Biomedical Engineering (BIEN)

Interim Chairperson: Lars E. Olson, Ph.D.
Biomedical Engineering Graduate Programs website (http://www.marquette.edu/engineering/biomedical/grad.shtml)

Degrees Offered

Master of Science, Master of Engineering; Doctor of Philosophy

Mission Statement

The Department of Biomedical Engineering is a dedicated team committed to the Jesuit tradition of the pursuit of truth. We develop leaders and problem solvers skilled at applying engineering, science and design principles to improve health in the service of humanity by:

- Discovering and disseminating new knowledge;
- Promoting critical thinking and lifelong learning;
- Guiding students to meaningful and ethical professional and personal lives;
- Fostering interdisciplinary and collaborative research and education through academic and industrial alliances;
- Continuing innovative leadership in education, research and industrial relationships; and
- Inspiring faculty and students to serve others.

Program Descriptions

The biomedical engineering program is interdisciplinary in nature, involving the application of engineering and mathematics to the solution of problems related to medicine and biology. The faculty reflect this interdisciplinary nature in their courses and research. Marquette faculty are synergistically complemented by faculty from the Medical College of Wisconsin. The Department of Biomedical Engineering fosters collaborative interactions between the two institutions. Research can be characterized by the general areas of bioinstrumentation/computers, biomechanics/biomaterials, rehabilitation bioengineering and systems physiology. More specific areas of research include: artificial limbs/prostheses, biomaterials, biotelemetry, cell transport and metabolism, cardiac electrophysiology, computers in medicine, functional imaging (magnetic resonance, X-ray), head and spinal cord trauma, hemodynamics, human motion analysis, medical and biological image analysis, physiological signal processing, rehabilitation engineering, systems physiology (cardiovascular, gastrointestinal, musculoskeletal, neuroscience, pulmonary), telerehabilitation, tissue engineering, hard and soft tissue biomechanics and transcutaneous power transfer.

Bioengineering and Functional Imaging Specializations — MU/MCW Joint doctoral programs

Bioengineering is the application of experimental and analytical techniques based on the engineering sciences to the development of biologics, materials, devices, implants, processes and systems that advance biology and medicine and improve medical practice and health care. The joint doctoral program in bioengineering is a collaborative effort between Marquette University and the Medical College of Wisconsin that aims to translate engineering technologies to clinical practice.

Functional imaging is the simultaneous quantification of the structural and functional aspects of a biological system. Modern X-ray, nuclear magnetic resonance and other means of imaging in relatively noninvasive ways have made functional imaging increasingly practical. The joint doctoral program in functional imaging trains students in the use of these new technologies to obtain high-resolution structural, kinematic and kinetic data from intact organs, and in the use of mathematical modeling to understand organ physiology.

For these joint programs, special registration is required since courses are taken at both institutions. Students must register for the course BIEN 6947 through Marquette University and for the matching MCW course through the Medical College of Wisconsin.

Prerequisites for Admission

Students with backgrounds in engineering, physical science and life science disciplines are eligible for admission to the master of science, master of engineering and doctoral programs in biomedical engineering. A baccalaureate degree in an appropriate area with a minimum grade point average of 3.000 is required. Applicants who do not have an engineering degree must complete prerequisite engineering requirements. The list of prerequisites can be obtained from the department office.

Application Requirements

Applicants must submit, directly to the Marquette University Graduate School:

1. A completed application form and fee online (http://marquette.edu/grad/future_apply.shtml).
2. Copies of all college/university transcripts except Marquette.*
3. Three letters of recommendation.
4. GRE scores (General Test only).

5. A brief statement of purpose that includes the proposed area of research specialization.
6. (For master of engineering applicants only) an interview with the M.E. program director.
7. (For international applicants only) a TOEFL score or other acceptable proof of English proficiency.

* Upon admission, final official transcripts from all previously attended colleges/universities, with certified English translations if original language is not English, must be submitted to the Graduate School within the first five weeks of the term of admission or a hold preventing registration for future terms will be placed on the student's record.

General Information

All admitted students are required to obtain and read the department's Graduate Student Handbook (http://www.marquette.edu/engineering/biomedical/documents/GradHandbook10-2-2013.pdf), which contains complete details about the biomedical engineering programs and additional departmental degrees. This handbook is available through the Biomedical Engineering Office (414) 288-3375 and website (http://www.marquette.edu/engineering/biomedical/grad.shtml).

Biomedical Engineering Master of Science (M.S.) Requirements

Specializations: Bioinstrumentation/Computers, Biomechanics/Biomaterials, Rehabilitation Bioengineering, Systems Physiology

Upon enrolling in the master of science program in biomedical engineering, a student selects one of four specializations. Faculty will design a curriculum and research program to address the specific goals of each student. Programs will include course work in engineering, biology, mathematics and medicine, all of which will be integrated with research laboratory experience.

A master of science student must complete 24 credit hours of course work (including three credit hours of physiology) and six credit hours of thesis work. The student also must pass a comprehensive examination and submit an approved thesis.

Accelerated Bachelor's-Master's Degree Program

This program allows Marquette University students to earn both their master of science degree in biomedical engineering and a bachelor of science degree in five years. Students currently enrolled in the undergraduate biomedical engineering program at Marquette University (with a GPA of 3.500 or above) may apply for admission to the five-year program during their junior year. Students must submit an application to the Graduate School, indicate their interest in the five-year program and meet all other admission criteria as stated in the Application Requirements section. (GRE test scores must be submitted before the start of the fifth year.)

Students may take master's level courses in their senior undergraduate year. These graduate courses count toward both the undergraduate and graduate degrees. The remaining courses are taken during the students' fifth year. Work on the students' theses research begins the summer between the junior and senior years. Students will continue to gain research laboratory experience the summer between the senior and fifth year, continuing through the final year, culminating in preparation of a written thesis and defense. Upon completion of the first term as master's candidates, students must petition the Graduate School to transfer courses taken as undergraduates to the master's degree.

Biomedical Engineering Master of Engineering (M.E.) Requirements

Specializations: Biocomputing, Bioimaging, Bioinstrumentation, Biomechanics, Biorehabilitation

Upon enrolling in the master of engineering program in biomedical engineering, a student selects one of five specializations and follows the curriculum designed for that specialization. The program includes course work in engineering, life sciences, mathematics, medicine and healthcare technologies management, all of which will be integrated in a capstone comprehensive written exam.

A master of engineering student must complete a total of 30 credit hours of course work, which includes three credits of independent readings and research. The student also must pass the capstone comprehensive examination.

Biomedical Engineering Doctoral Requirements

Specializations: Bioengineering, Bioinstrumentation/Computers, Biomechanics/Biomaterials, Functional Imaging, Rehabilitation Bioengineering, Systems Physiology

Upon enrolling in the doctoral program in biomedical engineering, a student selects his or her area of specialization. Faculty will design a curriculum and research program to address the specific goals of each student. Programs will include course work in engineering, biology, mathematics and medicine, all of which will be integrated with research laboratory experience.

The doctor of philosophy degree is conferred in recognition of marked ability and high attainment in the advancement of knowledge and pursuit of truth. The comprehensive knowledge expected of the student in his or her major field is such that the requirements for the degree usually take no less than four years of full-time work, or the equivalent, beyond the baccalaureate degree.

A doctoral student must complete a program of study prepared in consultation with his or her dissertation adviser and outlined on an approved Doctoral Program Planning Form. The program normally requires 36 credit hours of course work beyond the baccalaureate degree (a minimum of 18 credit hours

beyond the master's degree) plus 12 credit hours of dissertation work. Doctoral course work must include a minimum of three credit hours of graduate-level physiology. The student also must pass a doctoral qualifying examination (DQE) and submit and successfully defend a dissertation.

The Doctoral Candidacy Examination consists of both written and oral components. Students entering the doctoral program with a master's degree are required to take the written portion within two terms after entering the program. Students entering the doctoral program with a bachelor's degree are required to take the written portion before or at completion of 30 graduate credit hours or completion of the master's degree, whichever comes first. Each student is expected to complete the oral portion by the end of the third year.

The dissertation must represent an original research contribution showing high attainment and clear ability to do independent research. A public defense of the dissertation (the final oral examination) is conducted after the student has completed all other formal requirements for the doctoral degree and has submitted a completed doctoral dissertation to his or her doctoral committee. The dissertation defense is conducted in the form of a department seminar.

Courses

BIEN 5220. Embedded Biomedical Instrumentation. 3 cr. hrs.
Fundamentals of digital circuit design and analysis and the application to embedded biomedical instrumentation. Topics include microprocessor principles and programming and system design constraints for medical electronics. Laboratory provides applications of concepts introduced in class.

BIEN 5230. Intelligent Biosystems. 3 cr. hrs.
Use of emerging tools in systems biology and soft computing to explore how biosystems with highly distributed "intelligence" are designed to adapt to self- and environmentally-induced perturbations. Students obtain a basic understanding of key soft computing tools and use fuzzy expert system models. Applications to smart healthcare monitoring and future product design will be explored. Prereq: BIEN 4700/5700.

BIEN 5320. Biomedical Instrumentation Design. 3 cr. hrs.
Problems in instrumentation relating to physiological measurements in the laboratory and clinic. Electronic devices for stimulus as well as measurement of physiological quantities. Design of actual instruments. Features include mechanical design, accessory design and safety requirements.

BIEN 5400. Transport Phenomena. 3 cr. hrs.
Applications of mass, momentum, and mechanical energy balances to biomedical fluid systems. Study of physiological phenomena with an emphasis on cardiovascular systems and blood rheology.

BIEN 5410. Applied Finite Element Analysis. 3 cr. hrs.
Introduces the finite element solution method for linear, static problems. Includes calculation of element stiffness matrices, assembly of global stiffness matrices, exposure to various finite element solution methods, and numerical integration. Emphasizes structural mechanics, and also discusses heat transfer and fluid mechanics applications in finite element analysis. Computer assignments include development of finite element code (FORTRAN or C) and also use of commercial finite element software (ANSYS and/or MARC).

BIEN 5420. Biomaterials Science and Engineering. 3 cr. hrs.
Designed to introduce the uses of materials in the human body for the purposes of healing, correcting deformities and restoring lost function. The science aspect of the course encompasses topics including: characterization of material properties, biocompatibility and past and current uses of materials for novel devices that are both biocompatible and functional for the life of the implanted device. Projects allow students to focus and gain knowledge in an area of biomaterials engineering in which they are interested. Prereq: MEEN 2460 or cons. of instr.

BIEN 5500. Medical Imaging Physics. 3 cr. hrs.
Examines how light, X-rays, radiopharmaceuticals, ultrasound, magnetic fields, and other energy probes are generated and how they interact with tissues and detectors to produce useful image contrast. Addresses practical issues such as beam generation, dose limitations, patient motion, spatial resolution and dynamic range limitations, and cost-effectiveness. Emphasizes diagnostic radiological imaging physics, including the planar X-ray, digital subtraction angiography mammography, computed tomography, nuclear medicine, ultrasound, and magnetic resonance imaging modalities.

BIEN 5510. Image Processing for the Biomedical Sciences. 3 cr. hrs.
Introduces biomedical image processing. Topics explored include: the human visual system, spatial sampling and digitization, image transforms, spatial filtering, Fourier analysis, image enhancement and restoration, nonlinear and adaptive filters, color image processing, geometrical operations and morphological filtering, image coding and compression image segmentation, feature extraction and object classification. Applications in diagnostic medicine, biology and biomedical research are emphasized and presented as illustrative examples.

BIEN 5600. Neural Engineering. 3 cr. hrs.
Basic principles of neural engineering, properties of excitable tissues, quantitative models used to examine the mechanisms of natural and artificial stimulation. Basic concepts for the design of neuroprosthetic devices for sensory, motor and therapeutic applications. Design issues including electrode type, biomaterials, tissue response to stimulating electrodes and stimulus parameters for electrical stimulation and artificial control. Examples of how engineering interfaces with neural tissue show increasing promise in the rehabilitation of individuals of neural impairment.

BIEN 5610. Introduction to Rehabilitation Robotics. 3 cr. hrs.
Presents the fundamentals of robotics as it is applied to rehabilitation engineering. Specific topics include: the fundamentals of analysis and design of robot manipulators with examples and mini-projects taken from rehabilitation applications pertaining to robotic therapy devices and personal assistants. Additional topics include: overview of rehabilitation robotics field, human-centered design of rehabilitation robots issues and challenges, robot configurations, rigid motions and homogeneous transformations, Denavit-Hartenberg representation, robot kinematics, and inverse kinematics, Euler-Lagrange equations, trajectory generation, sensors, actuators, independent joint control, force control and safety.

BIEN 5620. Rehabilitation Engineering: Telerehabilitation Research Tools. 3 cr. hrs.
Introduces rehabilitation science as the study of tissue and functional change, including: overview of key human sensory modalities and neuromotor systems in the context of functional capabilities and human performance metrics; review of spontaneous recovery mechanisms in response to various types of tissue trauma; review of roles of genetics and gene transcription networks in pathology and functional recovery prognosis; and the concept of rehabilitative assessment and therapeutic interventions as an optimization problem. Also focuses on the use of assistive technology to enhance access to independent living and to optimize the delivery of rehabilitative healthcare services. Includes rehabilitation biomechanics of physical interfaces, use of access and usability engineering in product design and innovative assessment and intervention strategies for neurorehabilitation.

BIEN 5630. Rehabilitation Engineering: Prosthetics, Orthotics, Seating and Positioning. 3 cr. hrs.
Presents an overview of biomedical engineering as it applies to rehabilitation engineering, specifically, the design and prescription of prosthetic limbs, orthotic devices, and seating and positioning systems. Topics include: medical terminology, musculoskeletal anatomy, muscle mechanics, soft tissue mechanics, gait/locomotion, amputation surgery, lower extremity prosthetics, lower extremity orthotics, hand function, electromyography, upper extremity prosthetics, upper extremity orthotics, seating and positioning, and assistive devices.

BIEN 5640. Bioengineering of Living Actuators. 3 cr. hrs.
Overview of muscle tissue as a living actuator from the perspective of engineering design, systems biology, muscle modeling and adaptive control. Prereq: BIEN 4700/5700.

BIEN 5700. Systems Physiology. 3 cr. hrs.
Analyses of the underlying physiologic and bioengineering aspects of the major cell and organ systems of the human from an engineer's point of view. Classic physiologic approaches used to introduce topics including cell functions, nervous system, nerve, muscle, heart, circulation, respiratory system, kidney, reproduction and biomechanics. Design problems including models of cell-organ-system function and problems in biomechanics illuminate topics covered. Computer techniques and relevant instrumentation are incorporated. Experts on related topics are invited to speak as they are available.

BIEN 5710. Analysis of Physiological Models. 3 cr. hrs.
Development of continuous (compartmental) and distributed-in-space-and-time mathematical models of physiological systems and molecular events. Analytical and numerical methods for solving differential equations of the initial and boundary value types. Simulation of model response, and estimation of model parameters using linear and nonlinear regression analysis.

BIEN 5720. Cardiopulmonary Mechanics. 3 cr. hrs.
Examination of the physiological behavior of the cardiovascular and pulmonary systems from an engineering perspective. Emphasis is on understanding the mechanical basis of physiologic phenomena via experimental models.

BIEN 5931. Topics in Biomedical Engineering. 1-3 cr. hrs.
Course content announced prior to each term. Students may enroll in the course more than once as subject matter changes. Possible topics include biomechanics, experimental methods, neuroanatomy, telemetry, etc.

BIEN 6120. Introduction to the Finite Element Method. 3 cr. hrs.
Introduces finite element analysis as applied to linear, static problems. Application to problems in plane strain, plane stress, and axisymmetry. Development of shape functions and element stiffness matrices. Although primarily structural analysis, also considers problems in heat transfer and fluid mechanics. Use of user-written and packaged software. Prereq: CEEN 2130 or MEEN 2130; and matrix/linear algebra or equiv.

BIEN 6121. Applied Finite Element Analysis and Modeling. 3 cr. hrs.
Advanced finite element analysis as applied to nonlinear (both material and geometric nonlinearities), dynamic problems. Use of penalty methods and perturbed Lagrangian methods. Use of user-written and packaged software. Critical reviews of finite element analysis in biomechanical research. Prereq: BIEN 6120; or CEEN 6120 or equiv.

BIEN 6200. Biomedical Signal Processing. 3 cr. hrs.
Introduces students to statistical processing of biomedical data. Topics include: data acquisition, probability and estimation, signal averaging, power spectrum analysis, windowing, digital filters and data compression. Students complete several computer projects which apply these processing methods to physiologic signals. Prereq: MATH 2451; and proficiency in C or FORTRAN.

BIEN 6210. Advanced Biomedical Signal Processing. 3 cr. hrs.
Covers modern methods of signal processing encountered in the bio-medical field including parametric modeling, modern spectral estimation, multivariate analysis, adaptive signal processing, decimation/interpolation, and two-dimensional signal analysis. Students complete several computer projects which apply these modern techniques to physiologic data. Prereq: BIEN 6200 or equiv.; knowledge of C or FORTRAN.

BIEN 6220. Multidimensional Biomedical Time Series Analysis. 3 cr. hrs.
Theory and implementation of methods used to collect, model and analyze multidimensional time series encountered in biomedical applications such as functional imaging, electrophysiologic mapping and the study of physiologic control systems. Prereq: BIEN 6200; proficiency in C or FORTRAN.

BIEN 6300. Biomedical Instrumentation. 3 cr. hrs.
Explores relationships between instruments for physiologic measurement and monitoring with living systems. Physiologic signals, noise, and available sensors and transducers and their characteristics are discussed from time and frequency domain points of view. Systems topics include various new and conventional medical instrumentation. Other topics include clinical and new clinical laboratory instrumentation, instrumentation for research, artificial organs and prostheses. Includes the use of scientific literature, literature searches, design projects, computer projects. Prereq: BIEN 5700; or BIEN 5320; and high level computer language or equiv.

BIEN 6310. Microprocessor Based Biomedical Instrumentation. 3 cr. hrs.
Discusses the application of microprocessors, microcontrollers, and digital signal processors to biomedical instrumentation. Complements BIEN 6300, which covers transducers, sensors, analog signal conditioning, and analog to digital conversion. Emphasizes evaluating the memory, power, resolution, cost, and computational requirements of a particular application, and then selecting a type (microprocessor, microcontroller, or digital signal processor) and particular model of processor to satisfy the system requirements. Students design at least two complete processor based systems. Prereq: Knowledge of digital electronics and microprocessors.

BIEN 6320. Radio Frequency Applications in Biomedical Engineering. 3 cr. hrs.
Radio frequency design and applications for biomedical engineering and medicine. Circuit elements, equivalent circuits, impedance transformations, Smith Chart, two ports, scattering parameters, amplifiers, resonant circuits, mixers, receivers. Applications include telemetry, transcutaneous power transfer, hyperthermia, rf ablation, magnetic resonance imaging; HP-EESOF LIBRA and Ascent CAD are introduced as analysis and design tools. Guest speakers. Written and oral design reports. Prereq: Undergraduate background in circuit theory and analog electronics.

BIEN 6400. Biofluid Mechanics. 3 cr. hrs.
Development of the theory of fluid mechanics as applied to living systems. Considers both steady and unsteady flows of Newtonian and non-Newtonian fluids. Topics include: viscometry, blood flow, gas and aerosolflows, pulsatile flow and wave propagation and applications to the understanding of flows in organs and to the measurement of blood pressure and flow. Prereq: BIEN 4400 or equiv.; or MEEN 3320 or CEEN 3150.

BIEN 6410. Biological Mass Transfer. 3 cr. hrs.
Development of the theory of mass transfer. Fick's law and free diffusion. Osmosis, facilitated diffusion, active transport, transport across cell membranes and applications to cell biology and organ physiology.

BIEN 6420. Biomechanical and Biomaterial Systems Analysis. 3 cr. hrs.
Using fundamentals of biomaterials engineering and biocompatibility, analyzes the functions that organs serve and to analyze the efficacy and safety of artificial organs systems. Some organs/tissues discussed include the kidneys, liver, skeleton, skin, heart, muscles, eyes, and ears. Critically examines the suitability of state-of-the-art artificial organ systems, including artificial hearts, orthopaedic prostheses, kidney dialyzers, and cochlear devices to fulfill the functions of the replaced organs/tissues. Prereq: BIEN 5420.

BIEN 6440. Biomedical Engineering Analysis of Trauma. 3 cr. hrs.
An engineering analysis of the physiological changes following impact to the head, spinal cord, and limbs, and electrical events and effects on tissues are treated.

BIEN 6450. Musculoskeletal Biomechanics 1. 3 cr. hrs.
Emphasizes the interrelationship of force and motion as related to anatomic structure and function. Examines the forces and motions acting in the skeletal system and the various techniques used to describe them. Highlights current concepts as revealed in the recent scientific and engineering literature. Topics include: bone mechanics, joint mechanics, gait kinematics, instrumentation and measurement of biomechanical phenomena, and computer modeling of the musculoskeletal system. Prereq: MEEN 2120 or CEEN 2120 and MEEN 2130 or CEEN 2130.

BIEN 6451. Musculoskeletal Biomechanics 2. 3 cr. hrs.
Advanced concepts of kinematics and mechanics as they apply to the fields of biomechanics and rehabilitation. Covers aspects of gait, bone and joint surgery, and soft tissue surgery. Detailed study of joint mechanics, implant applications and mobility device function is performed. Includes advanced analysis and modeling as well as laboratory-based final project. Prereq: BIEN 6450.

BIEN 6470. Biomechanics of the Spine. 3 cr. hrs.
Analyzes anatomical and functional relationships among the hard and soft tissue structures of the spine as a function of vertebral column development, aging, disease and trauma. Emphasis given to the mechanisms of external and internal load transfer. Imaging (e.g. CT), experimental and finite element methods are used to study the effects of physiologic/traumatic loading, surgery and spinal disorders. Discusses current advancements in biomechanical/clinical literature.

BIEN 6500. Mathematics of Medical Imaging. 3 cr. hrs.
Begins with an overview of the application of linear systems theory to radiographic imaging (pinhole imaging, transmission and emission tomography), and covers the mathematics of computed tomography including the analytic theory of reconstructing from projections and extensions to emission computed tomography and magnetic resonance imaging. Topics may also include three-dimensional imaging, noise analysis and image quality, and optimization. Contains advanced mathematical content.

BIEN 6600. Neuromotor Control. 3 cr. hrs.
Overview of current issues in neuromotor control and movement biomechanics. Special emphasis on the study of normal and impaired human movement. Topics include: muscle mechanics, biomechanics of movement, neural circuitry, strategies for the neural control of movement (including a discussion of adaptation and motor learning) and potential applications of biomedical engineering techniques to the study and improvement of impaired motor function. Prereq: BIEN 3300 which may be taken concurrently or equiv.; or cons. of instr.

BIEN 6610. Rehabilitative Biosystems. 3 cr. hrs.
Examines the plastic changes in biological systems that occur in response to targeted stimuli. These processes involve responses by cells to chemical, mechanical, or electrical stimuli (which may be related), which may be influenced or directed using engineering techniques. Examines the homeostasis of physiologic systems and their response to pathologic and rehabilitative stimuli. Examines engineering applications involving the diagnosis and rehabilitation of musculoskeletal, neurologic and cardiopulmonary biosystems in the context of the underlying cellular mechanisms. Prereq: BIEN 5700 which may be taken concurrently; and PHYS 1004.

BIEN 6620. Modeling Rehabilitative Biosystems. 3 cr. hrs.
Introduction to large-scale mathematical models of various physiological systems of interest in rehabilitation (e.g., cardiovascular, pulmonary, musculoskeletal, etc.). Discusses mathematical modeling, a widely used tool for testing hypotheses regarding the underlying mechanisms of complex systems such as physiological systems in health, disease and recovery. For each, simulation is used to further our understanding of the adaptive processes of these systems in response to physiological/pathophysiological stresses and rehabilitative interventions. Prereq: BIEN 5710 and BIEN 5700.

BIEN 6700. Analysis of Physiological Systems. 3 cr. hrs.
Introduction to the use of mathematical models in quantifying physiological systems. Analyzes model formulation. Applications of analytical and numerical solution techniques and parameter estimation methods. Prereq: BIEN 5710.

BIEN 6710. Cellular and Molecular Bioengineering. 3 cr. hrs.
Main topics include: cellular biomechanics with an emphasis on the cardiovascular system, molecular bioengineering, biotransport phenomena, and tissue engineering with focus on artificial internal organs. Cellular biomechanics topics covered are biomechanics of the endothelium, endothelial-immune cell interactions, and blood cell structural biomechanics. Topics in molecular bioengineering include chemotaxis and chemokinesis, and modeling of receptor-mediated endocytosis. Biotransport and tissue engineering topics include bioreactor design and the analysis and development of artificial internal organs like the liver and pancreas.

BIEN 6931. Topics in Biomedical Engineering. 3 cr. hrs.
Subject matter variable as determined by needs of biomedical graduate students. Students may enroll more than once as the subject matter changes. Possible topics: biostatistics, experimental methods, neuro-anatomy, etc.

BIEN 6932. Advanced Topics in Biomedical Engineering. 3 cr. hrs.
Advanced topics in design and analysis of biomedical instruments, devices and interfaces. Project approach drawing from current literature and current projects of laboratories of affiliated institutions. Topics include bioelectronics, biomechanics, biomaterials, and rehabilitation engineering.

BIEN 6947. Medical College of Wisconsin/Joint Degree. 1-8 cr. hrs.
Graduate-level course in selected areas of the life sciences offered at the Medical College of Wisconsin. May be taken by doctorate BIEN students at Marquette University. Prereq: Cons. of dept. ch.

BIEN 6953. Seminar in Biomedical Engineering. 0 cr. hrs.
Scholarly presentations on current topics in biomedical engineering and related areas by visiting professors, resident faculty and graduate students. Attendance is required of all full-time graduate students. SNC/UNC grade assessment. Mandatory for all full-time BIEN graduate students.

BIEN 6954. Seminar in Biomedical Computing. 0 cr. hrs.
Scholarly presentations on current topics in biomedical engineering and related areas by visiting professors, resident faculty and graduate students. Attendance is required of all full-time graduate students. SNC/UNC grade assessment. Mandatory for all full-time BIEN graduate students.

BIEN 6960. Seminar: Journal Club. 0-3 cr. hrs.
0 credit will be SNC/UNC grade assessment; 1-3 credits will be graded.

BIEN 6995. Independent Study in Biomedical Engineering. 1-3 cr. hrs.
Prereq: Cons. of instr. and cons. of dept. ch.

BIEN 6999. Master's Thesis. 1-6 cr. hrs.
S/U grade assessment. Prereq: Cons. of instr.

BIEN 8110. Research Methodologies 1. 3 cr. hrs.
Development of research aims and hypotheses, identification of relevant scientific literature, experimental approaches, statistical design, and pilot work to obtain preliminary results. Emphasizes written communication of research theme. The course project consists of the development of a research proposal including research aims, background, pilot experiments, and experimental design and methodology. Prereq: Accepted Ph.D. student in biomedical engineering.

BIEN 8120. Research Methodologies 2. 3 cr. hrs.
Oral and written communication of research results including graphics and text. Addresses graphical presentation of data and conceptual development of a scientific presentation and a manuscript. Emphasizes the basics of clear and effective scientific communication. Work culminates in the development of a scientific manuscript for peer review. Prereq: Accepted Ph.D. student in biomedical engineering.

BIEN 8210. Teaching Methodologies. 3 cr. hrs.
Seminar aimed at issues important for teaching in a university setting. Topics include: development of teaching philosophy, planning a class, designing a syllabus, assessing student learning and using technology in the classroom. Taught in conjunction with the Preparing Future Faculty (PFF) program. Prereq: Accepted Ph.D. student in biomedical engineering.

BIEN 8995. Independent Study in Biomedical Engineering. 1-3 cr. hrs.
In-depth research on a topic or subject matter usually not offered in the established curriculum with faculty and independent of the classroom setting. Prereq: Cons. of instr. and cons. of dept. ch.

BIEN 8999. Doctoral Dissertation. 1-12 cr. hrs.
S/U grade assessment. Prereq: Cons. of instr.

BIEN 9970. Graduate Standing Continuation: Less than Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9974. Graduate Fellowship: Full-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9975. Graduate Assistant Teaching: Full-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9976. Graduate Assistant Research: Full-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9984. Master's Comprehensive Examination Preparation: Less than Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9985. Master's Comprehensive Examination Preparation: Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9986. Master's Comprehensive Examination Preparation: Full-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9987. Doctoral Comprehensive Examination Preparation: Less than Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9988. Doctoral Comprehensive Examination Preparation: Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9989. Doctoral Comprehensive Examination Preparation: Full-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9991. Professional Project Continuation: Less than Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9992. Professional Project Continuation: Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9993. Professional Project Continuation: Full-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9994. Master's Thesis Continuation: Less than Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9995. Master's Thesis Continuation: Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9996. Master's Thesis Continuation: Full-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9997. Doctoral Dissertation Continuation: Less than Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9998. Doctoral Dissertation Continuation: Half-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.

BIEN 9999. Doctoral Dissertation Continuation: Full-Time. 0 cr. hrs.
Fee. SNC/UNC grade assessment. Prereq: Cons. of dept. ch.