 317 or ESE 318 and ESE 319; Corequisites: BME 320B.
Credit 3 units. EN: TU

**E62 BME 400 Independent Study**
Independent investigation on topic of special interest. This course has no engineering topics units. Prerequisites: junior or senior standing and permission of program director. 
Credit variable, maximum 6 units.

**E62 BME 400A Independent Study**
Independent investigation on a topic of special interest. This course has 1 unit of engineering topics. The student and mentor must justify the number of engineering topic units being requested and the BME department’s accreditation committee must approve the requested number of engineering topics. Prerequisites: junior or senior standing and permission of program director. 
Credit 1 unit. EN: TU

**E62 BME 400B Independent Study**
Independent investigation on a topic of special interest. This course has 2 units of engineering topics. The student and mentor must justify the number of engineering topic units being requested and the BME department’s accreditation committee must approve the requested number of engineering topics. Prerequisites: junior or senior standing and permission of program director. 
Credit 2 units. EN: TU

**E62 BME 400C Independent Study**
Independent investigation on a topic of special interest. This course has 3 units of engineering topics. The student and mentor must justify the number of engineering topic units being requested and the BME department’s accreditation committee must approve the requested number of engineering topics. Prerequisites: junior or senior standing and permission of program director. 
Credit 3 units.

**E62 BME 401 Biomedical Engineering Design**
A design project experience to prepare students for engineering practice. Working individually or in small groups, students undertake an original design or redesign of a component or system of biotechnological significance. The design experience requires application of knowledge and skills acquired in earlier classes and laboratory work; it incorporates engineering standards and realistic constraints that include most of the following considerations: economic, environmental, ethical, manufacturability, sustainability, health and safety, social and political. Students prepare written reports and present their designs orally to their classmates and panels of faculty members and industrial representatives. Prototype construction is not generally required but may be encouraged subject to available time and financial and material resources. Prerequisites: BME 301A, BME 301B and senior standing.
Credit 3 units. EN: TU

**E62 BME 402 Senior Design II**
BME 402 is a continuation of the BME 401 class. Working in small groups, students take a paper design completed in BME 401, and build a prototype. The students evaluate, optimize and undertake the building of the design. The design experience requires application of knowledge and skills acquired in earlier course work; it incorporates engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social and political. Students prepare written reports and participate in oral design reviews to a panel of faculty members and industrial representatives. Prototype construction is the final goal of the class. Prerequisites: BME 401, senior standing, and approval of the instructor.
Credit 3 units. EN: TU

**E62 BME 410 International Community Service Learning Project**
This pass/fail course is a 2-week summer international experience in conjunction with the faculty and students of our partner, The Biomedical Engineering Institute of Hong Kong Polytechnic University. Students first attend an orientation at HKPU to learn about functional electrical stimulation (FES) and treating cerebral palsy with orthotic devices. The entire group then goes to a clinic in mainland China where they put into practice what they have learned, the former in patients who have suffered strokes and the latter in children with cerebral palsy - working in teams to diagnose, fit and fabricate orthotic devices. A written summary of the experience is the final product. Academic credits are awarded at the end of the fall semester following the summer experience. Prerequisites: completion of junior year, BME 301A. Enrollment: Students must apply by Feb. 1 each spring. Enrollment is restricted to 10 of the applicants. 
Credit 2 units.

**E62 BME 413 Engineering for First- and Third-World Health**
Biomedical engineering, as a discipline, aspires to improve the human condition through the alleviation of suffering in disease; through diagnosis, treatment and prevention; and through the promotion of health. Although BME can address several problems at several levels, one distinction arises in practice, and a second in undergraduate life. The real-world problems and solutions arise in the developed and developing world; these domains share several similarities but also feature real
differences that call upon differential engineering approaches. This course examines the engineering principles and practice that best apply to emergent solutions and unmet challenges in First-World and Third-World health. The collegiate experience often isolates the majority of undergraduate courses as “foundational” or “core” rather than applicable to very current, challenging, multidimensional problems. Our department, our school and university, and our societies value the contribution of engineers in solving real-world problems. Indeed, students very often achieve meaningful impact in real-world problems, but experienced most directly through extracurricular, not curricular, experience. This course provides the framework for students to build substantive ties between their curricular base and extracurricular problems and solutions. Corequisites: junior or senior standing; E62 BME 301A and/or 301B. Prerequisites: Candidate students need to have had previous engagement outside of class (through extracurriculars, volunteering, employment, etc.) with a particular problem in First- or Third-World medicine or health, most broadly construed. At registration students submit a short paragraph identifying the problem and how the student has engaged the problem outside the traditional classroom. This problem serves as the theme for the student's independent engineering analysis in the course. Identification of the problem, through submission of the paragraph, will move students from the waitlist to course registration (up to the seat limit).

E62 BME 422 Kinetics In Cell Signaling and Metabolism
This course focuses on the development of mathematical descriptions for chemical modification, and catalysis in cells. We build a foundation to understand time-dependent reactions in biological systems and then explore models for the flow of information through metabolic pathways. Additionally, we examine experimental methods for understanding receptors, transmitters and catalysis. Prerequisites: BME 301B. BME 320B, ESE 317 or ESE 318 and 319.

E62 BME 423 Biomaterials Science
An understanding of the interactions between biological systems and artificial materials is of vital importance in the design of medical devices. This course introduces the principles of biomaterials science, unifying knowledge from the fields of biology, materials science, surface science and colloid science. The course is taught from the primary scientific literature, focusing on the study of protein/surface interactions and hydrogel materials.

E62 BME 450 Numerical Methods for Computational Modeling in Biomedicine
Advanced computational methods are required for the creation of biological models, from protein folding to whole-organ function. Students are introduced to the process of model development from beginning to end, which includes model formulation, how to solve and parameterize equations, and how to evaluate model success. To illustrate the potential of these methods, participants systematically build a model to simulate a “real-life” biological system that is applicable to their research or interest. A mechanistic appreciation of the methods will be gained by programming the methods in a low-level language (C++) in a Linux environment. While extensive programming knowledge is not required, participants are likely to find that some programming background is helpful.

E62 BME 458A Biological Transport
The principles of mass, momentum and energy transport are applied to the analysis of selected processes of biomedical and biotechnological interest. Topics include dynamics of blood flow, oxygen and solute transport, steady and transient diffusion in reacting systems, pharmacokinetic analysis and heat transfer. Prerequisite: ChE 366 or ChE 367 or graduate standing.

E62 BME 459 Intermediate Biomechanics
This course covers several of the fundamental theories of continuum mechanics that are needed to solve problems in biomechanics. The theories of nonlinear elasticity, hydrodynamics and viscoelasticity are applied to a large range of biological samples including bone, blood, muscles, cellular membrane, blood vessels, and blood cells. Other topics include mechanics of microvilli and flagella, fluid flow around the contact lens, and deformation of single cells and molecules. Prerequisites: BME 240 and ESE 317 (or ESE 318 and ESE 319).

E62 BME 461 Protein Structure and Dynamics
This course covers the concepts and methods involved in the analysis of protein structure, stability, folding and misfolding. Topics include protein structural elements, amyloid structure, intra- and intermolecular forces, folding pathways and intermediates, phi-value analysis, kinetics of protein folding and of amyloid formation, and their application to problems of bioengineering and biophysics. Two thirds of the course consists of lectures, the other third is student seminars, in which each student presents a paper from primary literature and its concept and methodology that is discussed in detail. Prerequisites: BME 320B Bioengineering Thermodynamics or equivalent.

E62 BME 462 Protein Function and Interactions
This course focuses on the interactions between proteins, nucleic acids, small molecules and drugs. We begin with the elements of molecular recognition, binding and prediction of interactions. We next move on to molecular kinetics, inhibition and allosteric regulation. Finally we look at modeling regulatory networks and signaling pathways using systems biology approaches.

E62 BME 463 Orthopaedic Biomechanics — Bones and Joints
Basic and advanced solid mechanics applied to the musculoskeletal system, with a primary focus on bone and joint mechanics. Topics include: forces in joints; gait analysis; axial, torsional and bending loading of bones; mechanical properties (elastic, fracture, creep, fatigue) and composition of bone; bone adaptation and basic concepts of bone biology; joint kinematics; total hip and knee replacement; mechanical consequences of injury (fracture) and disease (osteoporosis). This class is geared to graduate students and upper-level undergraduates familiar
E62 BME 464 Orthopaedic Biomechanics — Cartilage/ Tendon
Basic and advanced viscoelasticity and finite strain analysis applied to the musculoskeletal system, with a primary focus on soft orthopaedic tissues (cartilage, tendon and ligament). Topics include: mechanical properties of cartilage, tendon and ligament; applied viscoelasticity theory for cartilage, tendon and ligament; cartilage, tendon and ligament biology; tendon and ligament wound healing; osteoarthritis. This class is geared to graduate students and upper-level undergraduates familiar with statics and mechanics of deformable bodies. Prerequisites: BME 240 or equivalent. Note: BME 5902 (BME 463/563) Orthopaedic Biomechanics — Bones and Joints is NOT a prerequisite.
Credit 3 units. EN: TU

E62 BME 468 Cardiovascular Dynamics
This course focuses on the analysis of blood flow through the heart and blood vessels. Basic cardiovascular anatomy and physiology; principles of continuum mechanics. Flow through heart chambers, valves, and coronary arteries; peristaltic flow in the embryonic heart. Steady and unsteady flow in tubes; wave propagation in blood vessels; flow in collapsible tubes; microcirculation. Prerequisites: BME 240 or equivalent and EECE 301 or MEMS 3410 or equivalent, or permission of instructor.
Same as BME 568
Credit 3 units. EN: TU

E62 BME 471 Bioelectric Phenomena
This course is a quantitative introduction to the origins of bioelectricity with an emphasis on neural and cardiac electrophysiology. Topics include electric fields and current flow in volume conductors; cell membrane channels and their role in generating membrane potentials; action potentials and their propagation in myelinated and unmyelinated axons as well as cardiac tissue. Minor topics of discussion include both skeletal muscle and nonhuman (e.g., electric fish) sources of bioelectricity. Prerequisite: ESE 330.
Credit 3 units. EN: TU

E62 BME 472 Biological Neural Computation
This course considers the computations performed by the biological nervous system with a particular focus on neural circuits and population-level encoding/decoding. Topics include Hodgkin-Huxley equations, phase-plane analysis, reduction of Hodgkin-Huxley equations, models of neural circuits, plasticity and learning, and pattern recognition and machine learning algorithms for analyzing neural data. Note: Graduate students in psychology or neuroscience who are in the cognitive, computational and systems neuroscience curriculum pathway may register in Biol 5657 for three credits. For non-BME majors, conceptual understanding and selection/application of right neural data analysis technique are stressed. Hence homework assignments/examinations for the two sections are different, however all students are required to participate in a semester-long independent project as part of the course. Calculus, differential equations, basic probability and linear algebra
undergraduates need permission of the instructor. Biol 5657
prerequisites: Permission from the instructor.
Same as BME 572
Credit 3 units. EN: TU

E62 BME 4902 Special Topics: Cellular Neurophysiology
This course examines the biophysical concepts of synaptic function with the focus on the mechanisms of neural signal processing at synapses and elementary circuits. The course combines lectures and discussion sessions of primary research papers. Topics include synaptic and dendritic structure, electrical properties of axons and dendrites, synaptic transmission, rapid and long-term forms of synaptic plasticity, and mechanism of information coding, mechanisms of learning and memory, function of synapses in sensory systems, models of synaptic disease states such as Parkinson and Alzheimer's diseases. Additionally, a set of lectures is devoted to modern electrophysiological and imaging techniques, and modeling approaches to study synapses and neural circuits. Prerequisites: senior or graduate standing.
Same as BME 5902
Credit 3 units. EN: TU

E62 BME 4903 Physical Methods for Biomedical Scientists
The course introduces the spectrum of biophysical techniques used in biomedical sciences with a focus on advanced fluorescence spectroscopy. The first half of the course introduces the concepts behind techniques such as: dynamic light scattering, SPR, analytical ultracentrifugation size-exclusion and affinity chromatography, atomic force microscopy, fluorescence spectroscopy, FRET, FTIR, circular dichroism, fluorescence correlation spectroscopy, and sub-diffraction microscopy. The second half of the course is held as six three-hour block lab classes in which students use these techniques in experiments on protein folding, protein stability and amyloid formation. Prior attendance of BME 461 Protein Structure and Dynamics is encouraged. Because of limited room in the experimental lab, attendance is limited to nine students.
Prerequisites: senior or graduate standing.
Credit 3 units.

E62 BME 4904 Interfaces and Attachments in Natural and Engineered Structures
Attachment of dissimilar materials in engineering and surgical practice is a perennial challenge. Bimaterial attachment sites are common locations for injury, repeated injury and mechanical failure. Nature presents several highly effective solutions to the challenge of bimaterial attachment that differ from those found in engineering practice. This course bridges the physiologic, surgical and engineering approaches to connecting dissimilar materials and aims to advance the field by providing the first ever cross-disciplinary treatment of the subject. The course elucidates natural bimaterial attachments and outline engineering principles underlying successful attachments to the communities of tissue engineers and surgeons. The course includes an in-depth analysis of the biology of attachments in the body and mechanisms by which robust attachments are formed. The course also reviews current concepts of attaching dissimilar materials in surgical practice (e.g., for rotator cuff tendon-to-bone repair) and engineering (e.g., attachment of composite wings to the aluminum fuselage of an aircraft). The course concludes with a discussion of bioengineering approaches
E62 BME 502 Cardiovascular MRI — Physics to Clinical Application
This graduate course (seniors welcome) covers the basic physics involved in creating an image by magnetic resonance technology. The use of this technology, specifically as it applies to the unique challenges of cardiovascular applications, is examined. This includes topics such as motion compensation techniques, real-time imaging, exogenous contrast enhancement and quantitative flow measurements, for example. As much as one-third of the class involves actual case studies and the discussion of clinical use for cardiovascular MRI. Students demonstrate competence in the subject through a combination of homework, a final examination and a small semester project. Prerequisites: Calculus, introductory human physiology/anatomy/biology course.
Credit 3 units. EN: TU

E62 BME 502L MRI Practicum
This hands-on lab course, taught at the Medical School campus using research-dedicated clinical MRI scanners, extends the concepts and theory of MRI learned in BME 502. Emphasis is placed on learning to operate a clinical MRI scanner to obtain data useful to biomedical experimentation. The level of understanding goes beyond the basic clinical user interface, deeper into hardware and software. The lab includes topics such as image acquisition and manipulation, k-space (i.e., Fourier domain), RF coil design, proton and non-proton spectroscopy and imaging, and general pulse sequence design. In addition to assisted lab time, participants are expected to spend some additional time using the MRI scanners and/or simulators, performing image analysis in, e.g., MATLAB or ImageJ, and designing pulse sequences. Students demonstrate competence through a combination of hands-on experimentation, practical exams and written lab reports. The lab is taught at the Research Clinical Scanners in the CORTEX building, Dept. of Medicine. Prerequisite: BME 502.
Credit 2 units.

E62 BME 503A Cell and Organ Systems Biology
This 1.5-semester course integrates and extends the basic principles of cell biology and physiology to the functions of the major organ systems of the body, i.e., muscle, cardiovascular, renal, respiratory, gastrointestinal and endocrine. Same as M75 503, offered through the medical school. This course is open to biomedical engineering students only. Permission must be obtained by the chairman in Biomedical Engineering. Starts at same time as Medical School classes and ends the middle of spring semester.
Credit 6 units.

E62 BME 504 Light Microscopy and Optical Imaging
Recent advances in optics, microscopy and probe design have led to a dramatic expansion of options for measuring structural and functional features of biological tissue with light. Course topics include the basic physics underlying vital light microscopy, use of voltage-sensitive and calcium-sensitive fluorescent probes, multiphoton and confocal imaging, and image acquisition/processing. Special emphasis is placed on imaging neural tissue and live preparations. Students read current literature and devise a research project based upon an imaging technology.
Credit 3 units.

E62 BME 506 Seminar in Imaging Science and Engineering
This seminar course consists of a series of tutorial lectures on Imaging Science and Engineering with emphasis on applications of imaging technology. Students are exposed to a variety of imaging applications that vary depending on the semester, but may include multispectral remote sensing, astronomical imaging, microscopic imaging, ultrasound imaging, and tomographic imaging. Guest lecturers come from several parts of the university. This course is required of all students in the Imaging Science and Engineering program; the only requirement is attendance. This course is graded Pass/Fail. Prerequisite: Admission to Imaging Science and Engineering Program. Same as E81 CSE 596 (when offered) and E62 BME 506.
Same as ESE 596
Credit 1 unit.

E62 BME 5068 Fundamentals of Molecular Cell Biology
This is a core course for incoming graduate students in Cell and Molecular Biology programs to learn about research and experimental strategies used to dissect molecular mechanisms that underlie cell structure and function, including techniques of protein biochemistry. Enrolling students should have backgrounds in cell biology and biochemistry, such as courses comparable to L41 Biol 334 and L41 Biol 4501. The format is two lectures and one small group discussion section per week. Discussion section focuses on original research articles. Same as M15 5068 and M04 5068.
Same as Biol 5068
Credit 4 units.

E62 BME 511 Biotechnology Techniques for Engineers
This course is a survey of techniques that biomedical engineers working in biotechnology and biomedical engineering will encounter in research or industry. It serves to introduce the important advances in the state of the art in molecular and cell biology. Students learn the basis of standard biological techniques and when these techniques should be applied, as well as their shortcomings. This course provides students with a toolbox of techniques to approach the analysis of cellular and molecular interactions. Techniques include recombinant DNA methods, PCR, protein expression and purification, protein analysis, mammalian cell culture, light microscopy, and immunohistochemistry. Prerequisites: graduate standing in biomedical engineering and BME 530A or equivalent.
Credit 3 units. EN: TU

E62 BME 523 Biomaterials Science
An understanding of the interactions between biological systems and artificial materials is of vital importance in the design of medical devices. This course introduces the principles of biomaterials science, unifying knowledge from the fields of biology, materials science, surface science and colloid science. The course is taught from the primary scientific literature, focusing on the development of mathematical models of protein/surface interactions.
Credit 3 units. EN: TU
E62 BME 5231 Biomaterials Science: Polymer Physics
The properties of polymeric biomaterials are largely predictable from basic polymer physics principles. Topics discussed include: single chain conformations, thermodynamics of mixing and polymer solutions, networks and gelation, rubber elasticity and swelling, and polymer dynamics.
Credit 2 units.

E62 BME 524 Tissue Engineering
This course integrates the principles and methods of engineering and life sciences toward the fundamental understanding of normal and pathological mammalian tissues especially as they relate to the development of biological substitutes to restore, or improve tissue function. Current concepts and strategies including drug delivery, tissue and cell transplantation, and in vivo tissue regeneration are introduced as well as their respective clinical applications. Prerequisites: BME 366 or ChE 367; or MEMS 3410, Biol 2960 and 2970.
Credit 3 units. EN: TU

E62 BME 525 Engineering Aspects of Biotechnology
An understanding of engineering principles such as kinetics and transport is essential to the successful scale up of processes for the production of biological therapeutics. This course discusses the use of protein-based therapeutics and their production in bacterial and mammalian cells. The course unifies concepts learned in biology, thermodynamics and transport to understand the need for engineering in the field of biotechnology. The impact of emerging technologies such as genomics, proteomics, micro arrays, tissue engineering and gene therapy on the biotechnology industry also is described. Prerequisites: BME 320A, BME 366 or ChE 367, Biol 2960/2970.
Credit 3 units. EN: TU

E62 BME 527 Design of Artificial Organs
Medical devices that replace the function of one of the major organs in the body must usually interface with flowing blood. Examples include total artificial hearts, left ventricular assist devices, membrane oxygenators, hemodialysis systems and encapsulated endocrine cells. The design of these devices relies on integration of knowledge from a variety of fields, in particular computational fluid dynamics and blood rheology. We study the process by which a concept for a device eventually leads to a functioning, blood-contacting medical device, with most of the focus on the design of left ventricular assist devices. Students learn to use CAD to design blood pumping devices, test their designs via computational fluid dynamics, and 3-D print and test their pumps with water. Prerequisite: BME 366 or equivalent course in Transport Phenomena (including momentum and mass transfer).
Credit 3 units. EN: TU

E62 BME 530 Modeling Biomolecular Systems I
Same as Biol 5476
Credit 3 units.

E62 BME 530A Molecular Cell Biology for Engineers
This course is designed for upper-level undergraduates and first-year graduate students with a background in engineering. This course covers the biology of cells of higher organisms: protein structure and function; cellular membranes and organelles; cell growth and oncogenic transformation; cellular transport, receptors and cell signaling; the cytoskeleton, the extracellular matrix and cell movement. Emphasis is placed on examples relevant to biomedical engineering. The course includes two lectures per week and one discussion section. In the discussion section, the emphasis is on experimental techniques used in cell biology and the critical analysis for primary literature. Note this course does not count for engineering topics credits and is meant to fulfill a life science requirement for engineering or physical sciences graduate students. Prerequisites: Biol 2960 and 2970 or graduate standing.
Credit 4 units.

E62 BME 533 Biomedical Signal Processing
Course designed for graduate students with little or no background in signal processing. Continuous-time and discrete-time application of signal processing tools to a variety of biomedical problems. Course topics include review of linear signals and systems theory, frequency transforms, sampling theorem, basis functions, linear filtering, feature extraction, parameter estimation and biological system modeling. Special emphasis is placed on signal transduction and data acquisition. Additional topics include noise analysis of real-world biosignals, biological system identification, stochastic/chaotic/fractal/nonlinear processes in biological systems. Concepts learned in class are applied using software tools to identify biomedical signals such as biological rhythms, chemical concentrations, blood pressure, speech, EMG, ECG and EEG. Prerequisite: graduate standing or consent of instructor.
Credit 3 units. EN: TU

E62 BME 537 Computational Molecular Biology
This course focuses on mathematical and algorithmic issues in systems biology and biological sequence analysis. The essential mathematics is introduced first. Systems biology topics include synthetic biology, dynamical systems modeling, mapping and modeling gene regulatory networks, constraint based approaches to predictive modeling of metabolic networks, and the integration of regulatory and metabolic models. Sequence analysis topics include, Hidden Markov Models, parameter inference, sequence alignment and modeling transcription factor binding sites. This course includes a combination of paper and pencil homework assignments and programming labs. Prerequisites: an introductory course in computer programming or equivalent experience and at least two semesters of calculus.
Credit 3 units. EN: TU

E62 BME 538 Cell Signal Transduction
This class covers the elements of cell signal transduction important to human development, homeostasis and disease. Lectures are combined with primary literature review to cover canonical signaling and current topics within the field. Spatial, time and dose-dependent aspects of signaling are of particular focus. Topics include: G protein-coupled receptors, receptor tyrosine kinases, adhesion signaling, the MAPK cascade, lipid signaling, the DNA damage response, and autocrine, paracrine and juxtacrine signaling. Prerequisites: BME 530A or BME 5068.
Credit 3 units.

E62 BME 540 Modeling Biomolecular Systems II
This course is a continuation of BME 530/Biol 5476, covering additional topics in computer modeling and simulation. The lectures cover the theory and underlying algorithms, while the laboratories and term project provide the students with hands-on experience in using various software packages. Topics include: statistical mechanics concepts in molecular simulations;
E62 BME 540A Biomechanics
Advanced topics in the application of mechanics to biological problems. The specific topics selected for discussion reflect current faculty research interests and may include: mechanics and energetics of contractility, membrane mechanics, material properties of cells and tissues, and micromechanical measurement systems.
Credit 3 units. EN: TU

E62 BME 5610 Protein Structures and Dynamics
This course covers the concepts and methods involved in the analysis of protein structure, stability, folding and misfolding. Topics include protein structural elements, amyloid structure, intra- and intermolecular forces, folding pathways and intermediates, phi-value analysis, kinetics of protein folding and of amyloid formation, and their application to problems of bioengineering and biophysics. One half of the course consists of lectures, the other half is a student seminar, in which each student presents a paper from primary literature and its concept and methodology that is discussed in detail. Prerequisites: senior or graduate level, prior course work in physical chemistry/thermodynamics.
Same as BME 461
Credit 3 units. EN: TU

E62 BME 5620 Protein Function and Interactions
This course covers the concepts and methods involved in the analysis of protein structure, stability, folding and misfolding. Topics include protein structural elements, amyloid structure, intra- and intermolecular forces, folding pathways and intermediates, phi-value analysis, kinetics of protein folding and of amyloid formation, and their application to problems of bioengineering and biophysics. One half of the course consists of lectures, the other half is a student seminar, in which each student presents a paper from primary literature and its concept and methodology that is discussed in detail. Prerequisites: senior or graduate level, prior course work in physical chemistry/thermodynamics.
Same as BME 461
Credit 3 units. EN: TU

E62 BME 563 Orthopaedic Biomechanics — Bones and Joints
Basic and advanced solid mechanics applied to the musculoskeletal system, with a primary focus on bone and joint mechanics. Topics include: forces in joints; gait analysis; axial, torsional and bending loading of bones; mechanical properties (elastic, fracture, creep, fatigue) and composition of bone; bone adaptation and basic concepts of bone biology; joint kinematics; total hip and knee replacement; mechanical consequences of injury (fracture) and disease (osteoporosis). This class is geared to graduate students and upper-level undergraduates familiar with statics and mechanics of deformable bodies. Prerequisites: BME 240 or equivalent.
Credit 3 units. EN: TU
E62 BME 564 Orthopaedic Biomechanics — Cartilage/Tendon
Basic and advanced viscoelasticity and finite strain analysis applied to the musculoskeletal system, with a primary focus on soft orthopaedic tissues (cartilage, tendon and ligament). Topics include: mechanical properties of cartilage, tendon and ligament; applied viscoelasticity theory for cartilage, tendon and ligament; cartilage, tendon and ligament biology; tendon and ligament wound healing; osteoarthritis. This class is geared to graduate students and upper-level undergraduates familiar with statics and mechanics of deformable bodies. Prerequisite: BME 240 or equivalent. Note: BME 590Z (BME 463/563) Orthopaedic Biomechanics — Bones and Joints is NOT a prerequisite. Credit 3 units. EN: TU

E62 BME 568 Cardiovascular Dynamics
This course focuses on the analysis of blood flow through the heart and blood vessels. Basic cardiovascular anatomy and physiology; principles of continuum mechanics. Flow through heart chambers, valves and coronary arteries; peristaltic flow in the embryonic heart. Steady and unsteady flow in tubes; wave propagation in blood vessels; flow in collapsible tubes; microcirculation. Prerequisites: BME 240 or equivalent and ChE 367 or MEMS 341 or equivalent, or permission of instructor. Credit 3 units. EN: TU

E62 BME 572 Biological Neural Computation
This course considers the computations performed by the biological nervous system with a particular focus on neural circuits and population-level encoding/decoding. Topics include Hodgkin-Huxley equations; phase-plane analysis; reduction of Hodgkin-Huxley equations; models of neural circuits; plasticity and learning; and pattern recognition and machine learning algorithms for analyzing neural data. Note: Graduate students in psychology or neuroscience who are in the Cognitive, Computational and Systems Neuroscience curriculum pathway may register in Biol 5657 for three credits. For non-BME majors, conceptual understanding, and selection/application of right neural data analysis technique are stressed. Hence homework assignments/examinations for the two sections are different, however all students are required to participate in a semester-long independent project as part of the course. Prerequisites: Calculus, Differential Equations, Basic Probability and Linear Algebra undergraduates need permission of the instructor. Biol 5657 prerequisites: permission from the instructor. Credit 3 units. EN: TU

E62 BME 573A Applied Bioelectricity
This course focuses on the design of bioelectric devices for use in clinical patients. Cardiac pacemakers and defibrillators as well as neural stimulators (e.g., deep brain, vagal) are the basis for a case-study approach to designing and developing new bioelectrical medical devices. In addition to the engineering design aspects, issues such as product liability, FDA approval, etc., are discussed. Prerequisite: BME 471 Bioelectric Phenomena or instructor’s permission. Credit 3 units. EN: TU

E62 BME 574 Quantitative Bioelectricity and Cardiac Excitation
Action potential generation, action potential propagation, source-field relationships in homogeneous and inhomogeneous media, models of cardiac excitation and arrhythmia, quantitative electrocardiography. Prerequisites: differential equations, Laplace transform, electromagnetic field theory (undergraduate level). Credit 3 units. EN: TU

E62 BME 575 Molecular Basis of Bioelectrical Excitation
Ion channels are the molecular basis of membrane excitability in all cell types, including neuronal, heart and muscle cells. This course presents the structure and the mechanism of function of ion channels at the molecular level. It introduces the basic principles and methods in the ion channel study as well as the structure-function relation of various types of channels. Exemplary channels that have been best studied are discussed to illustrate the current understanding. Prerequisites: knowledge of differential equations, electrical circuits and chemical kinetics. Credit 3 units.

E62 BME 578 Biological Imaging Technology
This class develops a fundamental understanding of the physics and mathematical methods that underlie biological imaging and critically examine case studies of seminal biological imaging technology literature. The physics section examines how electromagnetic and acoustic waves interact with tissues and cells, how waves can be used to image the biological structure and function, image formation methods and diffraction limited imaging. The math section examines image decomposition using basis functions (e.g., Fourier transforms); synthesis of measurement data, image analysis for feature extraction, reduction of multidimensional imaging datasets, multivariate regression and statistical image analysis. Original literature on electron, confocal and two photon microscopy, ultrasound, computed tomography, functional and structural magnetic resonance imaging and other emerging imaging technology are critiqued. Same as ESE 589
Credit 3 units. EN: TU

E62 BME 5901 Integrative Cardiac Electrophysiology
Quantitative electrophysiology of the heart, integrating from the molecular level (ion channels, regulatory pathways, cell signaling) to the cardiac cell (action potential and calcium transient), multicellular tissue (cell-cell communication) and the whole heart (SA and AV nodes, specialized conduction system, fiber structure and anisotropy, anatomical considerations). Prerequisite: consent of instructor. Credit 3 units.

E62 BME 5902 Cellular Neurophysiology
This course examines the biophysical concepts of synaptic function with the focus on the mechanisms of neural signal processing at synapses and elementary circuits. The course combines lectures and discussion sessions of primary research papers. Topics include synaptic and dendritic structure, electrical properties of axons and dendrites, synaptic transmission, rapid and long-term forms of synaptic plasticity, information analysis by synapses and basic neuronal circuits, principles of information coding, mechanisms of learning and memory, function of synapses in sensory systems, models of synaptic disease states such as Parkinson and Alzheimer's diseases. Additionally, a set of lectures is devoted to modern electrophysiological and imaging techniques, and modeling approaches to study synapses and neural circuits. Prerequisite: senior or graduate standing.
E62 BME 5903 Physical Methods for Biomedical Scientists
The course introduces the spectrum of biophysical techniques used in biomedical sciences with a focus on advanced fluorescence spectroscopy. The first half of the course introduces the concepts behind techniques such as: dynamic light scattering, SPR, analytical ultracentrifugation size-exclusion and affinity chromatography, atomic force microscopy, fluorescence spectroscopy, FRET, FTIR, circular dichroism, fluorescence correlation spectroscopy, and sub-diffraction microscopy. The second half of the course is held as six three-hour block lab classes in which the students use these techniques in experiments on protein folding, protein stability and amyloid formation. Prior attendance of BME 461 Protein Structure and Dynamics is encouraged. Prerequisites: senior or graduate standing. Same as BME 4903 Credit 3 units.

E62 BME 5904 Special Topics: Nanostructured Surfaces and Materials and Their Applications in Biomedical Research
Although this course is primarily designed for graduate students and seniors in biomedical engineering, the selected topics are also appropriate for students in other departments such as chemistry, physics, chemical engineering, mechanical engineering and materials science. This course presents an overview of the basic principles and recent activities in representative areas of nanoscience and nanotechnology. We deal with the chemistry and physics of materials, structures and surfaces with feature sizes less than 100 nm: For example, when does size matter? How do we engineer the properties of materials/structures/surfaces through size control? Is there the lowest limit for the size? How do we synthesize nanomaterials, fabricate nanostructures and generate nanoscale patterns? What are the challenges in these newly developed areas? What are the unique applications of nanostructured materials in biomedical research? Prerequisites: general chemistry and general physics. Credit 3 units.

E62 BME 5905 Neural Computation & Motor Behavior
This course considers current problems in motor neuroscience. Emphasis is placed on experimental paradigms and computational models that most directly address how the brain represents, transforms and estimates information during movement, and how these computations adapt with experience. Graduate students from all engineering and science disciplines who aspire to deeply consider and address these issues should attend. Prerequisites: recommended background in neuroscience and/or numerical implementation of differential equations. Credit 3 units.

E62 BME 5906 Brain Networks
Large networks of interconnecting elements are now accessible for study with increasingly sophisticated simulation methods. Brain networks represent an exceptionally attractive target for such study. This course includes a survey of modern analytic methodology used to evaluate a range of biological neural networks from relatively simple cellular networks in model animals and in vitro to abstracted networks of functional areas in the human cerebral cortex. Course work involves lectures on methodology and recent findings as well as readings from the primary literature. Prerequisites: Math 217 Differential Equations, graduate standing or consent of instructor. Credit 3 units.

E62 BME 5907 Advanced Concepts in Image Science
The course exposes students to a unified treatment of the mathematical and statistical principles of imaging. This includes the deterministic analysis of imaging systems that includes continuous-to-continuous, continuous-to-discrete and discrete-to-discrete mappings from objects to images. In addition, imaging systems are analyzed in a statistical framework where stochastic models for objects and images are introduced. Methodologies for task-based image quality assessment are reviewed, which includes classification tasks and receiver operator characteristic (ROC) analysis. Basic concepts of inverse problems and tomography also are covered. Prerequisite: graduate standing or consent of instructor. Credit 3 units.

E62 BME 5908 The Cell as a Machine
The goals of this course are to provide a working understanding of the basic cell functions and the physical and chemical principles underlying them. In practical terms, we attempt to solve a number of important problems relevant to replication, transcription, translation, translocation, motility and other important functions. Classes consist of online videotaped lectures (three hours per week) and live weekly Q&A sessions. Prerequisites: basic physical chemistry, calculus, biology, graduate standing or approval by adviser or department. Credit 3 units.

E62 BME 5909 Physiology of the Heart
This is a comprehensive cardiac physiology course for biomedical engineers, which includes (1) history, philosophy and methodology of cardiac physiology and cardiac engineering, (2) structure, biochemistry and biophysics of the heart, (3) signal transduction and regulation, (4) normal physiology and pathophysiology, and (5) current approaches to therapy of heart disease. Textbook: Arnold M. Katz, *Physiology of the Heart*, 5th edition. Credit 3 units.

E62 BME 591 Biomedical Optics I: Principles
This course covers the principles of optical photon transport in biological tissue. Topics include a brief introduction to biomedical optics, single-scatterer theories, Monte Carlo modeling of photon transport, convolution for broad-beam responses, radiative transfer equation and diffusion theory, hybrid Monte Carlo method and diffusion theory, and sensing of optical properties and spectroscopy. Prerequisite: Math 217. Credit 3 units. EN: TU

E62 BME 5910 Reverse Engineering the Human Brain
This course investigates classic and current research that identifies the processes by which the human brain transforms, estimates and adapts to underlie mental and physical behavior. We consider how these studies succeed or fail to identify the systemic properties that make us human. The focus is on behavioral approaches, but we also integrate into our study physiological, neurologic and imaging approaches. Credit 3 units. EN: TU
E62 BME 5911 Cardiovascular Biophysics Journal Club
This journal club is intended for beginning graduate students, advanced undergraduates and MSTP students with a background in the quantitative sciences (engineering, physics, math, chemistry, etc). The subjects covered are inherently multidisciplinary. We review landmark and recent publications in quantitative cardiovascular physiology, mathematical modeling of physiologic systems and related topics such as chaos theory and nonlinear dynamics of biological systems. Familiarity with calculus, differential equations and basic engineering/thermodynamic principles is assumed. Knowledge of anatomy/physiology is optional.
Credit 1 unit. EN : TU

E62 BME 5912 Applied Mathematics for Biomedical Sciences
This course focuses on mathematical methods and concepts required for research in BME and related biomedical sciences. The course is organized around five modules: Linear Algebra, Differential Equations, Functionals, Variational Calculus and Statistical Analysis. The lectures introduce mathematical concepts and the application of these concepts to problems in biomedical sciences such as imaging, biotechnology, systems biology, network science and biophysics. Students are expected to have a background in advanced calculus, vector calculus, introductory linear algebra, differential equations and related topics in engineering mathematics. This course is open to graduate students and upperclass students majoring in engineering, particularly BME.
Credit 3 units.

E62 BME 5913 Molecular Systems Biology: Computation & Measurements for Understanding Cell Physiology and Disease
This project-based (MATLAB) class introduces several current techniques for systems-level measurement of molecules and a set of computational techniques for inferring biological meaning from such experiments. The biology and measurement techniques for systems-level discovery of gene expression, metabolites, proteins and post-translational modifications, and regulatory RNA are covered with a focus on understanding their involvement in cancer, diabetes and inflammatory disorders. A range of computational topics, including dimensionality reduction techniques, correlations between measurements and outcomes, and network modeling and inference are introduced and practiced in the course in order to understand how systems-level measurements can lead to inference in cell physiology. A working knowledge of molecular biology, differential equations, linear algebra and statistics is required.
Credit 3 units. EN : TU

E62 BME 5914 Stem Cell Engineering
This course is intended to provide a foundation in the application of analytical engineering approaches for the quantitative study of stem cell biology and effective translation of stem cells into therapies and diagnostics. The progression of the course content is intended to lead students through the conceptual process of identifying an appropriate type of stem cell based on functional attributes for a desired application, isolation and purification of desired cell type(s), expansion in a stable state, directing the differentiation to specific phenotype(s), and use of appropriate characterization techniques and quality control metrics to quantitatively assess cell phenotype for the development of stem cell-based technologies. Prerequisites: Graduate standing and cell biology.
Credit 3 units.

E62 BME 592 Biomedical Optics II: Imaging
This course covers optical imaging technologies. Topics include ballistic imaging, optical coherence tomography, Mueller optical coherence tomography, diffuse optical tomography, photoacoustic tomography and ultrasound-modulated optical tomography. Prerequisites: Math 217, BME 591.
Credit 3 units. EN: TU

E62 BME 599 Master's Research
Credit variable, maximum 6 units.