BMEN 101 Introduction to Biomedical Engineering
Credit 1. 1 Lecture Hour.
Overview of biomedical engineering and the biomedical engineering industry, including specialties, degree requirements and scholastic programs in the Department of Biomedical Engineering.
Prerequisite: Admitted to major degree sequence.

BMEN 207 Computing for Biomedical Engineering
Credits 3. 2 Lecture Hours. 3 Lab Hours.
Introduction to the principles of computer programming for biomedical applications including program design and development, programming techniques and documentation; introduction to and programming in the LabVIEW and MATLAB environments.
Prerequisites: Admitted to major degree sequence; MATH 152, ENGR 112.

BMEN 211 Biomedical Applications of Circuits, Signals and Systems
Credits 3. 3 Lecture Hours.
Quantitative analysis of biomedical and physiological signals; A/D conversion and sampling; Fourier and Laplace transforms; filtering of biomedical signals and images; electrical circuits and analog representations of physiological systems as model systems.
Prerequisites: Admitted to major degree sequence; PHYS 208 and MATH 308, or concurrent enrollment.

BMEN 231 Foundations of Biomechanics
Credits 3. 3 Lecture Hours.
Introduction of biomechanics in formulating and solving problems in basic science, medical device development, and clinical intervention; emphasis on deriving differential equations in one spatial dimension for the five basic postulates of continuum biomechanics, identifying illustrative constitutive relations, and providing a unified approach to studying biosolid mechanics, biofluid mechanics, bioheat and mass transport, and biothermomechanics.
Prerequisite: Admitted to major degree sequence in biomedical engineering.

BMEN 253 Medical Device Design I
Credit 1. 3 Lab Hours.
FDA design controls for medical device development in a regulated environment; small-scale team biomedical engineering design project.
Prerequisite: BMEN 207.

BMEN 282/CHEN 282 Engineering Biology
Credits 3. 3 Lecture Hours.
Application of engineering principles to biological function at the molecular and cellular level.
Prerequisites: Admitted to major degree sequence and CHEM 101 and CHEM 111 or CHEM 107 and CHEM 117.
Cross Listing: CHEN 282.

BMEN 285 Directed Studies
Credits 0 to 4. 0 to 4 Other Hours.
Allows students to undertake special projects in biomedical engineering at an earlier point in their studies than required for BMEN 485.
Prerequisite: Approval of Director of Undergraduate Programs.

BMEN 291 Research
Credits 0 to 4. 0 to 4 Other Hours.
Research conducted under the direction of faculty member in biomedical engineering. May be repeated 2 times for credit.
Prerequisites: Freshman or sophomore classification and approval of instructor.

BMEN 305 Bioinstrumentation
Credit 1. 3 Lab Hours.
Introduction to biomedical instrumentation design; hands on acquisition of biomedical signals; design, building and testing of bioinstrumentation circuits including analog signal amplifiers and analog filter circuits.
Prerequisite: BMEN 211, BMEN 321 or concurrent enrollment.

BMEN 306 Biomeasurements Lab
Credit 1. 3 Lab Hours.
Introduction into experimental methods useful in biomedical engineering; includes the role of empiricism in biomedical research and development; the differences between observation and experimentation; and how to acquire, reduce, interpret, and present data.
Prerequisites: Admitted to major degree sequence in biomedical engineering; BMEN 240 and BMEN 341.

BMEN 310 Clinical Engineering
Credits 3. 3 Lecture Hours.
Equipment control concepts and techniques and their application in hospitals and in the medical profession; device evaluation specifications; preventative maintenance and service; calibration, regulation and medical product liability.
Prerequisites: Admitted to major degree sequence in biomedical engineering; BMEN 321.

BMEN 321 Biomedical Electronics
Credits 3. 3 Lecture Hours.
Introduction to biomedical signals; basic circuit analysis for biomedical signals; design of bioamplifier circuits; characteristics of linear and nonlinear circuit elements; design of basic electronic circuits, principles and practice of bioelectronic measurements.
Prerequisites: BMEN 211; junior or senior classification.

BMEN 322 Biosignal Analysis
Credits 3. 3 Lecture Hours.
Design and application of analog and digital signal analysis in biomedical engineering; characteristics of biomedical signals; design considerations for analog-to-digital and digital-to-analog circuitry; biosignal transformation methods; analog and digital filter design for biomedical signals.
Prerequisite: BMEN 321.

BMEN 341 Biofluid Mechanics
Credits 3. 3 Lecture Hours.
Introduction into the mechanics of fluids in biomechanics, including blood, synovial fluid and physiological solutions, with an emphasis on the importance of mechanobiology and the formation of biological problems within the context of 1) kinematics, 2) the concept of stress, 3) linear momentum balance, 4) constitutive relations, and 5) boundary conditions.
Prerequisites: Admitted to major degree sequence; junior or senior classification.
BMEN 342 Biomaterials and Medical Devices  
Credits 3. 3 Lecture Hours.  
Selection and use of materials in implantable and tissue contacting medical devices; mass transport in medical devices; regulation and testing of medical devices.  
Prerequisites: VTPP 435 and BMEN 341; junior or senior classification.

BMEN 343 Introduction to Biomaterials  
Credits 3. 3 Lecture Hours.  
Properties of natural and man-made materials commonly encountered in biomedicine and biomedical engineering; an integrated approach in the presentation of material structures, characteristics and properties; the basics of material structures, including crystalline and chemical structure, and microstructure; and bulk properties and characteristics of the materials developed from the microscopic origins.  
Prerequisites: MATH 308 and CHEM 227; junior or senior classification.

BMEN 344 Biological Responses to Medical Devices  
Credits 3. 3 Lecture Hours.  
Selection and characterization of materials in implantable and tissue contacting medical devices; biodegradation, biocompatibility, hemocompatibility and cell-material interactions of biomaterials.  
Prerequisite: BMEN 343, VTPP 435 or concurrent enrollment.

BMEN 345 Biomaterials Lab  
Credit 1. 3 Lab Hours.  
Experimental methods used to prepare and characterize polymeric biomaterials used in biomedical engineering; related fundamental aspects of forming a hypothesis, experimental design, empirical observation, data collection, interpretation and presentation of data.  
Prerequisite: BMEN 343.

BMEN 350 Statistics for Biomedical Engineering  
Credits 3. 3 Lecture Hours.  
Evaluation of the efficacy of clinical research; quantitative methods used in clinical trials in biomedical engineering; ethical and regulatory issues that must be considered during the design and implementation of any clinical trial, or pre-clinical study.  
Prerequisites: Junior classification; admitted to the major degree sequence (upper level).

BMEN 353 Medical Device Design II  
Credit 1. 3 Lab Hours.  
Identification of needs for biomedical engineering design solutions, development of design proposals, analysis of design project requirements and constraints.  
Prerequisite: BMEN 253 or equivalent; junior or senior classification.

BMEN 361 Biosolid Mechanics  
Credits 3. 3 Lecture Hours.  
Introduction to the mechanics of deformable media in biomedical engineering, including medical devices, biomaterials, and soft and hard biological tissues: emphasis on biomechanics and mechanobiology and formulation of problems within the context of basic continuum biomechanics; problems include analytical solutions for stress-strain analysis of extension, distension, bending, buckling, and torsion of biosolids.  
Prerequisites: Admitted to major degree sequence in biomedical engineering; BMEN 341.

BMEN 399 Engineering Professional Development  
Credits 0. 0 Other Hours.  
Participation in an approved high-impact learning practice; reflection on professional outcomes from engineering body of knowledge; documentation and self-assessment of learning experience at mid-curriculum point.  
Prerequisites: Admission to biomedical engineering; junior or senior classification or approval of instructor.

BMEN 400/VTPP 401 History of Human and Veterinary Medicine in Europe  
Credits 4. 4 Lecture Hours.  
Addresses the major developments in human and veterinary medicine in Europe from the Middle Ages to the present; explores key events and figures in medical history and analyzes issues of current biomedical concern in a historical context; for example, animal rights, ethics of humane experimentation, euthanasia.  
Prerequisites: Admitted to major degree sequence in biomedical engineering; VTPP 434.  
Cross Listing: VTPP 401.

BMEN 401 Principles and Analysis of Biological Control Systems  
Credits 3. 3 Lecture Hours.  
Techniques for generating quantitative mathematical models of physiological control systems and devices; the behavior of physiological control systems using both time and frequency domain methods.  
Prerequisite: BMEN 321.

BMEN 402 Biomedical Optics Laboratory  
Credits 3. 2 Lecture Hours. 3 Lab Hours.  
Biomedical optics technology; basic engineering principles used in developing therapeutic and diagnostic devices; hands-on labs including optical monitoring, diagnostic and therapeutic experiments.  
Prerequisite: PHYS 208 or approval of instructor.

BMEN 404 FDA Good Laboratory and Clinical Practices  
Credits 3. 3 Lecture Hours.  
Implementation of Good Laboratory Practices (GLP) for the submission of preclinical studies and use of Good Clinical Practices (GCP) in clinical trials in accordance with Food and Drug Administration (FDA) regulations; includes similarities and differences in GLP and GCP critical for the introduction of new drugs and medical devices.  
Prerequisites: BMEN 253; junior or senior classification.

BMEN 405 Virtual Instrumentation Design for Medical Systems  
Credits 3. 2 Lecture Hours. 3 Lab Hours.  
Design of medical systems using graphics programming language of LabVIEW including the designing and programming of three virtual systems as follows: cardiac monitor, electromyogram system for biomechanics, and sleep stage analyses from electroencephalograms.  
Prerequisites: BMEN 321 and BMEN 322.

BMEN 406 Medical Device Path to Market  
Credits 3. 3 Lecture Hours.  
Path to market for a medical device with specific attention to the regulatory affairs to enable the development of an appropriate regulatory strategy due to the highly regulated global environment.  
Prerequisites: BMEN 253; junior or senior classification, or approval of instructor.
BMEN 420 Medical Imaging
Credits 3. 3 Lecture Hours.
The principles of the major imaging modalities including x-ray radiography, x-ray computed tomography (CT), ultrasonography and magnetic resonance imaging; including a brief discussion on other emerging imaging technologies such as nuclear imaging (PET and SPECT).
Prerequisites: BMEN 211; junior or senior classification.

BMEN 422 Bioelectromagnetism
Credits 3. 3 Lecture Hours.
Electric, magnetic and electromagnetic phenomena associated with biological tissues; source modeling based on physiological current including line and volume conductor models as well as electromagnetic-based stimulation, sensing and imaging.
Prerequisites: Admission into the degree sequence of the major and BMEN 321 or approval of instructor.

BMEN 423 Microscale Bio-Optic Applications
Credits 3. 3 Lecture Hours.
Introduction to biomedical applications of lasers to manipulation, detection and visualization on (sub-)cellular length scales; emphasis on the governing principles on which applications are founded; includes applications from recent literature.
Prerequisites: BMEN 306 and BMEN 322; junior or senior classification.

BMEN 424 Biomedical Sensing and Imaging at the Nanoscale
Credits 3. 3 Lecture Hours.
Introduction to nanotechnology with an emphasis on biomedical techniques and medical applications; basic physics of contrast agents to the engineering of current sensing and imaging systems applied at the nanoscale.
Prerequisite: Senior classification or approval of instructor.

BMEN 425 Biophotonics
Credits 3. 3 Lecture Hours.
Theory and application of optical instrumentation, including light sources, lasers, detectors, and optical fibers; instrumentation and engineering in biomedical applications of optics in therapeutics, diagnostics, and biosensing.
Prerequisites: Admitted into the major degree sequence in biomedical engineering; junior or senior classification.

BMEN 426 Optical Biosensors
Credits 3. 3 Lecture Hours.
Biosensing principles and detailed analysis of optical methods for transduction; fluorescence-based transduction; molecular recognition of targets; immobilization of sensing reagents; quantitative analysis of sensing systems; design and characterization of sensing assays and associated measurement systems; review of historical and current trends in optical biosensors.
Prerequisite: Senior classification or approval of instructor.

BMEN 427 Magnetic Resonance Engineering
Credits 3. 2 Lecture Hours. 3 Lab Hours.
Design, construction and application of instrumentation for MR imaging; fundamentals of the architecture of an MR spectrometer and the gradient subsystem used for image localization; emphasis on the radiofrequency sensors and systems used for signal generation and reception.
Prerequisites: BMEN 420 or ECEN 410 or ECEN 411 or approval of instructor; junior or senior classification.

BMEN 428 Microcontrollers and Communications in Medical Devices
Credits 3. 2 Lecture Hours. 3 Lab Hours.
Principles of embedded system architecture and programming; fundamentals and theoretical foundations of wireless communication systems; hands-on experiences of how an embedded system could be used to solve problems in biomedical engineering; projects on wireless sensors and imaging for medical devices.
Prerequisite: BMEN 211 or approval of instructor.

BMEN 430 Medical Device Regulation
Credits 3. 3 Lecture Hours.
Introduction to the regulations of the U.S. Food and Drug Administration pertaining to testing and marketing medical devices.
Prerequisites: BMEN 310; junior or senior classification.

BMEN 431 Biomolecular Engineering
Credits 3. 3 Lecture Hours.
Foundations for understanding and experimental approaches for measuring and manipulating biomolecules; proteins, nucleic acids and carbohydrates; thermodynamics and kinetics of biomolecular reactions.
Prerequisites: Junior or senior classification; Biomedical Engineering majors only; or approval of instructor.

BMEN 432 Molecular and Cellular Biomechanics
Credits 3. 3 Lecture Hours.
Introduces biomolecules and their assemblies that play structural and dynamical roles in subcellular to cellular level mechanics; emphasis on quantitative/theoretical descriptions; discussions of the relevant experiment approaches to probe these nano to micro-scale phenomena; includes topics in self-assembly of cytoskeleton and biomembranes, molecular motors, cell motility, and mechanotransduction.
Prerequisite: BMEN 361.

BMEN 433 Biomolecular and Cellular Engineering Laboratory
Credits 3. 2 Lecture Hours. 3 Lab Hours.
Laboratory biosafety and biohazard awareness; cell culture protocols and standards for biocompatibility testing; setting protocols for cellular and biomolecular projects; bioimaging, bioassays and biomolecule activity testing.
Prerequisites: VTPP 435; BMEN 431 or concurrent enrollment; majors in biomedical engineering; junior or senior classification; or approval of instructor.

BMEN 440 Design of Medical Devices
Credits 3. 3 Lecture Hours.
Overview of the multiple issues in designing a marketable medical device, including the design process from clinical problem definition through prototype and clinical testing to market readiness; includes FDA regulation, human factors and system safety considerations and medical product liability.
Prerequisites: BMEN 342; senior classification in engineering.

BMEN 448 Healthcare Technology in the Developing World
Credits 3. 1 Lecture Hour. 6 Lab Hours.
Principles of operation for major types of medical equipment; physiology underlying the measurement; major functional (system) pieces for each instrument; typical problems/applications of each instrument.
Prerequisites: MATH 152, PHYS 208, and approval of instructor.
BMEN 450 Case Studies
Credit 1. 1 Lecture Hour.
Examines process through which clinically defined problems are addressed from the perspective of biomedical engineering through the use of case studies; includes issues of technology transfer and clinical evaluation.
Prerequisites: Admitted to major degree sequence; junior or senior classification.

BMEN 451 Cell Mechanobiology
Credits 3. 3 Lecture Hours.
Focus on how mechanical forces influence cell behavior through physical and biochemical mechanisms; integration of engineering and cell biology to solve biomedical problems, which includes developing models for applying forces to cultured cells and tissues and measuring changes in cell biochemistry, structure, and function.
Prerequisite: BMEN 341.

BMEN 452 Mass and Energy Transfer in Biosystems
Credits 3. 3 Lecture Hours.
Transport phenomena associated with physiological systems and their interaction with medical devices; exchange processes in artificial life support systems and diagnostic equipment.
Prerequisites: BMEN 341; MATH 308.

BMEN 453 Analysis and Design Project I
Credits 2. 6 Lab Hours.
Group or team biomedical engineering analysis and design project involving statement, alternative approaches for solution, specific system analysis and design.
Prerequisites: BMEN 321 and BMEN 353.

BMEN 454 Analysis and Design Project II
Credits 2. 0 Lecture Hours. 6 Lab Hours.
Continuation of BMEN 453.
Prerequisite: BMEN 453.

BMEN 455 Orthopedic Biomechanics
Credits 3. 3 Lecture Hours.
Development of competencies in biomechanical principles using practical examples and clinical case studies; application of biomechanical knowledge to the evaluation of musculoskeletal tissues and structures, and treatment options for musculoskeletal dysfunction.
Prerequisite: BMEN 361 or equivalent course approved by instructor.

BMEN 456 Motion Biomechanics
Credits 3. 3 Lecture Hours.
Skeletal anatomy and mechanics; muscle anatomy and mechanics; theory and application of electromyography; motion and force measuring equipment and techniques; inverse dynamics modeling of the human body; current topics in musculoskeletal biomechanics research.
Prerequisites: BMEN 207 or approval of instructor; junior or senior classification.

BMEN 460 Vascular Mechanics
Credits 3. 3 Lecture Hours.
Application of continuum mechanics to the study of the heart arteries; emphasis on the measurement and quantification of material properties, and the calculation of vascular stresses; analysis of several cardiovascular devices to reinforce the need for careful analysis in the device design.
Prerequisites: BMEN 240.

BMEN 461 Cardiac Mechanics
Credits 3. 3 Lecture Hours.
Application of continuum mechanics and computational solid mechanics to the study of the mammalian heart; utilization of continuum mechanics and finite element analysis in solving non-linear boundary value problems in biomechanics.
Prerequisites: BMEN 341 and BMEN 361.

BMEN 462 Vascular Fluid Mechanics
Credits 3. 3 Lecture Hours.
Bio-fluid mechanics of the human circulatory system including examination of disease development and medical treatments.
Prerequisites: BMEN 240 or equivalent; junior or senior classification.

BMEN 463 Soft Tissue Mechanics and Finite Element Methods
Credits 3. 3 Lecture Hours.
Application of continuum mechanics and finite element methods to the study of the mechanical behavior of soft tissues and associative applications in biomedicine.
Prerequisites: BMEN 341 and BMEN 361.

BMEN 465 Biomechanics Experiential Learning Lab
Credit 1. 3 Lab Hours.
Applications in biomechanics (solid and fluid); includes experimental methods used to investigate biomechanical factors in the assessment of therapeutic interventions; mechanical testing load frames; motion capture systems, high speed imaging and flow systems; hypothesis forming, experimental design, empirical observation, data collection and interpretation, and presentation of results.
Prerequisite: BMEN 361.

BMEN 466 Advanced Biomechanics
Credits 3. 3 Lecture Hours.
Application of fluid and solid mechanics to problems in biomedical engineering ranging from molecular-level to organ-level, including the mechanics of the cell cytoskeleton, whole cells, blood, arteries and the heart.
Prerequisites: Admitted to major degree sequence in biomedical engineering; BMEN 361; or approval of instructor.

BMEN 469 Entrepreneurial Issues in Biomedical Engineering
Credits 3. 3 Lecture Hours.
Description and analysis of issues associated with initiating business ventures to transfer biomedical technologies into the health care sector, including intellectual property protection, seed funding alternatives, and business strategies relevant to the biomedical engineering technology area; utilizing recent case studies of previous ventures.
Prerequisite: Admitted to major degree sequence (upper-level) in biomedical engineering.

BMEN 470/CHEN 470 Introduction of Biomedical Optics
Credits 3. 3 Lecture Hours.
Fundamentals of biomedical optics; basic engineering principles used in optical therapeutics, optical diagnostics and optical biosensing.
Prerequisites: MATH 308; PHYS 208.
Cross Listing: CHEN 470/BMEN 470.

BMEN 471 Numerical Methods in Biomedical Engineering
Credits 3. 3 Lecture Hours.
Application of numerical analysis to analyze molecular, cellular and physiological systems, using general techniques including programming in MATLAB to analyze steady and dynamic systems.
Prerequisites: BMEN 207 and VTPP 434.
BMEN 480 Biomedical Engineering of Tissues
Credits 3. 3 Lecture Hours.
Introduction to aspects of tissue engineering with and emphasis placed on tissue level topics including tissue organization and biological processes, with insights from recent literature (state-of-the-art).
Prerequisite: BMEN 343.

BMEN 482 Polymeric Biomaterials
Credits 3. 3 Lecture Hours.
Preparation, properties, and biomedical applications of polymers including polymerization; structure-property relationships; molecular weight and measurement; morphology; thermal transitions; network formation; mechanical behavior; polymeric surface modification; polymer biocompatibility and bioadhesion; polymers in medicine, dentistry, and surgery; polymers for drug delivery; polymeric hydrogels; and biodegradable polymers.
Prerequisite: BMEN 343.

BMEN 483 Polymeric Biomaterial Synthesis
Credits 3. 3 Lecture Hours.
Overview of polymer synthetic routes and key structure-property relationships with emphasis on the design of polymeric systems to achieve specific properties; tissue engineering and drug delivery applications will be used as model systems to explore the process of biomaterial design from synthesis to device evaluation.
Prerequisite: BMEN 343 or approval of instructor.

BMEN 485 Directed Studies
Credits 0 to 6. 0 to 6 Other Hours.
Allows students to undertake special projects in biomedical engineering.
Prerequisite: Approval of instructor or Director of Undergraduate Programs.

BMEN 486 Biomedical Nanotechnology
Credits 3. 3 Lecture Hours.
Nanotechnology applications in biomedicine; concepts of scale; unique properties at the nanoscale; biological interaction, transport, and biocompatibility of nanomaterials; current research and development of nanotechnology for medical applications, including sensors, diagnostic tools, drug delivery systems, therapeutic devices, and interactions of cells and biomolecules with nanostructured surfaces.
Prerequisite: BMEN 343, senior classification or approval of instructor.

BMEN 487 Drug Delivery
Credits 3. 3 Lecture Hours.
Mechanisms for controlled release of pharmaceutically active agents and the development of useful drug delivery systems; controlled release mechanisms including diffusive, convective, and erosive driving forces by using case studies related to oral, topical and parenteral release in a frontier interdisciplinary scientific research format.
Prerequisite: Senior classification in biomedical engineering or approval of instructor.

BMEN 489 Special Topics in...
Credits 1 to 4. 1 to 4 Lecture Hours. 1 to 4 Lab Hours.
New or unique areas of biomedical engineering which are of interest to biomedical engineering and other undergraduate students.

BMEN 491 Research
Credits 0 to 4. 0 to 4 Other Hours.
Research conducted under the direction of faculty member in biomedical engineering. May be repeated for credit.
Prerequisites: Junior or senior classification and approval of instructor.