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, imaging, cardiovascular engineering, cell and tissue engineering, molecular cellular and systems engineering, neural engineering, regenerative engineering, and women's health technologies. All students in biomedical engineering are encouraged to join and be active in the Biomedical Engineering Society.

Mission Statement

The Department of Biomedical Engineering at Washington University in St. Louis (WashU BME) seeks to provide a first-class engineering education that prepares students for a variety of careers and a cutting-edge graduate program that advances knowledge and technology with the goal to improve human well-being.

Program Educational Objectives

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 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
- Complete professional degrees (e.g., in medicine, dentistry, law)

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. The BS in Biomedical Engineering program at Washington University in St. Louis is accredited by the Engineering Accreditation Commission of ABET (https://www.abet.org), under the commission's General Criteria and Program Criteria for Biomedical Engineering.

The curriculum is structured around a basic core of 80 credits. In addition, a complementary set of courses totaling at least 40 credits completes the degree requirements.

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, including engineering sciences and engineering design appropriate to biomedical engineering. The BS–BME degree at Washington University requires 47 credits of engineering topics. The basic core curriculum includes 32 engineering topics credits. Therefore, students pursuing a BS–BME degree will need 15 additional engineering topics credits beyond the basic core curriculum. They also may receive up to 6 credits 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 credit requirements, please refer to the Undergraduate Curriculum webpage.

Bachelor's/Master's (BS/MS) Program in Engineering

This program provides undergraduate students the opportunity to earn a McKelvey master's degree by combining undergraduate and graduate studies in an integrated curriculum. Interested engineering students should discuss the program with their BME academic and Engineering Undergraduate Students Services advisors by the end of their junior year in order to best develop a plan for their senior year leading into their master's year. For McKelvey undergraduates, this program normally takes one additional year to complete. More information is available on the McKelvey undergraduate Bulletin page.

Double Majors

An option available to students majoring in biomedical engineering is the double major, which leads to a second professional BS degree in one of the other engineering disciplines in four years. A BME degree in combination 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 advanced placement 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 advisor in the second department as early as possible.

Premedical Preparation

Training in BME is also excellent preparation for various professional schools, particularly medical schools. Many students complete their premedical requirements while obtaining their BME degrees. Premedical preparation is not a major; rather, it allows students to fulfill the requirements needed for entry to medical school. Further information can be obtained by visiting the Premedicine webpage and by contacting the McKelvey School of Engineering's Health Professions Advisor, Jessica Allen, at jessicaa@wustl.edu.

Cooperative Experience

Cooperative experience is available to upper-level students at numerous life science/technology companies both in the St. Louis area and nationwide. This experience is particularly valuable for students who wish to enter industry. However, since most companies ask that students spend the equivalent of one semester and a summer participating in these experiences, it may be difficult to complete the degree requirements in eight semesters, unless students enter with sufficient advanced placement credits and/or take summer courses.

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

Phone:	314-935-7208
Website:	https://bme.wustl.edu/academics/undergraduate-programs/index.html

Faculty

Chair

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

Endowed Professor

Rohit V. Pappu
Gene K. Beare Distinguished Professor of Biomedical Engineering
PhD, Tufts University
Macromolecular self assembly and function; computational biophysics

Professors

Dennis L. Barbour
MD, PhD, Johns Hopkins University
Application of novel machine learning tools to diagnose and treat disorders of perception and cognition

Cory Berkland
PhD, University of Illinois
Developing new therapeutics and biomaterials for improving human health

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

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

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

Jon Silva
PhD, Washington University
Ion channel biophysics

Chao Zhou
PhD, University of Pennsylvania
Optical coherence tomography

Quing Zhu
Edwin H. Murty Professor of Engineering
PhD, University of Pennsylvania
Biophotonics and multimodality ultrasound and optical imaging

Associate Professors

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

Song Hu
PhD, Washington University in St. Louis
Optical and photoacoustic technologies for high-resolution structural, functional, metabolic and molecular imaging in vivo

Michelle Oyen
PhD, University of Minnesota
Bioengineering approaches to the study of pregnancy and childbirth; mechanical properties of hydrogel and hydrogel composite materials; biomimetic materials referencing both hard and soft natural tissues

Jai S. Rudra
PhD, Louisiana Tech University
Peptide-based biomaterials; immunoengineering; immunology of nanoscale aggregates; development of vaccines and immunotherapies

Kurt A. Thoroughman
PhD, Johns Hopkins University
Human motor control and motor learning; neural computation

Assistant Professors

Yifan Dai
PhD, Case Western Reserve University
Decodes and encodes the physical chemistry of biological soft matter to understand biology and engineering precision medicine

Nate Huebsch
PhD, Harvard University
Cell-material Interactions, iPSC-based tissue modeling to study cardiac development and disease

Abhinav Kumar Jha
PhD, University of Arizona
Development of computational-imaging solutions for diagnosing and treating diseases

Christine M. O'Brien
PhD, Vanderbilt University
Developing optical spectroscopy and imaging tools to solve global problems in maternal-fetal health and reproductive diseases

Alexandra Rutz
PhD, Northwestern University
Engineering of electronic tissues using materials design and fabrication-based approaches

Ismael Seáñez
PhD, California Institute of Technology
Neuro-rehabilitation tools and programs that promote active use of residual mobility and maximize recovery through the use of body-machine interfaces

Michael D. Vahey
PhD, Massachusetts Institute of Technology
Biophysical mechanisms of infectious disease; fluorescence microscopy; microfluidics

Principal Lecturer

Patricia Widder
MS, Washington University

Lecturer

Katherine Schreiber
PhD, Saint Louis University

Professor of Practice

Joseph Klaesner
PhD, Vanderbilt University

Senior Professor

Larry Taber
PhD, Stanford University
Mechanics of growth and development; cardiac mechanics

Senior Emeritus Professors

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

Frank Yin
MD, PhD, University of California, San Diego

Majors

The Major in Biomedical Engineering

The BS in Biomedical Engineering requires completion of the courses in the Core Curriculum as well as five upper-level Tier courses beyond the Core, as described below. Students must meet all McKelvey School of Engineering and Washington University requirements, including the English proficiency requirement (please refer to the Engineering Degree Requirements page). They must also satisfy ABET requirements for a professional degree, which require the accrual of 47 engineering topics units over their course work. A list of Topics Units - Engineering Courses is available on the Engineering Student Services website.

The Basic Core

The Biomedical Engineering Core Curriculum consists of 80 credits, outlined below.

Courses	Units
Physical Sciences	
General Chemistry (Chem 111A or Chem 105, Chem 112A or Chem 106)(111A and 112A recommended)	6
General Chemistry Laboratory I, II (Chem 151, Chem 152)	4
General Physics (Physics 191, Physics 191L, Physics 192, Physics 192L)	8
	18
Biological Science	
Principles of Biology I (Biol 2960)	4
Physiological Control Systems (Biol 3058)	2
	6
Mathematics	
Calculus II & III (Math 132, Math 233)	6
Differential Equations (Math 217)	3
Engineering Mathematics A & B (ESE 318, ESE 319)	6
Probability and Statistics for Engineering (ESE 326)*	3
	18
Engineering Science	
Computer Science (CSE 131)	3
	3
Biomedical Engineering	
Introduction to Biomedical Engineering (BME 140)	3
Introduction to Biomedical Circuits (BME 220)**	4
Biomechanics (BME 240) and Biomechanics Lab (BME 240L)	4
Quantitative Physiology I, II (BME 301A, BME 301B)	8
Bioengineering Thermodynamics (BME 320B)	3
Transport Phenomena in BME (BME 366)	3
Senior Design A, B (BME 401A, BME 401B)	4
	29

Other	
Engineering Practice and Professional Values (Engr 4501, Engr 4502 and Engr 4503)	3
Technical Writing (Engr 310)	3
	6
Total Basic Core	**80**

* Engr 328 Engineering Statistics with Probability can be substituted for ESE 326 Probability and Statistics for Engineering.

** ESE 230 Introduction to Electrical and Electronic Circuits can be substituted for BME 220 Introduction to Biomedical Circuits.

Students must complete **five upper-level Tier engineering courses (15 units), five humanities and social sciences courses (15 units), and three general electives courses (minimum 10 units)** beyond the Core Curriculum to complete the major and to prepare for particular fields of employment or education beyond the baccalaureate degree. At least two of the five Tier electives need to be drawn from the Tier I course list below; the remaining three can be chosen from Tier I or Tier II. Students must complete a minimum of **120 units** to meet the degree requirements.

Tier I

For the most up-to-date Tier list, please refer to the BME website.

Tier II

All upper-level (300-500) engineering and physics courses that carry 3 engineering topics units (with the exception of required courses such as BME 301A, BME 301B, BME 320B, and so on) count as Tier II electives.

Minors

Please visit the following page for information about the biomedical engineering minor:

- Minor in Biomedical Data Science

Courses

Visit online course listings to view semester offerings for E62 BME.

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 will 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: Phys 197, Chem 111A, and college level calculus.
Credit 3 units. EN: TU

E62 BME 220 Introduction to Biomedical Circuits
Electricity is central to normal and abnormal biological function, spanning scales from the subcellular to whole systems. Scientists and engineers also use electrical engineering to design and implement interaction with biological tissue, from classical physiological experiments to cutting-edge brain-computer interfaces. This course will begin the study of bioelectrical engineering by introducing simple electrical elements, circuits, amplifiers, and instrumentation. Relevant biological examples and computer modeling will be used throughout. The lab component will provide hands-on laboratory practice with simple electrical elements, circuits, amplifiers, instrumentation, and computer modeling, with a focus on biomedical applications. BME 220 fulfills the circuits requirement for BME students in place of ESE 230. Prerequisite: L31 Phys 192/192L; Corequisite: Math 217.
Credit 4 units. EN: TU

E62 BME 220L Biomedical Circuits Laboratory
This course covers the lab portion only of E62 BME220. It is open only to those students who have completed an approved lecture-only circuits course and who need to fulfill the circuits lab requirement for the BS-BME degree. Students wishing to enroll will be placed on a waitlist and reviewed by the BME department.
Credit 1 unit. EN: TU

E62 BME 231 Foundations of Biomedical Computing
This elective course provides a basis for solving problems in biomedical engineering through coding and computation. Coding structures applied to concepts in linear algebra, statistics, and probability are introduced as a foundation to more advanced biomedical data science applications in machine learning and artificial intelligence. The course is taught using Python; no prior knowledge of Python is expected or required. Students should be comfortable with high school level algebra and geometry. This course is required as prerequisite for BME440, Biomedical Data Science, and is a required course for the Biomedical Data Science minor.
Credit 3 units. EN: TU

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: L31 Phys 191 or 193
Credit 3 units. EN: TU

E62 BME 240L Biomechanics Laboratory
This course will consist of hands-on laboratory experiments in topics relevant to bioengineering mechanics such as statics of rigid bodies, viscoelasticity, and stress/strain analysis of biological materials. A focus of the course will be extending fundamental mechanical principles to biological applications through experimentation. The course is designed to follow and enhance the material covered in BME 240. Additionally, students will have the opportunity to design their own experiments, explore topics of special interest, and present their findings. Prerequisite: concurrent or completed E62 BME 140
Credit 1 unit. 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, ESE 230, Biol 3058 (Previously Biol 3050 or 3059), ESE 319, or permission of instructor.
Credit 4 units. EN: TU

E62 BME 301B Quantitative Physiology II
A course (lecture and supervised laboratory sessions) 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, ESE 230, ESE 319, Biol 3058, or permission of instructor.
Credit 4 units. EN: TU

E62 BME 320B Bioengineering Thermodynamics
This course covers the foundations of thermodynamics with strong emphasis on concepts and the translation of concepts. Topics to be covered include the first and second laws of thermodynamics, probabilistic descriptions of entropy, consequences of the first and second laws in ideal and non-ideal single- and multicomponent systems, free energies as descriptors of equilibria in laboratory and biological systems, chemical equilibria, phase equilibria, treatment of aqueous solvents and mixtures, colligative properties, thermodynamics of protein folding, and protein binding equilibria. The material, the lectures, and the homeworks emphasize learning that enables the translation of concepts into mathematical analysis. A strong background in differential calculus of multiple variables and differential equations (Math 217) is required. Emphasis is placed on regular homeworks and working in collaborative groups. The main textbook for the course will be "Molecular Driving Forces: Statistical Thermodynamics in Chemistry and Biology", 2nd edition by Ken A. Dill and Sarina Bromberg published by Garland Science. The lectures and course notes will also draw on other sources including the classical book by Herbert Callen. A weekly recitation section, BME 320A, is offered on Tuesdays between 4:00 PM and 5:30 PM. Students are strongly urged to attend lectures and the recitation section.
Credit 3 units. EN: TU

E62 BME 329 Biothermodynamics in Practice
This course will include 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 will be extending fundamental scientific principles to biological applications. Students will have the opportunity to design their own experiments, explore topics of special interest, and present their findings. Prerequisites: L07 Chem 111A, L07 Chem 151, L31 Phys 191/191L, L31 Phys 192/192L
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 will be derived. Systematic derivation of differential equations appropriate for different types of transport problems will be explored. Solutions of the resulting differential equations for simple chemical/biological systems will then be sought. Macroscopic descriptions of fluid flow will be applied to the design of blood pumps for the heart. Unsteady mass transfer with diffusion, advection and chemical reactions will also be applied to the transport of proteins, metabolites and therapeutics throughout the body. Prerequisites: E62 BME 240, L24 Math 217, E35 ESE 318, E35 ESE 319
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 approval of the BME Undergraduate Studies Committee
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 Undergraduate Studies Committee must approve the requested number of engineering topics. Prerequisites: junior or senior standing and approval of the BME Undergraduate Studies Committee
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 Undergraduate Studies Committee must approve the requested number of engineering topics. Prerequisites: junior or senior standing and approval of the BME Undergraduate Studies Committee
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 Undergraduate Studies Committee must approve the requested number of engineering topics. Prerequisites: junior or senior standing and approval of the BME Undergraduate Studies Committee
Credit 3 units. EN: BME T, TU

E62 BME 4015 Biomedical Data Science Capstone Design
Previously described as BME 401DS. This course provides a client-centered design experience in biomedical data science. Students will work as individuals or in small teams with possible clients to define and scope an unmet need in biomedical data science. The students will work on an original solution or a redesign of an existing solution to address the unmet need. The design experience will involve application of knowledge and skills acquired in earlier coursework. It will also incorporate best practices in biomedical data science, including ethical considerations such as respect for persons, social license, and vulnerabilities; patient safety and privacy; and HIPAA compliance. Students will be guided through the design process and will produce and present appropriate deliverables for their project. This course is required for the Biomedical Data Science minor. Prerequisites: BME 440 or consent of instructor.
Credit 3 units. EN: BME T

E62 BME 401A Senior Capstone Design A
A hands-on design experience to provide students practical application of engineering. Working in small teams, students will either meet with possible clients to discern a biomedical problem, or bring an original idea of their own to the class. The students will work on an original design or redesign of a component or system of biomedical engineering significance. The students will be taught how to craft a project scope with the required design specifications. The design

experience will require application of knowledge and skills acquired in earlier coursework; it will incorporate engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, FDA, social, and political. Students will prepare written reports and present their designs orally to a panel of faculty members and industrial representatives. The final product of BME 401A will be a descriptive paper design of their solution. Prerequisite: BME Senior Standing
Credit 2 units. EN: TU

E62 BME 401B Senior Capstone Design B
A hands-on design experience to provide students practical application of engineering. Working in small teams, students will work towards building a prototype of the student design which was a product of 401A. The students will be expected to design a verification and validation plan to test the prototype built. The design experience will require application of knowledge and skills acquired in earlier coursework and lab experiences; it will incorporate engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, FDA, social, and political. Students will prepare written reports and present their designs orally to a panel of faculty members and industrial representatives. The final product of BME 401B will be a prototype, and a descriptive paper describing their solution documenting how the prototype satisfies the design specifications, with the validation and verification results. Prerequisites: BME 401A
Credit 2 units. EN: TU

E62 BME 402 Senior Design II
BME 402 is a continuation of BME 401. Working in small groups, students will take a paper design completed in BME 401 and build a prototype. They will evaluate, optimize, and undertake the building of the design. The design experience will require the application of knowledge and skills acquired in earlier course work; it will incorporate engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social and political. Students will prepare written reports and participate in oral design reviews involving 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 1 unit. EN: TU

E62 BME 410 Service Learning Experience in Guangdong and Hong Kong
This pass/fail course is a 2-week international service-learning experience in conjunction with the faculty and students of our partner, Department of Biomedical Engineering at the Hong Kong Polytechnic University (PolyU). During the summer, students first attend an orientation at PolyU 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.
Credit 2 units.

E62 BME 432 Physics of Biopolymers
This course will cover physics concepts from the statistical physics of polymers and polymer solutions to describe proteins, nucleic acids, and bioinspired polymers. Topics include statistical physics concepts, theoretical and numerical descriptions of polymers, applying these descriptions to biopolymers, the thermodynamics of polymer solutions, concepts of polymer dynamics, descriptions of polymeric materials and advanced topics in phase transitions and molecular design. The material will be fast-paced and involve rigorous mathematical descriptions, experimental design, interpretations of experimental data, and some numerical simulations. The course will be heavy on individual homework and team-based project work. Direct connections between concepts and modern topics in biology and biomaterials will be emphasized. Prerequisites: BME 320B or equivalent and a first course in transport phenomena.
Credit 3 units. EN: TU

E62 BME 440 Biomedical Data Science
This course will cover data analysis, statistical methods, AI, machine learning, predictive modeling, and data visualization, with applications to medicine and health. As part of the course, BME faculty will present biomedical data science topics from their research areas. Students will learn to prepare, transform, visualize, validate, model, and communicate information about datasets, and they will design and implement an independent project to address a biomedical data science problem. Prior Python experience required. Prerequisites: E35 ESE 318, E35 ESE 326, (E62 BME 231 or E81 CSE 217A), or equivalent courses
Credit 3 units. EN: TU

E62 BME 442 Biomacromolecules Design and Engineering
Biological macromolecules (i.e., carbohydrates, lipids, proteins, and nucleic acids) are important components of the cell and its supporting matrix that perform a wide array of functions. This course will introduce the principles and recent advances in nucleic acid/gene engineering, protein/peptide engineering, and chemical/enzymatic conjugation technologies; it will also discuss the application of engineered biomacromolecules in clinical therapeutics/diagnostics, biosensing, bioimaging, and biocatalysis. Students will learn material through lectures, reading, homework, scientific publications, and molecular visualization tools. Students will work individually or in pairs/groups to develop and lead discussions on engineering biomacromolecules and molecular characterization techniques. Prerequisite: Basic knowledge of genes and cloning.
Credit 3 units. EN: TU

E62 BME 443 Molecular and Cellular Engineering
The ability to engineer biological function at the cellular level holds tremendous potential for both basic and applied science. This course aims to provide knowledge and practical proficiency in the methods available for measuring and controlling the molecular organization of eukaryotic cells. Topics to be covered include genome engineering using viral- and CRISPR-Cas systems; spatial and temporal control of proteins and their interactions; methods for characterizing and engineering post-translational modifications; and the relationship between cellular organization and function in migration, immune cell target recognition, and differentiation. Examples from recent scientific literature will provide the foundation for these topics.
Credit 3 units. EN: TU

E62 BME 444 Biomedical Instrumentation
This course will include operational and instrumentation amplifiers for bioelectric event signal conditioning, interfacing and processing; instrumentation noise analysis and filter design; A/D converters and hardware and software principles as related to sampling, storing, processing, and display of biosignals; modeling, analysis, and operation of transducers, sensors, and electrodes, for physiological and imaging systems; and an introduction to ultrasound, X-ray, and optical imaging systems. In addition, students will be involved in three projects of designing and building instrumentation amplifier and filter systems, ultrasound systems, and optical systems. Prerequisites: BME 301A and BME 301B.

Credit 3 units. EN: TU

E62 BME 459 Intermediate Biomechanics
This course covers several of the fundamental theories of solid mechanics that are needed to solve problems in biomechanics. The theories of nonlinear elasticity, viscoelasticity, and poroelasticity are applied to a large range of biological tissues including bone, articular cartilage, blood vessels, the heart, skeletal muscle, and red blood cells. Other topics include muscle activation, the biomechanics of development and functional adaptation, and the mechanics of hearing. Prerequisites: BME 240 and ESE 318 and ESE 319 or equivalent, or permission of instructor.
Same as E62 BME 559
Credit 3 units. EN: TU

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 590Z (463/563) Orthopaedic Biomechanics--Bones and Joints is NOT a prerequisite.
Same as E37 MEMS 5564
Credit 3 units. EN: TU

E62 BME 4642 Human-Machine Interfaces
This course will provide an overview of neurorehabilitation technologies for individuals with neuromotor disorders. Topics will include the neurophysiology of human motor and sensory systems, motor control and adaptation, and neuroplasticity in the damaged brain and spinal cord. Human-machine interface systems including prostheses, orthoses and exoskeletons, wheelchairs, neuroprosthetics, brain-machine interfaces, and wearable robots will be discussed with an emphasis on their clinical applications for restoration of motor and sensory functions. Lecture material and assignments will draw from current scientific literature and research. All students will be placed on a waitlist. Registration will be split between undergraduate and graduate students. Prerequisite: BME 301 Quantitative Physiology I or equivalent introductory physiology course preferred.
Credit 3 units. EN: BME T, TU

E62 BME 465 Biosolid Mechanics
Introduction to the mechanical behaviors of biological tissues of musculoskeletal, cardiac and vascular systems. Topics to be covered include static force analysis and nonlinear optimization theory; linearly elastic models for stress-strain analysis and solutions to relevant problems in bioelasticity; models of active structures (e.g., muscles); strain energy methods and nonlinear tissue behaviors; and introductory theory for finite element analysis. Emphasis will be placed on modeling stress-strain relations with relevance to biological tissues. Prerequisites: BME 240 or equivalent and ESE 318 and ESE 319.
Credit 3 units. EN: TU

E62 BME 469 Cardiac Electrophysiology
This course is an introduction to cardiac electrophysiology with an emphasis on arrhythmia mechanisms, experimental methods, and clinical applications. Topics will include modeling of cardiac arrhythmias, mapping of cardiac electric activity, pacemakers and defibrillators, and ablation of cardiac tissue.
Credit 3 units. EN: TU

E62 BME 470 Mathematics of Imaging Science
This course will expose students to a unified treatment of the mathematical properties of images and imaging. This will include an introduction to linear vector space theory, operator theory on Hilbert spaces, and concepts from applied functional analysis. Further, concepts from generalized functions, Fourier analysis, and radon transform will be discussed. These tools will be applied to conduct deterministic analyses of imaging systems that are described as continuous-to-continuous, continuous-to-discrete, and discrete-to-discrete mappings from object properties to image data. In addition, imaging systems will be analyzed in a statistical framework where stochastic models for objects and images will be introduced. Familiarity with Engineering-level mathematics, Calculus, Linear algebra, introduction to Fourier analysis is expected. Prerequisite: Senior standing or permission of instructor.
Same as E62 BME 570
Credit 3 units.

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 will include electric fields and current flow in volume conductors; cell membrane channels and their role in generating membrane potentials; and action potentials and their propagation in myelinated and unmyelinated axons as well as cardiac tissue. Minor topics of discussion will include both skeletal muscle and non-human (e.g., electric fish) sources of bioelectricity.
Credit 3 units. EN: TU

E62 BME 472 Biological Neural Computation
This course will consider 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 & 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 L41 5657 for three credits. For non-BME majors, conceptual understanding, and selection/application of right neural data analysis technique will be stressed. Hence homework assignments/examinations for the two sections will be 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. L41 5657 prerequisites: Permission from the instructor
Same as E62 BME 572
Credit 3 units. EN: TU

E62 BME 4735 Biomedical Engineering Entrepreneurship
Students will learn about entrepreneurship, including IP, business development, and fundraising, through case studies.
Credit 3 units.

E62 BME 4780 Engineering for Women's Health
Engineering approaches have many uses in improving women's health, from basic science understanding through to clinical implementation. This course will start with an overview of female reproductive anatomy and physiology and continue with case studies from different engineering sub-fields as applied to women's health. Students will complete case studies and one in-depth project on women's health engineering topics.
Credit 3 units. EN: TU

E62 BME 479 Biofabrication & Medical Devices
This course will cover materials design and modern manufacturing methods for biofabricated tissues and medical devices (with a particular emphasis on bioelectronic devices). Topics will include additive manufacturing and their materials requirements along with how these methods have evolved to use biomaterials and cells, such as bioprinting. State-of-the-art in vitro and implantable devices for diagnostic and therapeutic purposes will be discussed with emphasis on how their properties have advanced from developments in materials and manufacturing. Lecture material and assignments will draw from both current market devices and the clinical standard-of-care as well as ongoing research and recent scientific literature. All students will be placed on a waitlist. Registration will be split between undergraduate and graduate students. Prerequisite: E62 BME 523 or equivalent biomaterials introductory course
Credit 3 units. EN: TU

E62 BME 4902 Cellular Neurophysiology
This course will examine 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 will be devoted to modern electrophysiological and imaging techniques, and modeling approaches to study synapses and neural circuits. Prerequisite: Senior or graduate standing.
Same as E62 BME 5902
Credit 3 units. EN: TU

E62 BME 494 Ultrasound Imaging
Ultrasound imaging is the most widely used medical imaging modality in the world. This course offers an introduction to the medical ultrasound field. It exposes students to fundamental physical principles of ultrasound, ultrasound imaging, and ultrasound therapy. It will also introduce emerging ultrasound technologies in industry and clinics. Students will learn via lectures, homework, lab exercises, and a final project to gain knowledge, learn the ability to think critically, and develop problem-solving skills.
Credit 3 units. EN: TU

E62 BME 496 Design and Development of Optical Imaging Systems
In this course, students will learn the design principles of optical imaging systems and learn to use optical simulation software, such as ZEMAX/OpticsStudio. There is also hands-on imaging system development components that will allow students to practice skills developed to make prototype imaging systems. Prerequisites: ESE 330, ESE438 or equivalent
Credit 3 units. EN: TU

E62 BME 501C BME Doctoral Seminar Series
This is a credit option for BME students who attend regularly scheduled BME seminars (or approved substitute seminars). A satisfactory grade is obtained by submission of a two-page peer-reviewed paper written by one of the regularly scheduled BME seminar speakers whose seminar the student attended. Papers are to be submitted to the Graduate Student Administrator for review by the Director of Doctoral Studies. Prerequisite: Current BME student in the second year or beyond.
Credit 1 unit.

E62 BME 505 Professional and Personal Pathways to the PhD Program
This course is designed to guide PhD students as they embark on their first year in the Biomedical Engineering program. Topics include choosing a thesis lab and mentor, creating individual development plans, career exploration, and building mentor realtionships through networking.
Credit 1 unit.

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 E35 ESE 596
Credit 1 unit.

E62 BME 5071 Radiobiology
Effects of ionizing radiations on living cells and organisms, including physical, chemical, and physiological bases of radiation cytotoxicity, mutagenicity, and carcinogensis. Textbook: Radiobiology for the radiologist. Eric Hall and Amato Giaccia. Two lectures per week. Prerequisites: Graduate student standing and one year each of biology, physics and organic chemistry, or approval of instuctor
Credit 2 units.

E62 BME 5072 Radiation Therapy Physics
Ionizing radiation use in radiation therapy to cause controlled biological effects in cancer patients. Physics of the interaction of the various radiation modalities with body-equivalent materials, and physical aspects of clinical applications. Lecture and Lab. Prerequisites: Graduate student standing or permission of instructor.
Credit 3 units.

E62 BME 519 Advanced Cognitive, Computational, and Systems Neuroscience
This course will develop critical thinking and analysis skills with regard to topics in Cognitive, Computational and Systems Neuroscience. A focus of the course will be aimed toward quantitative literacy, statistical methodology, and experience with the tools and best practices needed to conduct state-of-the-art research in modern studies of brain and behavior. Particular topics include machine learning, Big Data, reproducibility, equitable research and scientific visualization. Students will be provided with foundational and theoretical tools to ensure maximal scientific rigor in their own research by enabling them to think carefully about core issues in experimental design, and about key challenges and controversies that arise in relation to hypothesis testing, statistical inference and data management. Prerequisites: graduate standing or permission of the instructor.
Credit 3 units.

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 will introduce the principles of biomaterials science, unifying knowledge from the fields of biology, materials

science, surface science, and colloid science. The course will be taught from the primary scientific literature, focusing on the study of protein/surface interactions and hydrogel materials. E37 MEMS 3610 OR MEMS 3601 OR permission of instructor
Credit 3 units. EN: TU

E62 BME 528 Translational Regenerative Medicine
This course provides students with an opportunity to connect basic research with applications in translation for several tissues/disease models. Course sessions will alternate between literature on basic mechanisms of development/stem cell biology and applications led by researchers or clinicians working in each area. Areas of focus will include cardiovascular development/congenital heart disease and arrhythmia, lung, endocrinology/diabetes, gut/intestinal disorders, musculoskeletal, neural (peripheral and brain), liver, hematology, and eye. Emphasis on how discovery can be translated will be a major focus of the course. Students will be expected to review and present on primary literature in the field. Graduate Standing is required. Prerequisites: Graduate Standing Engineering or DBBS
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. It 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; and the cytoskeleton, the extracellular matrix, and cell movement. Emphasis will be placed on examples relevant to biomedical engineering. In addition to lecture material, a focus will be placed on understanding the experimental techniques used in cell biology and the critical analysis of primary literature. Note that this course does not count for engineering topics credits and that it is meant to fulfill a life science requirement for engineering or physical sciences graduate students. Prerequisites: Biol 2960 and Biol 2970 or graduate standing.
Credit 3 units.

E62 BME 532 Physics of Biopolymers and Bioinspired Polymers
This course will cover physics concepts from the statistical physics of polymers and polymer solutions to describe proteins, nucleic acids, and bioinspired polymers. Topics include statistical physics concepts, theoretical and numerical descriptions of polymers, applying these descriptions to biopolymers, the thermodynamics of polymer solutions, concepts of polymer dynamics, descriptions of polymeric materials and advanced topics in phase transitions and molecular design. The material will be fast-paced and involve rigorous mathematical descriptions, experimental design, interpretations of experimental data, and some numerical simulations. The course will be heavy on individual homework and team-based project work. Direct connections between concepts and modern topics in biology and biomaterials will be emphasized. Prerequisites: BME 320B or equivalent and a first course in transport phenomena.
Same as E62 BME 432
Credit 3 units. EN: TU

E62 BME 533 Biomedical Signal Processing
This course is designed for graduate students with little or no background in biomedical signal processing, with an emphasis on time- and frequency-domain analyses of biomedical signals and their applications to a variety of real-world biomedical problems. Technical topics of this course include a review of linear signals and systems theory, biomedical system modeling, time-domain analysis, frequency transforms, frequency-domain analysis, linear filter design, signal truncation and sampling, discrete Fourier transform, and fast Fourier transform. Application topics include noise analysis of biomedical signals and frequency analysis and machine learning in biomedical image processing. Concepts learned in class will be applied using software tools to biomedical signals such as biological rhythms, EMG, ECG, EEG, and biomedical images. Prerequisites: graduate standing or consent of instructor.
Credit 3 units. EN: TU

E62 BME 537 Computational Molecular Biology
This course is a survey of algorithms and mathematical methods in biological sequence analysis (with a strong emphasis on probabilistic methods) and systems biology. Sequence analysis topics include introduction to probability, probabilistic inference in missing data problems, hidden Markov models (HMMs), sequence alignment, and identification of transcription-factor binding sites. Systems biology topics include the mapping of gene regulatory networks, quantitative modeling of gene regulatory networks, synthetic biology, and applications of deep learning in computational biology. Prerequisite: CSE 131 or CSE 501N.
Same as E81 CSE 587A
Credit 3 units. EN: BME T, TU

E62 BME 538 Cell Signal Transduction
This course will cover the elements of cell signal transduction important to human development, homeostasis and disease. Lectures will be combined with primary literature review to cover canonical signaling and current topics within the field. Spatial, time and dose-dependent aspects of signaling will be 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. Prerequisite: BME 530A or BME 5068.
Credit 3 units.

E62 BME 5401 Biomedical Data Science
This course will cover data analysis, statistical methods, AI, machine learning, predictive modeling, and data visualization, with applications to medicine and health. As part of the course, BME faculty will present biomedical data science topics from their research areas. Students will learn to prepare, transform, visualize, validate, model, and communicate information about datasets, and they will design and implement an independent project to address a biomedical data science problem. Prior Python experience required. Prerequisites: E35 ESE 318, E35 ESE 326, (E62 BME 231 or E81 CSE 217A), or equivalent courses
Same as E62 BME 440
Credit 3 units. EN: TU

E62 BME 542 Biomacromolecules Design and Engineering
Biological macromolecules (i.e., carbohydrates, lipids, proteins, and nucleic acids) are important components of the cell and its supporting matrix that perform a wide array of functions. This course will introduce the principles and recent advances in nucleic acid/gene engineering, protein/peptide engineering, and chemical/enzymatic conjugation technologies; it will also discuss the application of engineered biomacromolecules in clinical therapeutics/diagnostics, biosensing, bioimaging, and biocatalysis. Students will learn material through lectures, reading, homework, scientific publications, and molecular visualization tools. Students will work individually or in pairs/groups to develop and lead discussions on engineering biomacromolecules and molecular characterization techniques. Prerequisite: Basic knowledge of genes and cloning.
Same as E62 BME 442
Credit 3 units. EN: TU

E62 BME 543 Molecular and Cellular Engineering
The ability to engineer biological function at the cellular level holds tremendous potential for both basic and applied science. This course aims to provide knowledge and practical proficiency in the methods available for measuring and controlling the molecular organization of eukaryotic cells. Topics to be covered include genome engineering using viral- and CRISPR-Cas systems; spatial and temporal control of proteins and their interactions; methods for characterizing and engineering post-translational modifications; and the relationship between cellular organization and function in migration, immune cell target recognition, and differentiation. Examples from recent scientific literature will provide the foundation for these topics.
Same as E62 BME 443
Credit 3 units. EN: TU

E62 BME 5430 Systems Analysis of Biological Signaling
This course covers biochemical and computational methods of cellular signaling pathway analysis. Topics include kinetics, differential equations, and sensitivity analysis, with emphasis on cellular and molecular vascular signaling in health and disease. Prerequisites: Biol 2960 and Math 217.
Credit 3 units. EN: TU

E62 BME 544 Biomedical Instrumentation
This course will include operational and instrumentation amplifiers for bioelectric event signal conditioning, interfacing and processing; instrumentation noise analysis and filter design; A/D converters and hardware and software principles as related to sampling, storing, processing, and display of biosignals; modeling, analysis, and operation of transducers, sensors, and electrodes, for physiological and imaging systems; and an introduction to ultrasound, X-ray, and optical imaging systems. In addition, students will be involved in three projects of designing and building instrumentation amplifier and filter systems, ultrasound systems, and optical systems. Prerequisites: BME 301A and BME 301B.
Same as E62 BME 444
Credit 3 units. EN: TU

E62 BME 5501 Translational Neuroengineering
This course focuses on the design of bioelectric devices for use in clinical patients. Neural stimulators (e.g., deep brain, vagal) will be the basis for a case-study approach to designing and developing new bioelectrical medical devices. This project-based course will introduce the student to the use of finite element solvers to design novel stimulators. In addition to the engineering design aspects, issues such as product liability, FDA approval, and so on will be discussed. Prerequisite: BME 471
Credit 3 units. EN: TU

E62 BME 5565 Mechanobiology of Cells and Matrices
At the interface of the cell and the extracellular matrix, mechanical forces regulate key cellular and molecular events that profoundly affect aspects of human health and disease. This course offers a detailed review of biomechanical inputs that drive cell behavior in physically diverse matrices. In particular, cytoskeletal force-generation machineries, mechanical roles of cell-cell and cell-matrix adhesions, and regulation of matrix deformations are discussed. Also covered are key methods for mechanical measurements and mathematical modeling of cellular response. Implications of matrix-dependent cell motility in cancer metastasis and embryonic development are discussed. Prerequisite: graduate standing or permission of the instructor
Same as E37 MEMS 5565
Credit 3 units. EN: TU

E62 BME 559 Intermediate Biomechanics
This course covers several of the fundamental theories of solid mechanics that are needed to solve problems in biomechanics. The theories of nonlinear elasticity, viscoelasticity, and poroelasticity are applied to a large range of biological tissues including bone, articular cartilage, blood vessels, the heart, skeletal muscle, and red blood cells. Other topics include muscle activation, the biomechanics of development and functional adaptation, and the mechanics of hearing. Prerequisites: BME 240 and ESE 318 and ESE 319 or equivalent, or permission of instructor.
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. Prerequisites: BME 240 or equivalent. Note: BME 590Z (463/563) Orthopaedic Biomechanics--Bones and Joints is NOT a prerequisite.
Same as E37 MEMS 5564
Credit 3 units. EN: TU

E62 BME 5642 Human-Machine Interfaces
This course will provide an overview of neurorehabilitation technologies for individuals with neuromotor disorders. Topics will include the neurophysiology of human motor and sensory systems, motor control and adaptation, and neuroplasticity in the damaged brain and spinal cord. Human-machine interface systems including prostheses, orthoses and exoskeletons, wheelchairs, neuroprosthetics, brain-machine interfaces, and wearable robots will be discussed with an emphasis on their clinical applications for restoration of motor and sensory functions. Lecture material and assignments will draw from current scientific literature and research. All students will be placed on a waitlist. Registration will be split between undergraduate and graduate students. Prerequisite: BME 301 Quantitative Physiology I or equivalent introductory physiology course preferred.
Same as E62 BME 4642
Credit 3 units. EN: BME T, TU

E62 BME 565 Biosolid Mechanics
Introduction to the mechanical behaviors of biological tissues of musculoskeletal, cardiac and vascular systems. Topics to be covered include static force analysis and nonlinear optimization theory; linearly elastic models for stress-strain analysis and solutions to relevant problems in bioelasticity; models of active structures (e.g., muscles); strain energy methods and nonlinear tissue behaviors; and introductory theory for finite element analysis. Emphasis will be placed on modeling stress-strain relations with relevance to biological tissues. Prerequisites: BME 240 or equivalent and ESE 318 and ESE 319.
Same as E62 BME 465
Credit 3 units. EN: TU

E62 BME 569 Cardiac Electrophysiology
This course is an introduction to cardiac electrophysiology with an emphasis on arrhythmia mechanisms, experimental methods, and clinical applications. Topics will include modeling of cardiac arrhythmias, mapping of cardiac electric activity, pacemakers and defibrillators, and ablation of cardiac tissue.
Same as E62 BME 469
Credit 3 units. EN: TU

E62 BME 570 Mathematics of Imaging Science
This course will expose students to a unified treatment of the mathematical properties of images and imaging. This will include an introduction to linear vector space theory, operator theory on Hilbert spaces, and concepts from applied functional analysis. Further, concepts from generalized functions, Fourier analysis, and radon transform will be discussed. These tools will be applied to conduct deterministic analyses of imaging systems that are described as continuous-to-continuous, continuous-to-discrete, and discrete-to-discrete mappings from object properties to image data. In addition, imaging systems will be analyzed in a statistical framework where stochastic models for objects and images will be introduced. Familiarity with Engineering-level mathematics, Calculus, Linear algebra, introduction to Fourier analysis is expected. Prerequisite: Senior standing or permission of instructor.
Credit 3 units.

E62 BME 572 Biological Neural Computation
This course will consider 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 & 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 L41 5657 for three credits. For non-BME majors, conceptual understanding, and selection/application of right neural data analysis technique will be stressed. Hence homework assignments/examinations for the two sections will be 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. L41 5657 prerequisites: Permission from the instructor
Credit 3 units. EN: TU

E62 BME 5735 Biomedical Engineering Entrepreneurship
Students will learn about entrepreneurship, including IP, business development, and fundraising, through case studies.
Same as E62 BME 4735
Credit 3 units.

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 will be discussed to illustrate the current understanding. Prerequisites: Knowledge of differential equations, electrical circuits, and chemical kinetics.
Credit 3 units. EN: TU

E62 BME 5771 Biomedical Product Development
Advances in science and technology have opened the healthcare field to innovation now more than any other time in history. Engineers and inventors can make real and rapid improvements to patient treatments, length of hospital stay, procedure time, cost containment, and accessibility to treatment. However, a successful transition from idea to implementation requires careful market analysis and strategy planning. This course will address the steps in this process, including personal and team strength assessement, medical need validation, brainstorming initial solutions, market analysis, solution evaluation, regulatory, patent, and intellectual property concerns, manufacturability, risk assessment and mitigation, and global considerations. Students will be expected to review resource material prior to coming to class in order to facilitate active class discussion and team-based application of the material during class; regular attendance will be key to course success. The course will focus on applying product development techniques to several real unmet medical needs; students will thus perform analysis and create reports and presentations for several different product solutions. Peer and faculty evaluations will provide feedback to improve individual technique. In addition, throughout the semester, local biomedical entrepreneurs will visit to share their expertise and experiences. Prerequisites: Graduate or professional student standing or permission of the instructor.
Credit 3 units.

E62 BME 5772 Biomedical Business Development
For medical innovators, a successful translation from product to market will require careful strategy and an understanding of the steps needed to form and fund a biotech business, either as a new startup or as an extension of the product line of an existing company. This course will address the steps in this process, including intellectual property concerns, R&D, clinical strategy, regulatory issues, quality management, reimbursement, marketing strategy, sales and distribution, operating plans, and approaches to funding. Prerequisites: Graduate or professional student standing or permission of the instructor.
Credit 3 units.

E62 BME 5780 Engineering for Women's Health
Engineering approaches have many uses in improving women's health, from basic science understanding through to clinical implementation. This course will start with an overview of female reproductive anatomy and physiology and continue with case studies from different engineering sub-fields as applied to women's health. Students will complete case studies and one in-depth project on women's health engineering topics.
Same as E62 BME 4780
Credit 3 units. EN: TU

E62 BME 579 Biofabrication & Medical Devices
This course will cover materials design and modern manufacturing methods for biofabricated tissues and medical devices (with a particular emphasis on bioelectronic devices). Topics will include additive manufacturing and their materials requirements along with how these methods have evolved to use biomaterials and cells, such as bioprinting. State-of-the-art in vitro and implantable devices for diagnostic and therapeutic purposes will be discussed with emphasis on how their properties have advanced from developments in materials and manufacturing. Lecture material and assignments will draw from both current market devices and the clinical standard-of-care as well as ongoing research and recent scientific literature. All students will be placed on a waitlist. Registration will be split between undergraduate and graduate students. Prerequisite: E62 BME 523 or equivalent biomaterials introductory course
Same as E62 BME 479
Credit 3 units. EN: TU

E62 BME 5799 Independent Study for Candidates in the Master of Engineering Program
Independent investigation on a topic of special interest. The student and mentor must justify the requested number of units. The MEng Program Director must approve the requested number of units.
Credit variable, maximum 6 units.

E62 BME 5820 Fundamentals and Applications of Modern Optical Imaging
Analysis, design, and application of modern optical imaging systems with emphasis on biological imaging. First part of course will focus on the physical principles underlying the operation of imaging systems and their mathematical models. Topics include ray optics (speed of light, refractive index, laws of reflection and refraction, plane surfaces, mirrors, lenses, aberrations), wave optics (amplitude and intensity, frequency and wavelength, superposition and interference, interferometry), Fourier optics (space-invariant linear systems, Huygens-Fresnel principle, angular spectrum, Fresnel diffraction, Fraunhofer diffraction, frequency analysis of imaging systems), and light-matter interaction (absorption, scattering, dispersion, fluorescence). Second part of course will compare modern quantitative imaging technologies including, but not limited to, digital holography, computational imaging, and super-resolution microscopy. Students will evaluate and critique recent optical imaging literature. Prerequisites: ESE 318 and ESE 319 or their equivalents; ESE 330 or PHY 421 or equivalent.
Same as E35 ESE 582
Credit 3 units. EN: TU

E62 BME 589 Biological Imaging Technology
This class will develop 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 will examine 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 will examine image decomposition using basis functions (e.g. Fourier transforms), synthesis of measurement data, image analysis for feature extraction, reduction of multi-dimensional 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 will be critiqued.
Same as E35 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. Prerequisite: Permission of Instructor
Credit 3 units. EN: BME T, TU

E62 BME 5902 Cellular Neurophysiology
This course will examine 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 will be devoted to modern electrophysiological and imaging techniques, and modeling approaches to study synapses and neural circuits. Prerequisite: Senior or graduate standing.
Credit 3 units. EN: TU

E62 BME 591 Biomedical Optics I: Principles
This course covers the principles of optical photon transport in biological tissue. This course covers the principles and applications 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, diffusion theory and applications, sensing of optical properties and spectroscopy, and photoacoustic imaging principles and applications. Prerequisite: Familiarity with Differential equations and partial differential equations
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 will 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.

E62 BME 5915 Journal Club in Neuroengineering
Classic papers on neuroscience topics including membrane excitability, synaptic transmission and signaling will be discussed by students and the instructor. The course is designed to bring graduate students with engineering, computational, and biological background to the bases of translational neuroscience and neurotechnology.
Credit 1 unit.

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: L24 Math 217; E62 BME 591
Credit 3 units. EN: BME T, TU

E62 BME 594 Ultrasound Imaging
Ultrasound imaging is the most widely used medical imaging modality in the world. This course offers an introduction to the medical ultrasound field. It exposes students to fundamental physical principles of ultrasound, ultrasound imaging, and ultrasound therapy. It will also introduce emerging ultrasound technologies in industry and clinics. Students will learn via lectures, homework, lab exercises, and a final project to gain knowledge, learn the ability to think critically, and develop problem-solving skills.
Same as E62 BME 494
Credit 3 units. EN: TU

E62 BME 595 Drug Delivery Systems: Principles and Applications
Drug delivery is a promising approach for transporting pharmaceutical treatments in the body to safely achieve the desired therapeutic effect, while reducing the undesired side effects. This course will introduce students to the fundamental concepts of drug pharmacokinetics and dynamics, the biological and physiochemical principles drug delivery systems are based on, and the advantages of such delivery systems. Additionally, we will introduce the design and development of advanced drug delivery platforms such as nano-carriers, cell/

gene delivery systems, drug-polymer conjugates and their relevant clinical applications. Finally, we will be having guest speakers from the industry, the university, as well as the office of technology management for Interdisciplinary Innovation & Entrepreneurship.
Credit 3 units.