Biomedical Engineering

Modern biomedical engineers face a far different world than those trained even two decades ago.

Explosive advances in our ability to probe and understand molecular and cellular processes and their interconnections now make it imperative that the powers of engineering be brought to bear at ever smaller, as well as at systemwide, levels. This will not only produce new discoveries at the most fundamental levels but also accelerate the translation of these discoveries into practical applications.

Our vision is that future leaders and lasting impact will arise from successfully integrating engineering concepts and approaches across molecular to whole-body levels. Moreover, those also trained to integrate the analytical, modeling and systems approaches of engineering to the complex and, sometimes overwhelming, descriptive details of biology will be uniquely positioned to address new and exciting opportunities. We are committed to educating and training the next generation of biomedical engineers with this vision in mind.

At Washington University, world-class biological, engineering and medical research — along with top-notch, state-of-the-art health care — are closely intertwined. For more than 50 years, collaborations between the School of Medicine and the School of Engineering & Applied Science have led to major advances in many areas including: positron emission tomography, medical applications of ultrasound, application of computers to hearing research, and development of heart valve flow simulators. Since the establishment of the Department of Biomedical Engineering in 1997, this atmosphere of collaboration and collegiality between the two schools has been further strengthened and expanded, leading to an exceptional degree of synergy that is one of our hallmarks. All of our core faculty have been hired since 1997 and comprise a young, dynamic and still-expanding group.

The core faculty, together with over 70 affiliated faculty from other departments form a network of mentors dedicated to training the next generation of biomedical engineers. Our goal is to educate students in an interdisciplinary manner so that they can effectively collaborate with physicians, biologists and other life scientists to build their careers. Students can elect to perform their research with any member of the network.

The commitment and diverse talent of these faculty provide a vast array of choices to enable students to refine their unique quantitative and analytical engineering skills and apply them to relevant biomedical problems. As a result, our graduates are well-equipped to work in multidisciplinary teams tackling cutting-edge and high impact problems of modern biomedical engineering.

Admissions Information

Please visit the Biomedical Engineering website (https://bme.wustl.edu/Pages/default.aspx) for admissions information.

Contact Information

Email: bme@seas.wustl.edu
Website: https://bme.wustl.edu/graduate

Degrees & Requirements

For more information about our graduate degrees, please visit the Biomedical Engineering (http://bulletin.wustl.edu/grad/engineering/biomedical) pages of the School of Engineering & Applied Science Graduate Programs Bulletin.

Research

Areas of Research

Health care problems posed by complex diseases present the most daunting challenges for modern society. These diseases include cancer, injuries to physiological systems, and disorders associated with embryonic development, aging and the adaptive immune system.

Our vision is that advances in the diagnosis and treatment of complex diseases will require integrative and multiscale engineering approaches to biology and biomedical sciences. The BME department faculty will produce advances in basic science, enabling technologies and multiscale systems science approaches that will provide a more holistic understanding of the spatiotemporal responses of biomolecular and cellular networks that give rise to the onset and progression of such diseases and the propagation of injuries.

This will involve an integrative approach with a synergistic focus on development, regeneration and degeneration of cells and tissues, and will be leveraged to transform the development of novel biomaterials, drugs and biomedical devices for diagnosis and treatment.

Biomedical & Biological Imaging (BBI)

This program seeks to bring the most innovative technology — whether it be next-generation hardware, multiple modalities, advanced image reconstruction or signal-processing methods, new contrast agents or novel applications — to bear on important basic science and clinical issues. Our goal is to develop new technologies to complement the already strong research and clinical imaging activities in our community.

Cancer Technologies (CT)

Cancer Technologies seeks to enhance our understanding and treatment options for cancer using the latest methods and approaches in engineering. The broad goals of Cancer Technologies are to apply the latest engineering methods and techniques (imaging, microfluidics, optogenetics) to enhance
understanding and therapy for cancer. Faculty working in this area seek to understand how cancer metastasizes by examining how cells migrate through tissue, enter the circulation, and exit at distant sites (lung, brain, liver, bone). In addition, faculty seek to develop novel imaging methods (ultrasound, photoacoustic) that can detect cancer at earlier stages, as well as provide information on the functional or metabolic state of the cancer.

**Cardiovascular Engineering (CVE)**

Cardiovascular disease is the number one cause of death and disability in the developed countries. Cardiovascular Engineering encompasses a multidisciplinary effort to improve our understanding of cardiovascular disease and develop better therapies. This program seeks to develop new methods to study, diagnose and treat cardiovascular diseases. Examples include understanding how molecules control the heartbeat, imagining the electrical potential at the surface of the heart, engineering cardiac tissues, and creating mathematical models to connect heart function to its nanoscale molecular foundation.

**Molecular & Cellular Systems Engineering (MCSE)**

The molecular and cellular networks that compose cells and tissues fundamentally determine the emergent properties that shape the physiology of healthy organs and pathological tissues that cause diseases, like neurodegeneration and cancer. Their complexity requires novel and integrated approaches that span scales, ideas and techniques. Pushing the boundary of knowledge in the direction of understanding molecular, cellular, and tissue systems will allow us to gain the insight required to build better therapies. This program seeks to develop innovative approaches for treating disease by manipulating molecules, cells or systems. For example, diseases associated with misfolded proteins, such as Alzheimer’s and Huntington’s, could be treated by understanding and eventually modifying how proteins fold into their complex three-dimensional, functional configurations. Better understanding of most biological processes is likely to depend upon systemwide approaches at all levels.

**Neural Engineering (NE)**

Neural Engineering research involves fundamental and applied studies related to neurons, neural systems, behavior and neurological disease. This program involves fundamental and applied studies related to neurons, neural systems, behavior and neurological disease encompassing a spectrum of activities, including mathematical modeling; exploring novel approaches to sensory (vision, hearing, smell and touch) and motor processing; exploring fundamentals of neural plasticity; and designing neuroprosthetics. The approaches involve information processing at the molecular, cellular, systems and behavioral levels.

**Orthopedic Engineering (OE)**

Orthopedic Engineering combines principles of tissue engineering, cell biology, and biomechanics to generate new knowledge of bone and soft tissue biology and develop novel therapies to treat musculoskeletal disease. This program seeks to understand the mechanical and material properties of bone and soft tissues (muscle, cartilage) and to exploit biomaterial and cellular processes to mediate injury responses and promote regeneration. Computational models play a significant role in the design of and development of new experimental methods and protocols.

**Regenerative Engineering in Medicine (REM)**

Regenerative Engineering in Medicine combines cell and molecular biology, cell biophysics and engineering methods to understand and control the organization and function of tissues. This program seeks to determine the fundamental principles regulating growth and remodeling in natural and engineered tissues. The result will be a better understanding of normal growth processes and the responses of cells, tissues and organisms to disease and trauma. This knowledge will be applied to the development of materials that promote healing and the regeneration of functional tissues.

**Faculty**

**Chair**

Lori A. Setton (https://engineering.wustl.edu/Profiles/Pages/Lori-Setton.aspx)
Lucy and Stanley Lopata Distinguished Professor of Biomedical Engineering
PhD, Columbia University

**Endowed Professors**

Rohit V. Pappu (https://engineering.wustl.edu/Profiles/Pages/Rohit-Pappu.aspx)
Edwin H. Murty Professor of Engineering
PhD, Tufts University
Macromolecular self assembly and function; computational biophysics

Yoram Rudy (https://engineering.wustl.edu/Profiles/Pages/Yoram-Rudy.aspx)
Fred Saigh Distinguished Professor of Engineering
PhD, Case Western Reserve University
Cardiac electrophysiology; modeling of the cardiac system

Frank Yin (https://engineering.wustl.edu/Profiles/Pages/Frank-Yin.aspx)
Stephen F. and Camilla T. Brauer Distinguished Professor of Biomedical Engineering
MD, PhD, University of California, San Diego
Tissue and cell biomechanics; hemodynamics
**Professors**

Mark Anastasio ([https://engineering.wustl.edu/Profiles/Pages/Mark-Anastasio.aspx](https://engineering.wustl.edu/Profiles/Pages/Mark-Anastasio.aspx))
PhD, University of Chicago
Imaging sciences; phase-contrast; x-ray imaging

Jianmin Cui ([https://engineering.wustl.edu/Profiles/Pages/Jianmin-Cui.aspx](https://engineering.wustl.edu/Profiles/Pages/Jianmin-Cui.aspx))
PhD, State University of New York–Stony Brook
Ion channels; channel structure-function relationship; biophysics

Daniel Moran ([https://engineering.wustl.edu/Profiles/Pages/Daniel-Moran.aspx](https://engineering.wustl.edu/Profiles/Pages/Daniel-Moran.aspx))
PhD, Arizona State University
Motor control; neural engineering; neuroprosthetics; movement biomechanics

Quing Zhu ([https://engineering.wustl.edu/Profiles/Pages/Quing-Zhu.aspx](https://engineering.wustl.edu/Profiles/Pages/Quing-Zhu.aspx))
PhD, University of Pennsylvania
Biophotonics and multimodality ultrasound and optical imaging

**Assistant Professors**

Jan Bieschke ([https://engineering.wustl.edu/Profiles/Pages/Jan-Bieschke.aspx](https://engineering.wustl.edu/Profiles/Pages/Jan-Bieschke.aspx))
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 ([https://engineering.wustl.edu/Profiles/Pages/Hong-Chen.aspx](https://engineering.wustl.edu/Profiles/Pages/Hong-Chen.aspx))
PhD, University of Washington
Physical acoustics; therapeutic ultrasound and ultrasound imaging

Nate Huebsch ([https://bme.wustl.edu/faculty/Pages/default.aspx](https://bme.wustl.edu/faculty/Pages/default.aspx))
PhD, Harvard University
Joining January 2018

Kristen Naegle ([https://engineering.wustl.edu/Profiles/Pages/Kristen-Naegle.aspx](https://engineering.wustl.edu/Profiles/Pages/Kristen-Naegle.aspx))
PhD, Massachusetts Institute of Technology
Computational systems biology with emphasis on cellular networks involved in cancer and diabetes

Jon Silva ([https://engineering.wustl.edu/Profiles/Pages/Jonathan-Silva.aspx](https://engineering.wustl.edu/Profiles/Pages/Jonathan-Silva.aspx))
PhD, Washington University
Ion channel biophysics

Michael D. Vahey ([https://bme.wustl.edu/faculty/Pages/default.aspx](https://bme.wustl.edu/faculty/Pages/default.aspx))
PhD, Massachusetts Institute of Technology
Joining March 2018

**Associate Professors**

Dennis L. Barbour ([https://engineering.wustl.edu/Profiles/Pages/Dennis-Barbour.aspx](https://engineering.wustl.edu/Profiles/Pages/Dennis-Barbour.aspx))
MD, PhD, Johns Hopkins University
Auditory physiology; sensory cortex neurocircuitry; novel perceptual diagnostics and therapeutics

Vitaly Klyachko ([https://engineering.wustl.edu/Profiles/Pages/Vitaly-Klyachko.aspx](https://engineering.wustl.edu/Profiles/Pages/Vitaly-Klyachko.aspx))
PhD, University of Wisconsin-Madison
Synaptic function and plasticity; neural circuits; information analysis; neurological disorders

Baranidharan Raman ([https://engineering.wustl.edu/Profiles/Pages/Barani-Raman.aspx](https://engineering.wustl.edu/Profiles/Pages/Barani-Raman.aspx))
PhD, Texas A&M University
Computational and systems neuroscience; neuromorphic engineering; pattern recognition; sensor-based machine olfaction

Jin-Yu Shao ([https://engineering.wustl.edu/Profiles/Pages/Jin-Yu-Shao.aspx](https://engineering.wustl.edu/Profiles/Pages/Jin-Yu-Shao.aspx))
PhD, Duke University
Cell mechanics; receptor and ligand interactions; molecular biomechanics

**Senior Professors**

Larry Taber ([https://bme.wustl.edu/faculty/Pages/faculty.aspx?bio=19](https://bme.wustl.edu/faculty/Pages/faculty.aspx?bio=19))
PhD, Stanford University
Mechanics of growth and development; cardiac mechanics

**Lecturers**

Noah Ledbetter ([https://bme.wustl.edu/faculty/Pages/default.aspx](https://bme.wustl.edu/faculty/Pages/default.aspx))
PhD, University of Utah

Patricia Widder ([https://bme.wustl.edu/faculty/Pages/default.aspx](https://bme.wustl.edu/faculty/Pages/default.aspx))
MS, Washington University

**Courses**

Below are all BME graduate-level courses. Visit online course listings to view semester offerings for E62 BME (https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E62&crslvl=5:8).
E62 BME 501C BME Doctoral Seminar Series
This is a 1-unit 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. Prerequisites: Students must be current BME students in their second year and beyond in order to register. 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 E35 ESE 596 Credit 1 unit.

E62 BME 507 Radiological Physics and Dosimetry
This class is designed to construct a theoretical foundation for ionizing radiation dose calculations and measurements in a medical context and prepare graduate students for proper scientific presentations in the field of x-ray imaging and radiation therapy. Specifically, a student completing this course will be able to do the following: 1. Understand and apply key concepts specific to energy deposition for both ionizing photon interactions and transport in matter and for energetic charged particle interactions and transport in matter. Radiation sources include radioactivity, x-ray tubes, and linear accelerators. 2. Understand the theoretical details of ion-chamber based dosimetry and of both cavity-theory based (TG-21) and Monte-Carlo based (TG-51) clinical protocols. 3. Perform and present real-world style research projects as a group, and present these projects in a typical professional scientific format and style. 4. Achieve an appreciation of the history and potential future developments in ionizing radiation detection and dosimetry. Prerequisites: BS in physics or engineering and instructor approval. Credit 3 units.

E62 BME 5071 Radiobiology
Effects of ionizing radiations on living cells and organisms, including physical, chemical, and physiological bases of radiation cytotoxicity, mutagenicity and carcinogenesis. 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 instructor. Credit 2 units.

E62 BME 5073 Radiation Protection and Safety
This course will introduce concepts of radiation protection and safety. The focus will be on how to protect humans and environment from ionizing radiation. Special emphasis will be on radiological protection in clinics. Prerequisite: graduate student standing or permission of the instructor. 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 will be introduced as well as their respective clinical applications. Prerequisites: BME 366; or MEMS 3410, Biol 2960 and 2970; or permission of the instructor. 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 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. 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.
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 will be 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 will be applied using software tools to 1D biomedical signals such as biological rhythms, chemical concentrations, blood pressure, speech, EMG, ECG, EEG. Prerequisites: graduate standing or consent of instructor. Credit 4 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), profile HMMs, sequence alignment, and identification of transcription-factor binding sites. Systems biology topics include discovery of gene regulatory networks, quantitative modeling of gene regulatory networks, synthetic biology, and (in some years) quantitative modeling of metabolism. Prerequisite: CSE 131 or CSE 501N. Same as E81 CSE 587A. Credit 3 units.

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 juxtagraine signaling. Prerequisites: BME 530A or BME 508B. Credit 3 units.

E62 BME 550 Numerical Methods for Computational Modeling in Biomedicine
Advanced computational methods are required for the creation of biological models. Students will be 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 will 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 will be helpful. Students enrolled in the 550 graduate class will be required to complete a final project that incorporates the methods taught in class. Prerequisites: introductory programming course similar to E81 CSE 131. Same as E62 BME 450. 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 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. Two-thirds of the course will consist of lectures; the other third will be 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. Same as E62 BME 461. Credit 3 units. EN: TU

E62 BME 562 Mechanics of Growth and Development
This course applies the fundamental principles of solid mechanics to problems involving growth, remodeling and morphogenesis of cells, tissues and organs. Introduction to developmental biology, nonlinear elasticity, viscoelasticity and active contraction. Particular topics include cellular morphogenetic mechanisms, growth and development of the cardiovascular system, and adaptive remodeling of bone. Prerequisites: BME 240 or MEMS 241 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. Same as E37 MEMS 5564 Credit 3 units. EN: 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 5702 Application of Advanced Engineering Skills for Biomedical Innovators
Students will work in small teams to apply core engineering skills covered in BME 5701 such as FEM, CAD, microcontroller programming, circuit design, data informatics, and app development to particular clinical needs or processes chosen by the instructing staff. Prerequisites: BME 5701 or permission of instructor. Credit 3 units.

E62 BME 5711 Ideation of Biomedical Problems and Solutions
This course is part one of the year-long master's design sequence for the BME Master of Engineering. The course will begin with a boot camp primer of HIPAA certification, clinical etiquette, medical law, and intellectual property law. This will be followed by a rotation period of guided shadowing of clinicians. Following each rotation, students will review and present their findings, with a view toward problem solving and project generation. Three-fourths of the way through the course, students will form into teams, choose a master's project, and begin intensive study of their chosen problem or process. The final weeks of the course will focus on problem scope and definition, identification of creative alternatives, and consultation with experts in the field. Prerequisite: acceptance into the Master of Engineering program. Credit 3 units.

E62 BME 5712 Implementation of Biomedical Solutions
This course is part two of the year-long master's design sequence for the BME Master of Engineering. Students will work in small groups to begin to design a solution to the problem identified in BME 5711. Options and alternatives will be evaluated and a best-choice solution will be chosen, based on an in-depth study of constraints upon the problem, including engineering materials, economic, safety, social, manufacturing, ethical, sustainability, and other requirements. Core skills such as FEM, CAD, circuit design, microcontroller programming, and 3-D printing will be applied to create first an alpha mockup for proof of concept, followed by a full working prototype by the end of the semester. Prerequisites: BME 5711 or permission of instructor. Credit 3 units.

E62 BME 5713 Translation of Biomedical Solutions to Products
This course is the third and final part of the year-long master's design course sequence. Through a repeated sequence of iteration, fabrication and verification, design teams will refine and optimize their master's design project, bringing it to completion. Prerequisites: BME 5712 or permission of instructor. Credit 4 units.

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 3 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: BME 240 or equivalent, and Bio 240 and/or BME 5701. Undergraduates need permission of the instructor. Credit 3 units. EN: TU

E62 BME 5722 Feasibility Evaluation of Biomedical Products
This is the second course of the Master of Engineering - Biomedical Innovation sequence in product development. Students will practice the steps in biomedical product development, including medical need validation, brainstorming initial solutions, market analysis, solution evaluation, regulatory, patent, and intellectual property concerns, manufacturability, risk assessment and mitigation, and global considerations. 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. Local biomedical entrepreneurs will also visit to share their expertise and experiences. Prerequisite: admission to the Master of Engineering program. Credit 2 units.

E62 BME 5723 Realization of Biomedical Products in the Marketplace
This course is the third in the MEng-BMI Biomedical Product Development sequence, focusing on the final stages of analysis to bring forth a leading solution concept. Solution
concepts are screened for killer risks in the areas of intellectual property, regulatory, reimbursement, business models, and technical feasibility to identify viable concepts. From there, manufacturability and product specifications are evaluated against user and design requirements to select a concept that offers the highest value with lowest risk. Throughout the course, students will practice effective communication of risk factors through pitch presentations and executive summary reports. In addition, specialists from the St. Louis entrepreneurial community will share their experiences as guest speakers. Prerequisites: BME 5722; MEng-BMI candidates only. Credit 1 unit.

E62 BME 5731 Business Foundations for Biomedical Innovators
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 provide a first look at 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: BME 5731; MEng-BMI candidates only. Credit 2 units.

E62 BME 5732 Entrepreneurship for Biomedical Innovators
This course will apply the concepts covered in BME 5731 in an interactive process that will provide practical experience. Topics of intellectual property, R&D, clinical strategy, regulatory issues, quality management, reimbursement, marketing strategy, sales and distribution, operating plans, and approaches to funding will be covered. Along with practical exercises, access to specialists and experts in these topics from the St. Louis entrepreneurial community will be provided as an integral part of the course. Prerequisites: BME 5731; MEng-BMI candidates only. Credit 2 units.

E62 BME 5734 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 5735 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 5737 Biomedical Product Development
Advances in science and technology have opened the health care 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 assessment, 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 5779 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 500 or Physics 421 or equivalent.
Same as E35 ESE 582
Credit 3 units. EN: TU

E62 BME 5903 Physical Methods for Biomedical Scientists
The course will introduce the spectrum of biophysical techniques used in biomedical sciences with a focus on advanced fluorescence spectroscopy. The first half of the course (January to spring break) will introduce 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, sub-diffraction microscopy. The second half of the course will be held as six 3 h block lab classes (Fridays 10 a.m.-1 p.m.) in which the students will 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 will be limited to nine students. Prerequisite: senior or graduate standing.
Same as E62 BME 493
Credit 3 units. EN: TU

E62 BME 593 Computational Methods for Inverse Problems
Inverse problems are ubiquitous in science and engineering, and form the basis for modern imaging methods. This course will introduce students to the mathematical formulation of inverse problems and modern computational methods employed to solve them. Specific topics covered will include regularization theory, compressive sampling, and a survey of relevant numerical optimization methods. The application of these methods to tomographic imaging problems will be addressed in detail.
Prerequisites: ESE 318, 319, 326, 351.
Same as E62 BME 493
Credit 3 units. EN: TU

**E62 BME 594 Ultrasound Imaging**
Introduce basic principles of ultrasound imaging, diagnostic ultrasound imaging system, clinical applications, and emerging technologies in industry. Prerequisite: ESE 351.
Same as E62 BME 494
Credit 3 units. EN: TU

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

**E62 BME 600 Doctoral Research**
Credit variable, maximum 12 units.

**E62 BME 601 Research Rotation for BME Doctoral Students**

**E62 BME 601C Research Rotation for BME Doctoral Students**
Credit 3 units.

**E62 BME 602 Teaching Assistantship - Basic**
This is a pass/fail course for the fulfillment of the basic teaching requirement which is required for the PhD degree. A form obtained from the BME department must be submitted to the instructor at the end of the semester for approval in order to receive a grade.

**E62 BME 603 Teaching Assistantship - Advanced**
This is a pass/fail course for the fulfillment of the advanced teaching requirement which is required for the PhD degree. A form obtained from the BME department must be submitted to their thesis mentor upon completion of requirements for approval in order to receive a grade.

**E62 BME 883 Master’s Continuing Student Status**