Biomedical Engineering (BME)

BME 201/BMME 201 Computer Methods in Biomedical Engineering (3 credit hours)
Students develop computer-based problem solving techniques using Excel and MATLAB to solve introductory problems in Biomedical Engineering. Emphasis is on developing solution algorithms, implementing these with spreadsheets and computer programming, and presenting results in a clear and concise manner. Students registered for BME 201 who fail to matriculate into BME will be dropped from the course.

Prerequisite: BME matriculated students
Typically offered in Fall only

BME 205/BMME 205 Introduction to Biomedical Mechanics (4 credit hours)
Study of the state of rest or motion of bodies subjected to the action of forces. Properties of force systems, free body diagrams, concepts of equilibrium, kinematics of particles, newton's laws, conservational principles of energy of momentum in mechanics, mechanical vibrations and their applications in biomedical systems. Restricted to student in the Biomedical Engineering Department.

Credit cannot be received for both BME 205 and (CE 214 or MAE 206)
Typically offered in Fall and Spring

BME 207/BMME 207 Biomedical Electronics (4 credit hours)
Fundamentals of analog and digital circuit analysis and design as applied to biomedical instrumentation and measurement of biological potentials. Passive circuit components, node and mesh analysis, transient behavior, operational amplifiers, frequency response, analog filter design, diode, transistors, biological signal acquisition, binary math and logical operators, digital circuit design, circuit simulation tools and techniques. Laboratory exercises supplement the topics presented in class lectures.

Prerequisites: PY 208/209, BME Majors Only
Typically offered in Spring only

BME 209/BMME 209 Introduction to the Materials Science of Biomaterials (4 credit hours)
This course covers the chemistry, physics, and engineering theory underlying materials science and also discusses the diagnostic and analytical techniques necessary to assess these properties experimentally. This strong foundation prepares students to conceive and build better materials for a wide assortment of biomedical applications.

Co-req: PY 208/209. Pre-req: BME Students Only. Credit cannot be received for BME 209 and (MSE 200, MSE 201, MSE 203 or BME 203)
Typically offered in Fall and Spring

BME 215 Biomedical Mechanics Laboratory (1 credit hours)
This laboratory is part of BME 205 - Biomedical Mechanics and complements it with relevant labs and examples. Statics and dynamics subjects will be studied with experimental techniques, including strain gauges and accelerometers, and computational methods, including finite-element analysis and motion capture. Finally, the human arm will be studied to derive forces, moments, and kinematic properties during various exercises. BME student only.

Co-requisites: MAE 208
Typically offered in Fall and Spring

BME 217/BMME 217L Biomedical Electronics Laboratory (1 credit hours)
Laboratory in analog and digital circuit analysis. Electrical safety; Exercises in resistor networks, capacitors and inductors, steady-state and dynamic circuit behavior, active circuits, amplifiers, logic gates, combinatorial and sequential circuits, elementary digital system design, A/D conversion, biomedical applications.

Prerequisite: ECE 331, BME Majors
Typically offered in Spring only

BME 219 Materials Science of Biomaterials Lab (1 credit hours)
Introductory laboratory experience focused on integrating biological engineering and materials engineering principles by exploring key topics in materials science. Topics include biomaterial fabrication, evaluation of their physical properties and interpretation of results.

Pre-requisite: MSE 200 or MSE 201 or MSE/BME 203. Credit cannot be received for both BME 219 and BME 209
Typically offered in Fall and Spring

BME 290 Special Topics in Biomedical Engineering (1-4 credit hours)
A study in the special fields under the direction of the faculty. Offered as needed for presenting material not normally available in regular BME courses.

Typically offered in Fall, Spring, and Summer

BME 295/BMME 295 Research in Biomedical Engineering for Undergraduates (1-3 credit hours)
Opportunity for faculty mentored research in biomedical engineering. Approved plan of work required with significant independent research culminating in a final paper. Students must identify an advisor or co-advisor from within the BME faculty with whom to work on a regular basis. The advisor and BME Undergraduate Affairs Committee must approve the student project prior to the student registering for the course.

R: BME Majors, Departmental Approval Required
Typically offered in Fall and Spring

BME 298/BMME 298 Biomedical Engineering Design and Manufacturing I (2 credit hours)
This is the first in a series of four courses in Biomedical Design. The course introduces the tools and problem-solving skills required in the field of Biomedical Engineering.

Prerequisite: BME Majors
Typically offered in Fall and Spring

BME 299 BME Design and Manufacturing I Lab (1 credit hours)
BME 299 together with BME 252 or another course in CAD design fulfills the requirements of BME 298 Biomedical Engineering Design and Manufacturing I. In this course students learn some of the practical fundamentals of electronics manufacturing. Activities include use of bench equipment, soldering techniques, circuit board types, how to identify common electronic components and how they work in a circuit and simple C programming for microcontrollers.

Prerequisite: BME 252. Credit cannot be received for both BME 298 and BME 299
Typically offered in Fall only

BME 301/BMME 301 Human Physiology : Electrical Analysis (4 credit hours)
This course includes a quantitative approach to human physiology from the biomedical engineering perspective with an emphasis on neural, sensory, muscle, and cardiac physiology. Autonomic and somatic motor control will be discussed. Engineering applications, including neural stimulators, functional imaging, cochlear implants, artificial noses, vestibular implants, visual implants, artificial larynges, pacemakers and defibrillators will be discussed. Assignments include computer-based exercises using MATLAB.

Prerequisites: BIO 183, BM(M)E 201, [BME 210 or BM(M)E 207]
Typically offered in Fall only

BME 302/BMME 302 Human Physiology: Mechanical Analysis (4 credit hours)
This course explores a quantitative approach to human physiology from the biomedical engineering perspective with an emphasis on systems physiology described using mechanical properties. Topics include the physiological and mechanical behavior of the blood vessels, lungs, kidney muscles and larynx. In the course lab exercises, students investigate mechanical properties of fluids, electrolyte exchange in dialysis, spirometry and blood pressure measurement among other topics. The course culminates with the design of a novel laboratory experiment.

Prerequisite: BIO 183, [BM(M)E 205 or MAE 208], [BM(M)E 209 or BMME 150]
Typically offered in Spring only

BME 315/BMME 315 Biotransport (3 credit hours)
Quantification and modeling of heat and mass transfer in biomedical systems. Topics include heat transfer rate equations, conservation of energy, steady-state and transient heat transfer, Brownian motion, Fick's laws, conservation of mass equations, molecular transport through membranes, porous media, Stoke-Einstein relations, boundary layer theory, mass transfer coefficients and hemodialysis.

Prerequisite: BME/BMME 201 and (MA 341 or MA 331)
Typically offered in Fall only

BME 325/BMME 325 Biochemistry for Biomedical Engineers (3 credit hours)
An overview of how alterations in bioenergetics, enzyme catalysis, protein and membrane structure, carbohydrate, lipid and nucleic acid metabolism affect human health and how biomedical engineering tools are used to detect and monitor the problems by understanding these biochemical processes. Topics include: Biological Thermodynamics, Energy of macromolecular structure and binding, Structure/function of proteins, enzymes and nucleic acids, Kinetics, enzyme catalysis and biochemical network analysis, Generation of chemical and electrical potential in membranes, Carbohydrate/lipid/protein metabolism and energy production, DNA synthesis, transcription, Technologies used to monitor/detect biochemical processes including clinical imaging modalities.

Prerequisite: CH 221 and (BM[M]E 209 or MSE 201 or BMME 150 or BM[M]E 219); Restriction: No credit allowed for BM[M]E 325 AND [BCH 351 or BCH 451]
Typically offered in Fall only

BME 335/BMME 335 Biomaterials (3 credit hours)
Fundamental sciences behind the design and selection of biomaterials, including crystallography, polymer science, characterization, mechanical testing, and surface preparation. Integration of biomaterials into the body and its response, including inflammation and rejection. Semester-long research project.

Pre-req: BIO 183, (BM[M]E 209 or MSE 201)
Typically offered in Spring only

BME 345/BMME 345 Biomedical Solid Mechanics (3 credit hours)
This course covers topics ranging from multi-body systems to stress superposition to failure criteria to prepare students for the more advanced subjects of biomechanics and rehabilitation engineering. Topics include the following: Free-body diagrams, Multibody statics and dynamics, Linkage kinematics and kinetics, Anthropometric kinematics, Stress/strain/torsion, Beam bending, Stress superposition, Constitutive relationship, Strain gauges, Finite-element analysis, Failure analysis, Failure mechanisms.

P: BME 201 and (BM[M]E 205 OR BM[M]E 215 OR MAE 208 OR BMME 160) and (BM[M]E 209 or BM[M]E 219 OR MSE 201 OR BMME 150)
Typically offered in Spring only

BME 355/BMME 355 Biocontrols (3 credit hours)
Quantitative analysis of dynamic and feedback control systems, including modeling of physiological systems and physiological control systems, system time and frequency responses, control characteristics, and stability analysis. Design techniques for feedback systems in biomedical applications.

Prerequisite: BME/BMME 207 or BME/BMME 217 and MA 331 or MA 341
Typically offered in Spring only

BME 365/BMME 365 Linear Systems in Biomedical Engineering (3 credit hours)
Fundamentals of linear systems analysis as applied to problems in biomedical modeling and instrumentation. Properties of biomedical systems and signals. Representation of continuous- and discrete-time signals and system response. Convolution. Fourier analysis in continuous and discrete domains. Laplace transform. Frequency response and its application in biomedical systems. Filter design. Circuit analogs to mechanical and thermodynamics systems and their applications in modeling biomedical systems. Applications in biomedical instrumentation. Students use MATLAB to simulate and analyze biomedical linear systems. BME majors only.

Prerequisites: BME/BMME 201 and (BME/BMME 207 or BME/BMME 217); Corequisites: MA 341 or MA 331
Typically offered in Fall only

BME 375/BMME 375 Biomedical Microcontroller Applications (3 credit hours)
Overview of microcontroller-based systems, including applications, architecture, number systems, and languages. Students gain experience using a PIC-based microcontroller to input information from a user and output information using LEDs and LCD displays. Student will learn capabilities of the PIC through in class exercises and weekly programming assignments. Both assembly language and PIC-based C are used. Students develop a PIC-based heart rate monitor and work in pairs on a BME-related project of their choice.

Prerequisite: BM[M]E 201 and (BM[M]E 207 or BME 217)
Typically offered in Spring only

BME 385/BMME 385 Bioinstrumentation (3 credit hours)
Fundamentals of biomedical instrument design and implementation. Sensing mechanisms, sensor interfacing circuits, analog-to-digital conversion, biosignal capture and storage, embedded microprocessors, system integration and prototyping.

Prerequisite: [BM(M)E 207 or BM(M)E 217] and BM(M)E 201
Typically offered in Fall only

BME 398/BMME 398 Biomedical Engineering Design and Manufacturing II (2 credit hours)
In this course, you will learn the validation and verification stages of the design process as applied to the development of new medical devices. This course is the second part of a 3 year sequence in which you will learn the process of biomedical engineering design along with technical skills that will allow you to develop new devices to solve unmet medical needs.

Prerequisite: BM[M]E 298
Typically offered in Fall and Spring

BME 412 Biomedical Signal Processing (3 credit hours)
Fundamentals of continuous- and discrete-time signal processing as applied to problems in biomedical instrumentation. Properties of biomedical signals and instruments. Descriptions of random noise and signal processes. Interactions between randombiomedical signals and systems. Wiener filtering. Sampling theory. Discrete-time signal analysis. Applications of Z-transform and discrete Fourier transform. Digital filter design methods for biomedical instruments. BME or MS or PHD; credit not allowed for both BME 412 and BME 512.

Pre-reqs: BM(M)E 365 or BME 311
Typically offered in Spring only

BME 418/BME 518/ECE 518/ECE 418 Wearable Biosensors and Microsystems (3 credit hours)
This course surveys the methods and application of wearable electronics and microsystems to monitor human biometrics, physiology, and environmental conditions. Topics covered include wearable electrocardiograms, blood-glucose monitors, electronic tattoos, wearable energy harvesting, "smart" clothing, body area networks, and distributed population networks. Critical comparison of different sensor modalities, quantitative metrics, and how their limitations in realistic applications define the selection, design, and operation criteria of one type of sensor over another will be considered.

Prerequisite: Senior standing
Typically offered in Fall only

BME 425/BME 525 Bioelectricity (3 credit hours)
Quantitative analysis of excitable membranes and their signals, including plasma membrane characteristics, origin of electrical membrane potentials, action potentials, voltage clamp experiments, the Hodgkin-Huxley equations, propagation, subthresholdstimuli, extracellular fields, membrane biophysics, and electrophysiology of the heart. Design and development of an electrocardiogram analysis system.

Prerequisite: BME 302 or (ZO 421 and a course in electrical circuits)
Typically offered in Spring only

BME 429/BME 529 Cellular Engineering (3 credit hours)
Cellular Engineering utilizes engineering principles to solve problems in cellular and molecular biology, particularly in the context of regenerative medicine and cell therapies. This course will cover a broad range of topics that allow for quantitative analysis and manipulation of cellular and subcellular processes. Topics covered in this course include: cell growth kinetics; enzyme kinetics; signal transduction networks; genetic engineering; receptor-ligand interactions; quantitative analysis of cell-cell and cell-material adhesion; mechanisms of mechanotrandsuction; and commercialization and scale-up.

P: BME 325 or BMME 325 or BCH351
Typically offered in Fall only

BME 438/BME 538 Bone Mechanobiology (3 credit hours)
This course focuses on understanding the biology and mechanics of bone tissue, in healthy and altered states such as in injury, aging, and disease. Topics include: skeletal anatomy and physiology; bone tissue composition, structure, and function; mechanical behavior of bone at cell, tissue, and organ levels; skeletal functional adaptation to its mechanical environment; and experimental and analytical methods in bone mechanics and mechanobiology. Fundamental research in the field and clinical applications are discussed.

P: BME/BMME 335 or BME/BMME 345 or MAE 214 or CE 225
Typically offered in Spring only

BME 444/BME 544 Orthopaedic Biomechanics (3 credit hours)
Students study human body kinematics, force analysis of joints, and the structure and composition of biological materials. Emphasis is placed on the measurement of mechanical properties and the development and understanding of models of biological material mechanical behavior.

P: BM(M)E 301, BM(M)E 302, [BM(M)E 345 or MAE 214 or CE 313]
Typically offered in Fall only

BME 448/BME 548 Functional Tissue Engineering (3 credit hours)
This course focuses on the design of tissue engineered replacements which attempt to mimic the underlying structural and functional properties of the original tissue. Overall course objectives are to 1) provide students with the knowledge to understand the functional requirements of native tissues and topics related to functional tissue engineering, and 2) prepare students to design new engineered tissues that can meet physiological demands. Topics include: design of native tissues and replacements from an engineering perspective; tissue composition, structure, and function; modeling of native and engineered tissues; methods to enhance tissue engineered replacements; and regenerative engineering.

P: BME/BMME 345
Typically offered in Fall only

BME 451/BMME 451 BME Senior Design: Product Development (3 credit hours)
This course is part of a three year sequence and it expands on the skills and knowledge gained in BM(M)E 398. Students continue to learn the process of engineering design and learn new skills to produce solutions for unmet medical needs.

Pre-reqs: BME 398, BME 301 or 302, 2 gateway or specialty electives completed
Typically offered in Fall only

BME 452/BMME 452 BME Senior Design: Product Implementation and Strategy (3 credit hours)
This course is part of a three-year sequence and it expands on the skills and knowledge gained in prior design courses. Students continue to learn the process of engineering design and learn new skills to produce solutions for unmet medical needs. Implementation phase of the senior design experience.

Pre-reqs: BME 398, BME 301 or 302, 2 gateway or specialty electives completed; Co-req: taking at least 3 gateway or specialization electives
Typically offered in Spring only

BME 456/BME 556 Rehabilitation Robotics (3 credit hours)
This course explores the use of robotic and mechatronic technology to restore function in individuals with sensorimotor impairment. The theoretical framework will be introduced for assessment and design of both assistive and therapeutic applications. Students will create a computer model of movement of limb in conjunction with a mechatronic device.

P: [BM[M]E 205 or BM[M]E 215] and BM[M]E 302 and [BM[M]E 355 or BM[M]E 365 or BM[M]E 375]
Typically offered in Fall only

BME 463/BME 563 Biomedical Optics and Lasers (3 credit hours)
This course will focus on non-invasive methods/techniques that use visible light/NIR/UV to monitor biological processes in humans, animal models and cells. The first part of the course will focus on the basic principles of light (e.g. radiation transport equation) and light-tissue interactions. The second part will focus on a variety of spectroscopic and imaging methods, flow cytometry and more. Applications include: The pulse oximeter, monitoring metabolic activity and non-invasive diagnosis of diseases. The course is designed for biomedical engineering students who plan to work in the medical device industry.

Prerequisite: (MA 331 or MA 341) and [BM[M]E 301 or BMME 302]
Typically offered in Spring only

BME 464/BME 564 Microscopy (3 credit hours)
The course is an introductory class to microscopy. This course aims to build the intuition that engineers use to understand optical systems and will cover the basic principles of light, such as reflection and refraction, light-wave characteristics, polarization, interference, coherence and more, with an emphasis on optical components that utilize these concepts. A particular focus will be on microscopy and geometrical optics and multiple topics in this area such as: the Abbe theory of image formation, darkfield imaging and fluorescence microscopy. Recent literature in the field will be reviewed and complex imaging systems simplified in order to understand their design principles. The course is designed for biomedical engineering students who plan to work in the medical device industry.

Prerequisite: BME/BMME 365
Typically offered in Spring only

BME 466/TE 566/BME 566/TE 466 Polymeric Biomaterials Engineering (3 credit hours)
In-depth study of the engineering design of biomedical polymers and implants. Polymeric biomaterials, including polymer synthesis and structure, polymer properties as related to designing orthopedic and vascular grafts. Designing textile products as biomaterials including surface modification and characterization techniques. Bioresorbable polymers.

Prerequisite: PY 208 and (TE 200 or CH 220 or CH 221 or CH 225) and (MAE 206 or CE 214)
Typically offered in Fall only

BME 467/TE 467 Mechanics of Tissues & Implants Requirements (3 credit hours)
Application of engineering and biological principles to understand the structure and performance of tendons, ligaments, skin, and bone; bone mechanics; viscoelasticity of soft biological tissues; models of soft biological tissues; mechanics of skeletal muscle; and tissue-derived devices as well as interfaces between native tissues and synthetic devices.

Prerequisite: (ZO 160 or BIO 183) and (MAE 214 or CE 225)
Typically offered in Spring only

BME 481 Quality Management Systems for Engineers (3 credit hours)
This course is designed for biomedical engineering students who plan to work in industry. The course covers industry related topics including team work, conflict resolution, manufacturing and specifications, gap analysis, and root cause of analysis. Design topics including design of experiments, and standards and regulations relevant to the biomedical engineering profession are also covered. Lean and six sigma are taught with an option to test for a six sigma green belt if a six sigma project is completed in the following semester.

Co-reqs: BMME 697 or BME 451
Typically offered in Fall only

BME 483/BEC 483/BME 583/BEC 583 Tissue Engineering Technologies (2 credit hours)
In this half-semester laboratory module, students will gain practical experience with two key elements of tissue engineering: tissue building and angiogenesis. Using advanced culture techniques, students will construct a complex living tissue that closely resembles its natural counterpart, then assess its ability to support ingrowth of capillaries (angiogenesis). The effects of different biomaterials and angiogenic factors will be evaluated. The engineered tissue will be embedded, sectioned and stained for histological analysis.

Prerequisite: BIT 466/566 or permission of instructor
Typically offered in Fall only

BME 484/BME 584 Fundamentals of Tissue Engineering (3 credit hours)
This course covers essential concepts of organ and tissue design and engineering using living components, including cell-based systems and cells/tissues in combination with biomaterials, synthetic materials and/or devices. Topics include: In vivo tissue structure and function; Isolation and culture of primary cells and stem cells; Principles of cellular differentiation; Mass transport processes in cell culture systems; Design, production and seeding of scaffolds for 3D culture; Design of bioreactors to support high-density cell growth; State-of-the-art engineered tissue systems; Clinical translation; and Ethics.

Prerequisite: BIO 183, CH 221, and (MAE 201 or MSE 301 or CHE 315 or TE 303 or BME 315 or BME 325)
Typically offered in Spring only

BME 490/BMME 490 Special Topics in Biomedical Engineering (1-4 credit hours)
Offered as needed for presenting material not normally available in regular BME Department courses or for new BME courses on a trial basis.

Typically offered in Fall, Spring, and Summer

BME 491 Biomedical Engineering Honors Thesis I (3 credit hours)
First in a two-semester sequence of research courses that partially fulfills the requirements for graduation with departmental honors. Prior approval needed for enrollment. Students should identify a research mentor and research topic before applying. Minimum GPA requirement and written report are required. The course does not meet a graduation requirement, and can only be used to meet the requirements of graduation with departmental honors.

Typically offered in Fall only

BME 492 Biomedical Engineering Honors Thesis II (3 credit hours)
Second in a two-semester sequence of research courses that partially fulfills the requirements for graduation with departmental honors. Students work with a mentor on an independent research project. Minimum GPA requirement and written report are required. The course does not meet a graduation requirement if used to meet the requirements of graduation with departmental honors.

Prerequisite: BME 491 and project continuation approval by the BME Undergraduate Research Committee
Typically offered in Spring only

BME 495 Undergraduate Research in Biomedical Engineering (3 credit hours)
Opportunity for hands-on faculty mentored research project in biomedical engineering. Course may be a stand-alone project completed in one semester/summer or serve as part of a two-semester project. Approved plan of work required with significant independent research culminating in a final paper and presentation at the NC State Undergraduate Research Symposium or other appropriate venue. Students must identify an advisor from within the BME faculty with whom to work on a regular basis. The advisor must approve the student prior to the student registering for the course. The BME Undergraduate Coordinator must approve the use of the course as a restricted elective for the BME degree. Departmental Approval Required. Individualized/Independent Study and Research courses require a Course Agreement for Students Enrolled in Non-Standard Courses be completed by the student and faculty member prior to registration by the department.

Typically offered in Fall and Spring

BME 501 MedTech Innovation and Entrepreneurship I - Needs Discovery (4 credit hours)
This course utilizes clinical immersion to identify medical device and other healthcare opportunities. Students will be exposed to diverse healthcare environments and learn to triage opportunities based on financial, regulatory and intellectual property landscapes. Guest lectures will feature experts in the medical device, pharmaceutical and healthcare industries as well as local entrepreneurs.

Prerequisite: Graduate Standing; R: Restricted to students enrolled in the M.S. Biomedical Engineering - MedTech Innovation and Entrepreneurship Program
Typically offered in Summer only

BME 502 MedTech Innovation and Entrepreneurship II - Design and Regulation (4 credit hours)
This course teaches path-to-market concepts including regulatory aspects unique to medical devices and pharmaceuticals. Topics include detailed analyses of Phase I-IV clinical trials, 510(k) and PMA approvals, Investigational Device Exemption (IDE) Investigational New Drug (IND) application, Good Laboratory Practices (GLP) and clinical research organizations (CROs). Students will participate in frequent visits to local biotech companies. Guest lectures will feature experts in FDA processes, clinical research and early stage biotech ventures.

Prerequisite: Graduate Standing; R: Restricted to students enrolled in the M.S. Biomedical Engineering - MedTech Innovation and Entrepreneurship Program
Typically offered in Fall only

BME 503 MedTech Innovation and Entrepreneurship III - Product Development (4 credit hours)
This course covers product development and project management for new biomedical-related products from accessing various streams of funding to allocation of resources for rapid prototyping and scale-up manufacturing. Students will visit local biotech companies and prototyping facilities. A guest lecture series will feature best practices from entrepreneurs and industry practitioners.

Prerequisite: Graduate Standing; R: Restricted to students enrolled in the M.S. Biomedical Engineering - MedTech Innovation and Entrepreneurship Program
Typically offered in Spring only

BME 504 Medical Device Materials and Manufacturing (3 credit hours)
This course will immerse students in state-of-the-art medical device materials and manufacturing methods. Students will explore materials that are commonly used in medical devices, including metals such as nitinol and various grades of stainless steels, as well as engineering plastics such as PEEK and sustainable materials such as renewable polyethylene (PR) and polyethylene terephthalate (PET). The course will also introduce common manufacturing methods and design guides for each of the materials covered with the students responsible for the design and manufacture of components and subassemblies to demonstrate an understanding of the techniques. Finally, the students will be required to leverage some of these materials and manufacturing techniques to develop components and assemblies for use in their solutions for the needs identified in BME 501 and further developed in BME 502 and 503.

Restriction: Graduate Standing in M.S. Biomedical Engineering Program
Typically offered in Fall only

BME 512 Biomedical Signal Processing (3 credit hours)
Fundamentals of continuous- and discrete-time signal processing as applied to problems in biomedical instrumentation. Properties of biomedical signals and instruments. Descriptions of random noise and signal processes. Interactions between random biomedical signals and systems. Wiener filtering. Sampling theory. Discrete-time signal analysis. Applications of Z-transform and discrete Fourier transform. Digital filter design methods for biomedical instruments. Biomedical applications of filter design, signal restoration, and signal detection.

Prerequisite: BME 311, and ST 370 or ST 371
Typically offered in Spring only

BME 516/BMME 516 Advanced Drug Delivery (3 credit hours)
This course covers the engineering of novel pharmaceutical delivery systems with enhanced efficacy and safety profiles, with an emphasis on the design and application of materials that overcome drug delivery barriers or challenges. Topics will include drug delivery fundamentals and transport mechanisms, materials and formulations for drug delivery, and applications.

R: For Undergraduate students taking the course at the 500 level: BME 302 and BME 209 and CH 221; For Graduate students: Graduate standing
Typically offered in Spring only

BME 518/ECE 518/ECE 418/BME 418 Wearable Biosensors and Microsystems (3 credit hours)
This course surveys the methods and application of wearable electronics and microsystems to monitor human biometrics, physiology, and environmental conditions. Topics covered include wearable electrocardiograms, blood-glucose monitors, electronic tattoos, wearable energy harvesting, "smart" clothing, body area networks, and distributed population networks. Critical comparison of different sensor modalities, quantitative metrics, and how their limitations in realistic applications define the selection, design, and operation criteria of one type of sensor over another will be considered.

Prerequisite: Senior standing
Typically offered in Fall only

BME 522/ECE 522 Medical Instrumentation (3 credit hours)
Fundamentals of medical instrumentation systems, sensors, and biomedical signal processing. Example instruments for cardiovascular and respiratory assessment. Clinical laboratory measurements, theraputic and prosthetic devices, and electrical safetyrequirements. Students should have background in electronics design using operational amplifiers.

Typically offered in Spring only

BME 525/BME 425 Bioelectricity (3 credit hours)
Quantitative analysis of excitable membranes and their signals, including plasma membrane characteristics, origin of electrical membrane potentials, action potentials, voltage clamp experiments, the Hodgkin-Huxley equations, propagation, subthresholdstimuli, extracellular fields, membrane biophysics, and electrophysiology of the heart. Design and development of an electrocardiogram analysis system.

Prerequisite: BME 302 or (ZO 421 and a course in electrical circuits)
Typically offered in Spring only

BME 529/BME 429 Cellular Engineering (3 credit hours)
Cellular Engineering utilizes engineering principles to solve problems in cellular and molecular biology, particularly in the context of regenerative medicine and cell therapies. This course will cover a broad range of topics that allow for quantitative analysis and manipulation of cellular and subcellular processes. Topics covered in this course include: cell growth kinetics; enzyme kinetics; signal transduction networks; genetic engineering; receptor-ligand interactions; quantitative analysis of cell-cell and cell-material adhesion; mechanisms of mechanotrandsuction; and commercialization and scale-up.

P: BME 325 or BMME 325 or BCH351
Typically offered in Fall only

BME 538/BME 438 Bone Mechanobiology (3 credit hours)
This course focuses on understanding the biology and mechanics of bone tissue, in healthy and altered states such as in injury, aging, and disease. Topics include: skeletal anatomy and physiology; bone tissue composition, structure, and function; mechanical behavior of bone at cell, tissue, and organ levels; skeletal functional adaptation to its mechanical environment; and experimental and analytical methods in bone mechanics and mechanobiology. Fundamental research in the field and clinical applications are discussed.

P: BME/BMME 335 or BME/BMME 345 or MAE 214 or CE 225
Typically offered in Spring only

BME 540 Nanobiotechnology Processing, Characterization, and Applications (3 credit hours)
Topics at the interface of nanoscale science and biotechnology will be discussed. Chemical, physical, and biological properties of nanostructured biomaterials, devices, and systems. Lectures and problem-based learning will be used to present development of nanobiotechnology-enhanced materials and devices.

Prerequisite: BIO 183 and PY 212
Typically offered in Spring only

BME 544/BME 444 Orthopaedic Biomechanics (3 credit hours)
Students study human body kinematics, force analysis of joints, and the structure and composition of biological materials. Emphasis is placed on the measurement of mechanical properties and the development and understanding of models of biological material mechanical behavior.

P: BM(M)E 301, BM(M)E 302, [BM(M)E 345 or MAE 214 or CE 313]
Typically offered in Fall only

BME 548/BME 448 Functional Tissue Engineering (3 credit hours)
This course focuses on the design of tissue engineered replacements which attempt to mimic the underlying structural and functional properties of the original tissue. Overall course objectives are to 1) provide students with the knowledge to understand the functional requirements of native tissues and topics related to functional tissue engineering, and 2) prepare students to design new engineered tissues that can meet physiological demands. Topics include: design of native tissues and replacements from an engineering perspective; tissue composition, structure, and function; modeling of native and engineered tissues; methods to enhance tissue engineered replacements; and regenerative engineering.

P: BME/BMME 345
Typically offered in Fall only

BME 551 Medical Device Design (3 credit hours)
Student multidisciplinary teams work with local medical professionals to define specific medical device concepts for implementation. Medical specialty immersion with clinical departments at local medical centers; design input based on stakeholder-needs assessment' market analysis and intellectual property review; new medical devices with broad markets; design output and device specification; product feasibility and risk assessment; design for medical device manufacturing.

Typically offered in Fall only

BME 556/BME 456 Rehabilitation Robotics (3 credit hours)
This course explores the use of robotic and mechatronic technology to restore function in individuals with sensorimotor impairment. The theoretical framework will be introduced for assessment and design of both assistive and therapeutic applications. Students will create a computer model of movement of limb in conjunction with a mechatronic device.

P: [BM[M]E 205 or BM[M]E 215] and BM[M]E 302 and [BM[M]E 355 or BM[M]E 365 or BM[M]E 375]
Typically offered in Fall only

BME 560/BMME 560 Medical Imaging: X-ray, CT, and Nuclear Medicine Systems (3 credit hours)
Overview of medical imaging systems using ionizing radiation. Interaction of radiation with matter. Radiation production and detection. Radiography systems and applications. Tomography. PET and SPECT systems and applications.

Prerequisite: BME 311, ST 370 or ST 371, and PY 208

BME 563/BME 463 Biomedical Optics and Lasers (3 credit hours)
This course will focus on non-invasive methods/techniques that use visible light/NIR/UV to monitor biological processes in humans, animal models and cells. The first part of the course will focus on the basic principles of light (e.g. radiation transport equation) and light-tissue interactions. The second part will focus on a variety of spectroscopic and imaging methods, flow cytometry and more. Applications include: The pulse oximeter, monitoring metabolic activity and non-invasive diagnosis of diseases. The course is designed for biomedical engineering students who plan to work in the medical device industry.

Prerequisite: (MA 331 or MA 341) and [BM[M]E 301 or BMME 302]
Typically offered in Spring only

BME 564/BME 464 Microscopy (3 credit hours)
The course is an introductory class to microscopy. This course aims to build the intuition that engineers use to understand optical systems and will cover the basic principles of light, such as reflection and refraction, light-wave characteristics, polarization, interference, coherence and more, with an emphasis on optical components that utilize these concepts. A particular focus will be on microscopy and geometrical optics and multiple topics in this area such as: the Abbe theory of image formation, darkfield imaging and fluorescence microscopy. Recent literature in the field will be reviewed and complex imaging systems simplified in order to understand their design principles. The course is designed for biomedical engineering students who plan to work in the medical device industry.

Prerequisite: BME/BMME 365
Typically offered in Spring only

BME 566/TE 466/BME 466/TE 566 Polymeric Biomaterials Engineering (3 credit hours)
In-depth study of the engineering design of biomedical polymers and implants. Polymeric biomaterials, including polymer synthesis and structure, polymer properties as related to designing orthopedic and vascular grafts. Designing textile products as biomaterials including surface modification and characterization techniques. Bioresorbable polymers.

Prerequisite: PY 208 and (TE 200 or CH 220 or CH 221 or CH 225) and (MAE 206 or CE 214)
Typically offered in Fall only

BME 570 ImmunoEngineering (3 credit hours)
The immune system influences nearly all aspects of human health and therefore deserves consideration by investigators developing devices, drugs and strategies to improve human health. The course begins with a brief review of the immune system, fundamental immunological assays and the role of the immune system in disease. The second part of the course focuses on immune responses to a range of biomaterials. The third part will explore immune responses in the context of vaccines, immunotherapies and regenerative medicine.

P: Graduate Standing
Typically offered in Spring only

BME 571 Intro to Nano-Biomaterials (3 credit hours)
Chemical, physical, biological, and engineering aspects of nanostructured materials used in medical implants.

Prerequisites: Introduction to the Materials Science of Biomaterials (BME (MSE) 203), Human Physiology for Engineers I (BME 301) and Human Physiology for Engineers II (BME 302). Equivalent courses accepted at discretion of instructor.
Typically offered in Spring and Summer

BME 583/BEC 583/BME 483/BEC 483 Tissue Engineering Technologies (2 credit hours)
In this half-semester laboratory module, students will gain practical experience with two key elements of tissue engineering: tissue building and angiogenesis. Using advanced culture techniques, students will construct a complex living tissue that closely resembles its natural counterpart, then assess its ability to support ingrowth of capillaries (angiogenesis). The effects of different biomaterials and angiogenic factors will be evaluated. The engineered tissue will be embedded, sectioned and stained for histological analysis.

Prerequisite: BIT 466/566 or permission of instructor
Typically offered in Fall only

BME 584/BME 484 Fundamentals of Tissue Engineering (3 credit hours)
This course covers essential concepts of organ and tissue design and engineering using living components, including cell-based systems and cells/tissues in combination with biomaterials, synthetic materials and/or devices. Topics include: In vivo tissue structure and function; Isolation and culture of primary cells and stem cells; Principles of cellular differentiation; Mass transport processes in cell culture systems; Design, production and seeding of scaffolds for 3D culture; Design of bioreactors to support high-density cell growth; State-of-the-art engineered tissue systems; Clinical translation; and Ethics.

Prerequisite: BIO 183, CH 221, and (MAE 201 or MSE 301 or CHE 315 or TE 303 or BME 315 or BME 325)
Typically offered in Spring only

BME 590/BMME 590 Special Topics in Biomedical Engineering (1-6 credit hours)
A study of topics in the special fields under the direction of the graduate faculty.

Typically offered in Fall, Spring, and Summer

BME 650 Internship in Biomedical Engineering (1-3 credit hours)
Students obtain professional experience through advanced engineering work in industrial and commercial settings under joint supervision of a member of the graduate faculty and an outside professional.

Prerequisite: Graduate standing in BME
Typically offered in Fall, Spring, and Summer

BME 693 Master's Supervised Research (1-9 credit hours)
Instruction in research and research under the mentorship of a member of the Graduate Faculty.

Prerequisite: Master's student
Typically offered in Spring and Summer

BME 695 Master's Thesis Research (1-9 credit hours)
Thesis research.

Prerequisite: Master's student
Typically offered in Spring and Summer

BME 699 Master's Thesis Preparation (1-9 credit hours)
For students who have completed all credit hour requirements and full-time enrollment for the master's degree and are writing and defending their thesis.

Prerequisite: Master's student
Typically offered in Fall, Spring, and Summer

BME 790 Advanced Special Topics in Biomedical Engineering (1-6 credit hours)
A study of topics in advanced or emerging special areas under the direction of the graduate faculty. Experimental doctoral level courses.

Prerequisite: Graduate standing in engineering, physical, or biological sciences or textiles
Typically offered in Fall, Spring, and Summer

BME 802 Advanced Seminar in Biomedical Engineering (1 credit hours)
Elaboration of advanced subject areas, techniques and methods related to professional interest through presentations of personal and published works; opportunity for students to present and critically defend ideas, concepts, and inferences; opportunity for distinguished scholars to present results of their work. Discussions to uncover analytical solutions and analogies between problems in biomedical engineering and other technologies, and to present relationship of biomedical engineering to society.

Prerequisite: Doctoral student in BME or other engineering, physical science, or biological science majors, or textiles
Typically offered in Fall and Spring

BME 885 Doctoral Supervised Teaching (1-3 credit hours)
Teaching experience under the mentorship of faculty who assist the student in planning but the teaching assignment, observe and provide feedback to the student during the teaching assignment, and evaluate the student upon completion of the assignment.

Prerequisite: Doctoral student
Typically offered in Fall, Spring, and Summer

BME 890 Doctoral Preliminary Examination (1-9 credit hours)
For students who are preparing for and taking written and/or oral preliminary exams.

Prerequisite: Doctoral student
Typically offered in Summer only

BME 893 Doctoral Supervised Research (1-9 credit hours)
Instruction in research and research under the mentorship of a member of the Graduate Faculty.

Prerequisite: Doctoral student
Typically offered in Fall and Spring

BME 895 Doctoral Dissertation Research (1-9 credit hours)
Dissertation research.

Prerequisite: Doctoral student
Typically offered in Fall, Spring, and Summer

BME 899 Doctoral Dissertation Preparation (1-9 credit hours)
For students who have completed all credit hour, full-time enrollment, preliminary examination, and residency requirements for the doctoral degree, and are writing and defending their dissertations.

Prerequisite: Doctoral student
Typically offered in Spring and Summer