2025-26

BIOMEDICAL ENGINEERING

Degree Offered: Doctor of Philosophy in partnership with Marquette University

Program Description

Biomedical Engineering (BME) is an interdisciplinary field that is based on the application of engineering principles and experimental and analytical techniques to the development of biologics, materials, devices, implants, processes, and systems that advance biology and medicine and improve medical practice and health care.

The Doctor of Philosophy (PhD) degree in BME is a research degree that is intended to provide the graduate with the breadth and depth of knowledge in one area of specialization within BME, as well as the scientific research training needed for successful careers in academia, biomedical industry, or government. The research training process begins with the student working closely with his or her Dissertation Director and participating in his or her research program. Building on these experiences, the student begins to conduct independent research that eventually leads to an original contribution to the BME field.

Admission Requirements

In addition to the general Graduate School admission requirements, this program has additional specific requirements.

Graduates of accredited colleges or universities with a Bachelor's or Master's degree in various engineering, physical science, or life science disciplines or equivalent are eligible for admission to the joint MU-MCW PhD Program in BME.

Students who do not have an engineering degree are admitted into the PhD program on a conditional status based on successful completion (grade of B or better) of a sequence of leveling courses. These courses will provide them with fundamental engineering principles and analytical skills needed for successful completion of the PhD degree in BME. See the Handbook of MU-MCW PhD Program in BME for details.

Credits Required to Graduate

60 credits minimum

Program Credit Requirements

Upon enrolling in the doctoral program in BME, a student selects his or her area of specialization. Faculty designs a curriculum and research program to address the specific goals of each student. Program includes course work in engineering, biology, mathematics, and medicine, all of which are integrated with research laboratory experience.

The Doctoral Qualifying Examination (DQE) consists of both written and oral components. Students entering the doctoral program with a master's degree are recommended to take the DQE at or before the completion of 15 graduate credits of didactic coursework. Students entering the doctoral program with a bachelor's degree are recommended to take the DQE at or before completion of 30 graduate credits of didactic coursework. The written portion of the DQE involves writing a dissertation proposal in the form of an NIH-styleF30/F31

fellowship grant proposal and the oral portion involves presentation and defense of the dissertation proposal, in which the Dissertation Committee members serve as examiners.

A minimum of 60 graduate credits are required to complete the PhD degree in BME. For someone entering with a BS degree, this constitutes 36 credits in didactic coursework, 9 credits in dissertation, and a minimum of 15 credits in reading and research. For those entering with an MS degree or with 18 graduate credits (see Transfer of Credits Policy), they are required to complete a minimum of 18 credits in didactic coursework, 9 credits in dissertation, and a minimum of 33 credits in reading and research. Pre-requisite courses for applicants who do not have a BME degree are not counted as graduate credits. Reading and Research credits can be earned by registering and attending a seminar series, workshop, conference, journal club, or simply carrying dissertation-related activities. A student can register for up to 9 credits of reading and research per semester during fall and spring semesters and up to 6 credits during the summer. Students should register for dissertation credits in the semester they intend to defend their dissertation.

Fields of Study

- Bioinstrumentation
- Biomechanics
- Biomedical Imaging
- Cellular and Molecular Engineering
- Computational Biology and Bioinformatics
- Rehabilitation Bioengineering

Required Courses

All doctoral students must complete courses that satisfy the following competencies:

BIOM 6953/*BIEN 6953. Seminar in Biomedical Engineering. *0 credits.*
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 BME graduate students.

Bioethics (2 credits required)
BIOE 10222 Ethics and Integrity in Science and Course. *1 credit.*
This course provides the basis for understanding the ethical issues related to basic scientific and medical research, including animal and human subject research, fraud, and misconduct, and governmental, institutional, and researcher responsibilities. Bioethics 10222 is offered during the spring and summer terms only.

BIOE 10444 Research Ethics Discussion Series. *1 credit.*
Prerequisite: 10222 Ethics and Integrity in Science.
The course is directed by members of the Bioethics Faculty and provides facilitated discussions of a series of topics in research ethics. Discussions are led by members of the Basic Science faculty and are focused on ethical issues that commonly come up in biomedical research. The course is meant to not only reinforce the basic ethics taught in the online course Ethics and Integrity in Science, which is a prerequisite, but also to explore the gray areas of the individual topics. The intent is to offer students illustrative examples of ethical issues that might arise in their careers, to emphasize the ethical principles that apply in such situations, and the provide practical guidance on how these types of situations

should be correctly handled. This course is offered as a discussion series. Students are expected to attend and participate in the discussion. Bioethics 10444 is offered during the spring terms only.

Biomedical Sciences (3 credits required)
This core course can cover: cellular and systems physiology, neurophysiology, intra- and intercellular signaling, genetics and developmental biology, pharmacology, cellular pathology and immunology, microbiology, molecular biology, biochemistry).

***BIOL 5102. Experimental Molecular Biology.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

BIOM 5700/*BIEN 5700. Systems Physiology. *3 credits.*
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.

***BIOL 5703. Exercise Physiology.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

BIOM 5720/*BIEN 5720 Cardiopulmonary Mechanics. *3 credits.*
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.

PHYS 08204 Graduate Human Physiology. *3 credits.*
This course provides the fundamental aspects of: 1) cell membrane transport, 2) smooth, skeletal, and cardiac contractile mechanisms and excitation-contraction coupling, 3) principles of synaptic transmission, neurotransmittors, and neuromodulators, 4) respiratory mechanics, gas exchange in the lung, and control of breathing, 5) cardiac electrophysiology, hemodynamics, nervous and humoral control of the heart and cardiac output, 6) renal tubular transport, glomerular filtration, and regulation of sodium and water balance, 7) neural and humoral control of gastrointestinal absorption and motility, and 8) endocrinology including pituitary, adrenal cortical, thyroid, pancreatic and male and female reproductive organs. Material will be covered primarily in lecture format by expert physiologists in each respective area.

INBS 16215 Foundations in Biomedical Sciences I. *3 credits.*
This new course will be a didactic based course that will provide the background for understanding the biochemical basis of life. Students will learn about thermodynamic principles that drive biochemical and enzymatic reactions, protein structure and protein dynamics and the thermodynamic principles that define these structures and their interactions with other biomolecules, the principles that define their functional activities and then an application of this knowledge to an understanding of metabolic pathways. Students

will also learn how foundational biochemical principles apply to certain physiological settings in health and disease and how pharmacological intervention can modulate physiological responses. The format of the course involves lectures, in-class discussions, and review sessions which are designed to promote class participation.

INBS 16216 Foundations in Biomedical Sciences II. *3 credits.*
This is an interdisciplinary course that provides students with a foundation in the areas of gene expression, and basic and contemporary cell biology. The material is primarily presented in lecture format, but discussion sections and data interpretation discussions are also included. Students are expected to gain fundamental knowledge in the areas of gene regulation, translational and posttranslational control and cellular architecture.

INBS 16217 Foundations in Biomedical Sciences III. *3 credits.*
FBS III builds on the cell biology fundamentals introduced in the latter part of FBS I and II. This course starts with lectures on cell signaling and a discussion of a primary research article on the topic. The second part focuses on proteins specialized for ion flux and transport. Themes are exemplified by case studies on several diseases that affect either epithelial transport or excitable cells. The third part of the course focuses on DNA homeostasis, genetic principals, the basis of stem cells and cancer.

INBS 16218 Foundations in Biomedical Science IV. *3 credits.*
This course is designed to give students fundamental introductory concepts impacting the fields of Microbiology and Immunology, Neurobiology and Pharmacology in three modules. Topics were selected and integrated based on the essential concept that human biological responses and development are shaped by chemical cues. The impact on human biology from contact or colonization with microorganisms and the innate and adaptive immune responses to contact are discussed in the first module. Module 2 focuses on the physiological aspects of how signals are perceived and interpreted by the human nervous system. Module 3 communicates fundamental aspects of pharmacology, emphasizing the molecular and cellular levels of signaling and signal transduction. Each session is designed to incorporate current analytical methods, computational and statistical aspects of data analysis and clinical or practical impacts on human health and disease.

INBS 16271 Fundamentals of Neuroscience. *3.5 credits.*
Fundamentals of Neuroscience follows a multidisciplinary approach to current knowledge about the structural and functional properties of the nervous system. The mechanisms of the nervous system are described at the molecular, cellular, systems and complex brain function levels. The course includes in-class lectures, seminars from prominent scientists (video archives), and written assignments. The purpose of this course is to introduce 1st year graduate students to the structure and function of the human nervous system.

NSCI 12221 Advanced Systems Neuroscience. *3 credits.*
Prerequisite: 16271 Fundamentals of Neuroscience or consent of the course director.
Readings and discussion in cellular, molecular, and developmental neurobiology. Among the topics covered in this course are ion channels and the ionic basis of potentials; mechanisms of synaptic transmission; neurotransmitter receptors and their receptors; sensory signal transduction and neural development.

NSCI 12237 Cellular and Molecular Neurobiology. *3 credits.*
Prerequisite: 16271 Fundamentals of Neuroscience or consent of the course director.
Readings and discussion in cellular, molecular, and developmental neurobiology. Among the topics covered in this course are ion channels and the ionic basis of potentials; mechanisms of synaptic transmission; neurotransmitter receptors and their receptors; sensory signal transduction and neural development.

Biostatistical Methods (3 credits)

BIOS 04224 Biostatistical Computing. *3 credits.*
Prerequisites: Statistical Models and Methods I or concurrent registration
This course will cover the details of manipulating and transforming data required for statistical analysis. Topics include reshaping the data from a per-case to a per-event within a case and vice-versa. It will also cover the techniques necessary to write functions and macros in both SAS and R for developing new/modified data analysis methods. How to use R packages and C/C++ codes in R will also be covered. The LaTeX document production system is also introduced.

BIOS 04231 Statistical Models and Methods I. *3 credits*.
Prerequisite: Three semesters of calculus and one semester of linear algebra
This course will cover statistical techniques for basic statistics. Topics include one-sample/two-sample tests, analyses for count data and contingency tables, basic nonparametric methods including sign, rank-sum and signed-rank tests, simple linear regression model and inference, checking model assumptions, model diagnostics, correlation analysis, one-way analysis of variance, Kruskal-Wallis one-way ANOVA, simple logistic regression, and weighted linear regression. SAS/R will be used throughout the course.

BIOS 04232 Statistical Models and Methods II. *3 credits.*
Prerequisite: Statistical Models and Methods I
This course will cover various regression models for independent and correlated data. Topics include multiple linear regression, model diagnostics, variable selection, influence/leverage, outliers, collinearity, transformation, GLM including logistic and Poisson regression, overdispersion, GEE, mixed models, and GLMM. SAS/R will be used throughout the course.

BIOS 04233 Introduction to Statistical and Machine Learning. *3 credits.*
Prerequisite: Statistical Models and Methods II
This course will provide an introduction to statistical learning. Core topics include variable selection, penalized linear regression such as lasso, dimension reduction including principal component analysis, flexible regression techniques including kernel smoothing/smoothing splines/generalized additive models/regression trees, support vector machine, clustering, and random forests. Other topics that can be covered include but are not limited to ridge regression, group lasso, fused lasso, adaptive lasso, SCAD, Bayesian lasso, Bayesian group lasso, Bayesian CART, BART, neural network, feature screening, graphical models, and quantile regression.

BIOS 04363 Advanced Statistics I. *3 credits.*
Prerequisites: Statistical Models and Methods II, Statistical Inference II
This course covers both the theoretical framework and practical aspects of statistical models. The course will cover likelihood inference, properties of likelihood, exponential

families and GLM, large sample properties of likelihood-based inference, likelihood-based regression models, GEE, conditional and marginal likelihood, asymptotics of penalized regression.

BIOS 04365 Linear Models I. *3 credits.*
Prerequisites: Statistical Inference II
This course will cover review of matrix algebra and vector spaces, multivariate normal distribution, quadratic forms, least squares estimation, ANOVA, testing contrasts, multiple comparison, lack-of-fit test, multiple regression models, and mixed models. Emphasis is on theory.

***MSCS 5720. Statistical Methods.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***MSCS 5740. Biostatistical Methods and Models.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

Scientific and Technical Writing (2 credits)
INBS 16292 Writing a Scientific Paper. *1 credit.*
This course will present a step-by-step approach to putting together a scientific paper. Students will be divided into small groups, and these groups will stay together for the duration of the course. Each group will be given an identical set of data with which to compose a manuscript. Each week, a different aspect of paper writing will be discussed, and students will be given a take home assignment to write that particular component of the paper within the small groups. In the final week of the class, the finished papers will be peer reviewed by 2 other groups and a member of the faculty. The course will be graded on attendance, successful and timely completion of the assignments and evaluation of the final manuscript.

INBS 16293 Writing an Individual Fellowship. *2 credits.*
This course provides a systematic approach towards writing a F31-like individual research fellowship. Topics include the organization of the NIH, how the NIH invites investigators to submit applications to support their doctoral studies, how PhD trainees and their mentors respond to these invitations, and how the NIH reviews a fellowship application. A weekly didactic session will be presented to the entire group of students who will have weekly individual writing assignments to complete and will have a weekly small group session to share their progress towards the completion of their writing assignments. Each student will identify a mentor-approved research topic that will be developed into a fellowship proposal, emphasizing the writing of a Summary, Specific Aims Page, and Research Plan that will form the basis of their qualifying examination written report and a fellowship grant.

Leadership, Scientific Communication, and Teaching Skills (2 credits)
INBS 16290 Professional Development I. *1 credit.*
Emphasis in this course will be placed on oral and written communication, critical literature review, and responsible conduct in research. Students will learn good practices for peer review and perform interactive exercises to review each other's work.

INBS 16291 Professional Development II. *1 credit.*
Professional Development follows a multidisciplinary approach to promote individual career development in the biomedical sciences. The course includes lectures, discussion, sessions, seminars, and hands-on activities. Topics of particular emphasis are oral and written communication and rigor and ethics in scientific research.

***GRAD 8961. Science Storytelling.** *1 credit.*
Course offered through Marquette University only. See the MU bulletin for more details.

Applied Mathematics (3 credits)
E.g., applied mathematical methods, fluid mechanics, finite element methods, biomedical signal processing, signals and systems, etc.

BIOM/*BIEN 5400 Transport Phenomena. *3 credits.*
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 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

BIOM/*BIEN 5510 Image Processing for the Biomedical Sciences. *3 credits.*
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.

BIOM/*BIEN 6120 Introduction to the Finite Element Method. *3 credits.*
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.

BIOM/*BIEN 6200 Biomedical Signal Processing. *3 credits.*
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.

BIOM/*BIEN 6210 Advanced Biomedical Signal Processing. *3 credits.*
*Prerequisites: BIOM/*BIEN 6200 Biomedical Signal Processing.*
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.

BIOM 6500/*BIEN 6500 Mathematics of Medical Imaging. *3 credits.*
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.

BIOP 3240 Fourier Transformation. *3 credits.*
This course provides basic knowledge for students who will continue to study EPR or MRI. Material will cover the theory of Fourier transforms, digital transforms, MRI image generation, Fourier image reconstruction, and digital signal processing. An understanding of calculus and matrix algebra is recommended.

***EECE 6010 Advanced Engineering Mathematics.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***MEEN 5265 Intermediate Finite Element Method.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***MEEN 6101 Advanced Engineering Analysis I.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***MEEN 6102 Advanced Engineering Analysis II.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***MEEN 6360 Computational Fluid Mechanics.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***MEEN 6365 Computational Methods in Heat Transfer and Fluid Flow.** *3 credits*.
Course offered through Marquette University only. See the MU bulletin for more details.

Computational and Modeling Methods (3 credits)
E.g., numerical methods for solving mathematical models of physical and biological phenomena, regression analysis, data science and machine learning, biological network analysis, computer simulations of physiological systems, etc.

***BIEN 5410. Applied Finite Element Analysis.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

BIOM 5710/*BIEN 5710. Analysis of Physiological Models. *3 credits.*
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.

BIOM/*BIEN 6120 Introduction to the Finite Element Method. *3 credits.*
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.

BIOM 6620/*BIEN 6620. Modeling Rehabilitative Biosystems. *3 credits.*
Prerequisites: BIEN 5710 Analysis of Physiological Models and BIEN 5700 Systems of Physiology
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 hypothesis 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.

***COSC 5610 Data Mining.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***EECE 6820 Artificial Intelligence.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***EECE 6822 Machine Learning.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***EECE 6840 Neural Networks and Neural Computing.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

***MEEN 5270 Physical Systems Modeling.** *3 credits.*
Course offered through Marquette University only. See the MU bulletin for more details.

BIOM 35284. Computational Methods for Biomedical Research. *3 credits.*
This course focuses on modeling and computational techniques for simulation and analysis of biological systems, developed largely through application-driven examples. Examples will be developed to a depth at which models will be used to analyze real biological or physiological data. To accomplish this, the important details of the underlying biological systems must be described along with a complete step-by-step development of model assumptions, the resulting equations, and (when necessary) computer code.

BIOM 35285. Mathematical Biology. *3 credits.*
This course teaches the students how to express physiological problems in equations and how to solve such equations. Emphasis on physiological problem-solving methods rather than mathematical theory. Topics include the application of matrices, differential equations, and numerical analysis to problems in bioelectricity, biomechanics, and optics.

Elective Courses

18 credits required. Courses intended to satisfy this requirement should be selected in consultation with the student's Dissertation Director. A minimum of three unique courses relevant to each specialization are offered within a three-year timespan. Additional specialization-specific courses may be chosen from special topics offerings, overlapping courses with other specializations and graduate courses offered through other departments at MU and MCW. PhD students and MSTP students in the Joint BME Department are also required to register for the BME Department seminar series for the duration of their study (BIEN 6953, which counts for 0 credit/semester of reading and research). For a given semester, students are expected to attend at least two thirds of the seminars

Notes

**Courses offered at Marquette University*
Please see Biomedical Engineering Handbook for additional information.