Biomedical Engineering

**BMEN 5375 (EECS 5375 and MECH 5308)** Introduction to Robotics (3 semester credit hours) Fundamentals of robotics, rigid motions, homogeneous transformations, forward and inverse kinematics, velocity kinematics, motion planning, trajectory generation, sensing, vision, and control. Prerequisites: ENGR 2300 and (EE 4310 or BMEN 4310 or MECH 4310) or equivalent. (2-3) Y

**BMEN 6201 (BMEN 7201)** Career Development Skills for Biomedical Engineers MS (2 semester credit hours) Biomedical Engineering as a field requires a wide range of skills not traditionally taught in the classroom or lab, including self-presentation, collaboration, and science communication. This course bridges this knowledge gap through interactive training and assignments, and helps students to develop a career plan to help guide them to the most useful experiences in their graduate and professional career to meet their diverse goals. (2-0) Y

**BMEN 6203 (BMEN 7203)** Research Skills for Biomedical Engineers MS (2 semester credit hours) This course will introduce students to the research skills necessary for a successful graduate research career. Students will go through the process of planning and conducting a hands-on research project that can serve as the basis of a manuscript submission. Through this process students will learn research design terminology, steps in the research process, how to conduct systematic literature reviews, articulate clear research questions, testable hypotheses, and evaluate strengths and weaknesses of published articles. (2-1) Y

**BMEN 6302 (EECS 6302 and MECH 6317 and SYSM 6302)** Dynamics of Complex Networks and Systems (3 semester credit hours) Design and analysis of complex interconnected networks and systems. Basic concepts in graph theory; Eulerian and Hamiltonian graphs; traveling salesman problems; random graphs; power laws; small world networks; clustering; introduction to dynamical systems; stability; chaos and fractals. (3-0) Y

**BMEN 6324 (EECS 6324 and MECH 6324)** Robot Control (3 semester credit hours) Dynamics of robots; methods of control; force control; robust and adaptive control; feedback linearization; Lyapunov design methods; passivity and network control; control of multiple and redundant robots; teleoperation. Prerequisite: EECS 6331 or MECH 6300 or SYSM 6307. (3-0) T

**BMEN 6331** Medical Device Regulations and Regulatory Strategy (3 semester credit hours) This course will offer students exposure to the core concepts of the global medical device regulatory framework and provide a foundation for the practical application of the "least burdensome approach". The focus of the course is to aid students in the actual application of the regulations so that students are equipped to not only understand the core concepts embedded within the regulations but also apply them in real world biomedical engineering scenarios. The course will include all elements of the total product life-cycle; from initial device design to initial market entry, sustaining activities, post-market activities, and the subsequent obsolescence of the device. Special focus will be placed upon the Medical Device Regulatory landscapes found in the US, Canada, European Union, Brazil, South Korea, Mexico, Australia, and Japan. Department consent required. (3-0) Y

**BMEN 6332** Healthcare and Biotechnology Landscapes (3 semester credit hours) This course will take a
systems biomedical engineering approach to examine the influence of the healthcare and medical device technology landscapes, laws and regulations on the innovation and commercialization processes for biomedical technologies. Students will build a strong understanding of healthcare and medical device business requirements through the introduction of a wide variety of topics relevant to commercializing technical medical innovations from multidisciplinary perspectives. Students will gain practical experience through the application of learned concepts in class projects and assignments related to biomedical engineering business strategy development, commercial execution, and operational sustainability. Prerequisite: **BMEN 6331. (3-0) Y**

**BMEN 6333** Quality Management Systems and Compliance (3 semester credit hours) A good Quality Management System (QMS) assures that products meet specifications efficiently and effectively to gain customer satisfaction, and as a result, gain profitability. This course will cover pre/post market QMS requirements and expectations of performance, best practices in QMS development, QMS evaluation for different audiences, the cost of poor quality, and the role this plays on how to meet customer satisfaction. This course will also engage students in quality system internal audits and regulatory external audit facilitation and negotiation, writing responses to allegations of non-conformance for the regulatory agencies, and the consequences that can be expected when regulatory enforcement ensues. Department consent required. (3-0) Y

**BMEN 6334** Ethical and Legal Clinical Trial Considerations (3 semester credit hours) This course will examine the historical events that influenced the existing federal regulations that guide clinical research as well as the current ethical codes and guidelines pertaining to the use of animals and humans as research subjects. Students will explore the framework and principles of Good Clinical Practice (GCP) as it relates to the roles and responsibilities of various stakeholders like the FDA, Investigator, Sponsor, IRB and the study subject. They will learn the main principles guiding the conduct of ethical research, the importance of transparency, balancing incentives for engineering innovation, adverse events management and determining and enforcing appropriate safety levels. This course will also cover the current reimbursement environment for clinical trials and its impact on clinical use of devices. Department consent required. Prerequisite: **BMEN 6331. (3-0) Y**

**BMEN 6335** Design for Human Use (3 semester credit hours) Medical device design must be controlled in a way that ensures its safety and fulfillment of its intended use. This course provides the engineering value of relevant regulation and guidance throughout the product life cycle and how that relates to product quality and ultimately, customer satisfaction. Students will learn how to evaluate and understand human needs as a basis for designing and engineering new technologies and the practical implementation of design controls, risk management, requirements engineering, transfer planning, configuration control, and records. Department consent required. Prerequisite: **BMEN 6331. (3-0) Y**

**BMEN 6336** Regulatory Strategy and Submission (3 semester credit hours) Through interactive lectures and facilitated group projects, students gain an understanding of the regulatory pathways and how to develop and use a regulatory strategy to overcome barriers to entry in the medical device market. This course provides hands-on experience working with the regulations, guidance documents, and tools needed to develop an effective regulatory submission, including how to integrate regulatory strategy with product development and design control activities. This course will include U.S. regulatory pathways and a comparison to OUS pathways and evaluate the benefits of using a STED submission for global registrations. Prerequisite: **BMEN 6331. (3-0) Y**
BMEN 6337 Good Manufacturing Practices (3 semester credit hours) This course introduces students to the regulatory requirements and best practices for medical device good manufacturing practices. A wide range of engineering topics are taught that will expose students to the core concepts and deliverables in manufacturing engineering. Students will gain practical experience through the application of learned concepts in class projects and assignments related to engineering design and its manufacturing process development, planning, control, and improvement. Students will understand the influence of manufacturing throughout the regulated product lifecycle and learn to think critically and holistically when determining how to establish medical device manufacturing processes. Department consent required. Prerequisites: BMEN 6331 and BMEN 6333. (3-0) Y

BMEN 6342 Biomaterials and Medical Devices (3 semester credit hours) Covers advanced topics in the field of biomaterials which are used in the engineering design and testing of medical devices which are used to augment /replace soft and hard tissues. Overview of current challenges and successes with implantable devices, biomaterials properties, clinical requirements, clinical applications and cases, and in-vivo behavior of different classes of natural and synthetic materials. Advanced engineering analysis of biological response and biocompatibility, degradation and failure processes of implantable biomaterials/devices. Students will become familiar with several classes of biomaterials, their current clinical engineering applications, and state-of-the art research in the field. (3-0) Y

BMEN 6345 Self-Assembly of Biomaterials (3 semester credit hours) This course will introduce students to the emerging and evolving fields of self-assembly and nanoengineered biomaterials. Upon completion of the course students will understand the principles of self-assembly and self-organization of small molecules (e.g. thiols and surfactants), macromolecules (e.g. polymers, block co-polymers, proteins, DNA), and colloidal dispersions. Students will also learn the important role weak non-covalent forces (e.g. ionic bonds, hydrogen bonding, hydrophobic interactions) play in determining the structure of self-assembled systems. Finally students will learn how scientists and engineers are designing and exploiting the principles of self-assembly to produce functional biomaterials and the techniques to characterize these biomaterials from the nano to macro level. Topics to be covered include the following: Introduction to Self-Assembly; Intermolecular and Colloidal forces; Self-assembly in solutions micelles, bilayers, liquid crystals, emulsions; Colloidal Self-Assembly; Self-Assembly at Interfaces; Biomimetic Self-Assembly; Nanoparticles; and Nanostructured Films. Prerequisites: BIOL 2311 and CHEM 1312 and MATH 2417 and PHYS 2325 and instructor consent required. (3-0) Y

BMEN 6351 Biomedical Microdevices (3 semester credit hours) Introduction to concepts of medical microdevices; design methodology and its applications for diagnostics and therapeutics. (3-0) Y

BMEN 6355 (MSEN 6355) Nanotechnology and Sensors (3 semester credit hours) Introduction to the concept of nanotechnology, in context toward designing sensors/diagnostic devices. Identifying the impact of nanotechnology in designing "state-of-the art" sensors for healthcare applications. Topics include: nanotechnology and nanomaterials, principles of sensing and transduction and heterogeneous integration toward sensor design. (3-0) Y

BMEN 6360 (CHEM 5340 and MSEN 5340) Advanced Polymer Science and Engineering (3 semester credit hours) Polymer structure-property relations, Glass transition temperature and mechanical properties of polymers, Thermoplastics, thermosets, and elastomers, morphology of polymers, rheology of polymers, biodegradable and biocompatible polymers for drug delivery and tissue engineering applications. (3-0) R
BMEN 6365 Biomedical Image Processing (3 semester credit hours) This course covers basic digital image processing techniques used for the analysis of images. Topics include spatial and frequency domain filtering, image restoration, morphological operators (e.g., erosion and dilation) and their uses (e.g., boundary extraction, extraction of connected components), image segmentation and pattern recognition. A percentage of the course grade is based on projects, which require students to program image processing techniques and apply them to images. (3-0) Y

BMEN 6371 Bioelectric Systems (3 semester credit hours) Introduction to the theoretical and applied aspects of bioelectrical phenomena spanning cells to tissue. Beginning with a quantitative understanding of the basis of electrical excitability, the course covers bioelectrical signal propagation, the physical basis of extracellular potentials and stimulation, biopotential amplifier design and use, and clinically relevant biosignal acquisition and analyses. Prerequisites: Graduate standing and department consent required. (3-0) Y

BMEN 6372 (MECH 6314 and SYSM 6306) Engineering Systems: Modeling and Simulation (3 semester credit hours) This course will present principles of computational modeling and simulation of systems. General topics covered include: parametric and non-parametric modeling; system simulation; parameter estimation, linear regression and least squares; model structure and model validation through simulation; and, numerical issues in systems theory. Techniques covered include methods from numerical linear algebra, nonlinear programming and Monte Carlo simulation, with applications to general engineering systems. Modeling and simulation software is utilized (MATLAB/SIMULINK). (3-0) Y

BMEN 6373 (EEBM 6373) Anatomy and Human Physiology for Engineers (3 semester credit hours) This course provides an introduction to anatomy and human physiology for engineers and other non-life scientists. Topics include nervous system, muscle and cardiac function, digestive system, and immune system. (3-0) Y

BMEN 6374 (EEBM 6374) Genes, Proteins and Cell Biology for Engineers (3 semester credit hours) This course provides an introduction to principles of modern molecular and cellular biology for engineers and other non-life scientists. Topics include genes, protein structure and function, organization of cells and cellular trafficking. (3-0) Y

BMEN 6375 Techniques in Cell and Molecular Biology (3 semester credit hours) Introduction to cell and molecular laboratory techniques including DNA recombinant technology, protein biochemistry, structural biology, and molecular biology. Intended for engineers and other non-life-scientists. Prerequisite: BMEN 6374 or instructor consent required. (3-0) Y

BMEN 6377 Introduction to Protein Engineering (3 semester credit hours) Development of proteins with practical utility will be discussed, using examples and case studies taken from the current literature. Prerequisite: BMEN 6374 or instructor consent required. (3-0) Y

BMEN 6378 Mechanobiology for Engineers (3 semester credit hours) This course will introduce principles by which mechanical forces regulate biological processes in cells and tissues in healthy and diseased states. In order to understand mechanobiology from an engineering perspective, this course will review aspects of solid and fluid mechanics, cell biology, intracellular polymer mechanics, cellular mechanics and mechanotransduction, disease mechanisms, biological modeling and research methodology. In addition, the impact of mechanobiology in bone, arteries and various cell types will be discussed. (3-0) T
BMEN 6380 (EEBM 6380) Introduction to Cellular Microscopy (3 semester credit hours) Image formation, diffraction, labeling techniques, fluorescence and image processing techniques will be introduced. (3-0) R

BMEN 6381 (EEBM 6381) Advanced Concepts in Microscopy (3 semester credit hours) Continuation of BMEN 6380, with emphasis on advanced approaches such as vectorial diffraction, stochastic aspects of image formation and analysis. Prerequisite: BMEN 6380 or EEBM 6380 or instructor consent required. (3-0) R

BMEN 6382 Systems Biology (3 semester credit hours) An interdisciplinary approach to biology. It explores experimental, theoretical, and computational approaches from mathematics, physics, and engineering for the understanding and analysis of biological problems. Prerequisite: BMEN 6374 or instructor consent required. (3-0) Y

BMEN 6385 Biomedical Signals and Systems (3 semester credit hours) Time and Frequency domain analysis; continuous-time and discrete-time signals, linear-time invariant (LTI) systems and their properties. Frequency analysis of: LTI systems, continuous-time signals (Fourier series and Fourier transform) and discrete time signals [discrete Fourier series and discrete-time Fourier transform (DTFT)]. Sampling and signal reconstruction. Discrete Fourier transform (DFT) and fast Fourier transform (FFT). Filter design. MATLAB-based tutorials. Prerequisites: ENGR 2300 and EE 4310. (3-0) R

BMEN 6386 Biological Processes: Modeling and Simulation (3 semester credit hours) Introduces fundamental principles to develop and simulate mathematical and computer models of biological systems. Topics include modeling principles [continuous (differential equation models), discrete (Boolean network and Markov model), probabilistic (Bayesian network) and stochastic models] and model optimization. Methods to simulate mathematical biological models using computer programming (software: MATLAB) will be introduced. Prerequisite: MATH 2419 or equivalent. (3-1) R

BMEN 6387 (BIOL 5376) Applied Bioinformatics (3 semester credit hours) Genomic information content; data searches and multiple sequence alignment; mutations and distance-based phylogenetic analysis; genomics and gene recognition; polymorphisms and forensic applications; nucleic-acid and protein array analysis; structure prediction of biological macromolecules. Prerequisites: At least one semester of undergraduate statistics and probability, and two semesters of undergraduate calculus or instructor consent required. (3-0) T

BMEN 6388 (EECS 6336 and MECH 6313 and SYSE 6324) Nonlinear Systems (3 semester credit hours) Differential geometric tools, feedback linearization, input-output linearization, output injection, output tracking, stability. Prerequisite: EECS 6331 or MECH 6300 or SYSM 6307 or equivalent. (3-0) T

BMEN 6389 (BIOL 6385) Computational Biology (3 semester credit hours) Machine learning and probabilistic graphical models have become essential tools for analyzing and understanding complex systems biology data in biomedical research. This course introduces fundamental principles and methods behind the most important high throughput data analysis tools. Applications will cover molecular evolutionary models, DNA/protein motif discovery, gene prediction, high-throughput sequencing and microarray data analysis, computational modeling gene expression regulation, and biological pathway and network analysis. Prerequisite: Some background in elementary statistics/probability or introductory bioinformatics, or instructor consent required. (3-0) Y

BMEN 6391 (BIOL 6373) Proteomics (3 semester credit hours) Protein identification, sequencing, and analysis of post-translational modifications by liquid chromatography/tandem mass spectrometry;
determination of protein three dimensional structure by x-ray crystallography; its use in drug design; understanding protein interactions and function using protein chip microarrays. Prerequisites: one semester of undergraduate biochemistry and one semester of graduate biochemistry or instructor consent required. (3-0) T

**BMEN 6392** Bioinstrumentation and Systems (3 semester credit hours) Introduction to bioinstrumentation, biomedical signal acquisition, isolation, amplification, and conditioning, biopotential electrodes and amplifiers for ECG, EEG, ENG and EMG. Vascular system dynamics. Transmission and propagation of EM and RF signals around tissue. Biomedical applications. Prerequisite: **BMEN 6385.** (3-0) R

**BMEN 6393** Neural Engineering Methods and Applications (3 semester credit hours) This course will cover Neural Engineering methods used for neural ensemble recording and neural stimulation. Electrodes and devices used in Brain Machine Interfacing (BMI), deep brain stimulation (DBS), spinal cord stimulation (SCS), transcranial direct current stimulation (TDCS), and Peripheral Nerve Interfacing will be covered. Advanced techniques including modulation by optogenomics and the development of new voltage fluorescent probes will be explained. The use of neural prosthesis for the restoration of sensory and motor function will be reviewed. This course will help students to understand a wide range of methodology currently use to interrogate and modulate the nervous system. Recommended prerequisites: (BMEN 3330 or equivalent) and (BMEN 3350 or equivalent). (3-0) Y

**BMEN 6394** Medical Imaging Techniques and Image Processing (3 semester credit hours) In this course, the fundamental physical principals of modern medical imaging techniques will be covered, including x-ray, ultrasound, MRI, optical, nuclear, multi-modality imaging, and contrast agents. Students will also learn many common image processing methods, such as image reconstruction, filtering, segmentation, registration, and fitting. Recommended prerequisite: **EE 3302** or equivalent. (3-0) R

**BMEN 6V40** Individual Instruction in Biomedical Engineering (1-6 semester credit hours) Independent study under a faculty member's direction. Pass/Fail only. May be repeated for credit as topics vary (6 semester credit hours maximum). Department consent required. ([1-6]-0) R

**BMEN 6V70** Research in Biomedical Engineering (1-6 semester credit hours) Pass/Fail only. May be repeated for credit (6 semester credit hours maximum). Instructor consent required. ([1-6]-0) R

**BMEN 6V71** Seminars in Biomedical Engineering (1-3 semester credit hours) Pass/Fail only. May be repeated for credit. Department consent required. ([1-3]-0) R

**BMEN 6V87** Special Topics in Biomedical Engineering (1-9 semester credit hours) May be repeated for credit. Department consent required. ([1-9]-0) S

**BMEN 6V98** Thesis (1-9 semester credit hours) Pass/Fail only. May be repeated for credit. Instructor consent required. ([1-9]-0) S

**BMEN 7188** Advanced Seminars in Biomedical Engineering I (1 semester credit hour) Doctoral students will learn to give effective short-formatted presentations about their research interests and findings, develop critical and relevant questions during a scientific talk, and use feedback to improve their presentation skills. Students will learn these skills through watching scientific presentations from their peers and by presenting aspects of their own research to their peers. Department consent required. (1-0) R
BMEN 7189 Advanced Seminars in Biomedical Engineering II (1 semester credit hour) Doctoral students will continue learn to give effective short-formatted presentations about their research interests and findings, develop critical and relevant questions during a scientific talk, and use feedback to improve their presentation skills. Students will learn these skills through watching scientific presentations from their peers and by presenting aspects of their own research to their peers. Department consent required. Prerequisite: BMEN 7188. (1-0) Y

BMEN 7201 (BMEN 6201) Career Development Skills for Biomedical Engineers PhD (2 semester credit hours) Biomedical Engineering as a field requires a wide range of skills not traditionally taught in the classroom or lab, including self-presentation, collaboration, and science communication. This course bridges this knowledge gap through interactive training and assignments, and helps students to develop a career plan to help guide them to the most useful experiences in their graduate and professional career to meet their diverse goals. Required presentations help to prepare PhD students for dissertation defenses and job talks. (2-0) Y

BMEN 7203 (BMEN 6203) Research Skills for Biomedical Engineers PhD (2 semester credit hours) This course will introduce students to the research skills necessary for a successful graduate research career. Students will go through the process of planning and conducting a hands-on research project that can serve as the basis of a manuscript submission. Through this process students will learn research design terminology, steps in the research process, how to conduct systematic literature reviews, articulate clear research questions, testable hypotheses, and evaluate strengths and weaknesses of published articles. (2-1) Y

BMEN 7341 Biostatistics (3 semester credit hours) Biostatistics for Biomedical Engineers provides instruction on selected, important topics in biostatistical concepts and reasoning. Specific topics include tools for describing central tendency and variability in data; determining and justifying sample size; formulating hypotheses; selecting appropriate statistical analysis techniques; methods for performing inference on population means and proportions via sample data; statistical hypothesis testing and its application to group comparisons; general principles of study design; review of methods for comparison of discrete and continuous data; correlation and regression. This course emphasizes the practical application of skills for statistical interpretation of research data. Prerequisites: PhD standing and department consent required. (3-0) Y

BMEN 7342 Design of Experiments (3 semester credit hours) This graduate level course will walk students through the basics of experimental design in biomedical engineering with a focus on the practical application of skills and concepts to student research. Specific topics include understanding types of data; independent vs. dependent variables; design and selection of experimental controls; reagent standards and equipment calibration; forming robust, testable hypotheses; the danger of assumption; calculating sample size and power; forming evidence based conclusions; confounds and error; IRB documentation; selection of well-suited laboratory animals; informed consent; ethics in research; results forecasting; graphical representation of results; articulation of the research findings, and the implications of the findings in view of the strengths and weaknesses. Software packages including Excel and GraphPad will be demonstrated. Journal articles, including infamous retractions, will be reviewed and assessed for flaws in experimental design. Student-designed experiments relating to their work will be presented and reviewed. Prerequisites: PhD standing and department consent required. (3-0) Y

BMEN 7387 Independent Scientific Research in Biomedical Engineering (3 semester credit hours) This
course deals with both the theoretical and practical aspects of designing dissertation research and successfully defending the design in the dissertation proposal and/or dissertation examination. The research design component will be targeted to a specific independent project with the intent that the project will develop into the student's dissertation. The primary focus is on developing a sound research design with appropriate controls and statistical power analyses. May be repeated (9 semester credit hours maximum). (3-0) S

**BMEN 7V87** Advanced Topics in Biomedical Engineering (1-9 semester credit hours) Independent scientific research in Bioengineering. May be repeated for credit as topics vary. Department consent required. ([1-9]-0) S

**BMEN 7V95** Special Topics in Biomedical Engineering (1-9 semester credit hours) Advanced specialized topics in Biomedical Engineering. Subject matter will vary from semester to semester. May be repeated for credit as topics vary (9 semester credit hours maximum). Prerequisites: PhD Standing and department consent required. ([1-9]-0) R

**BMEN 8188** Advanced Seminars in Biomedical Engineering III (1 semester credit hour) Doctoral students will continue learn to give long-formatted presentations about their research as a part of preparing for their dissertation defense, conference talks, and job talks. Students will learn these skills through watching scientific presentations from their peers and by presenting aspects of their own dissertation work to their peers. Department consent required. (1-0) Y

**BMEN 8V40** Advanced Instruction in Biomedical Engineering (1-9 semester credit hours) Advanced research in biomedical engineering. Pass/Fail only. May be repeated for credit. Department consent required. ([1-9]-0) R

**BMEN 8V70** Advanced Research In Biomedical Engineering (1-9 semester credit hours) Pass/Fail only. May be repeated for credit. Instructor consent required. ([1-9]-0) R

**BMEN 8V99** Dissertation (1-9 semester credit hours) Pass/Fail only. May be repeated for credit. Instructor consent required. ([1-9]-0) S