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. It 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 c

fellowship grant proposal and the oral portion involves presentation and defense of the dissertation proposal, in whic h the Dissertation Committee members serve as exa miners.

A minimum of 60 graduate credits are required to c omplete the PhD degree in BME. For someone ent ering with a BS degree, this c onstitutes 36 c redits in didactic c oursework, 9 credits in d issertation, and a m inimum of 15 c redits in reading and research. For those entering with an MS degree or with 18 g raduate credits (see Transfer of C redits Policy), they are required to complete a minimum of 18 c redits in didactic c oursework, 9 c redits in dissertation, and a m inimum of 33 c redits in reading and research. Pre-requisite courses for applicants who do not have a BME degree are not counted as graduate credits. Reading and 5esearch credits can be earned by registering and attending a seminar series, workshop, c onference, journal club, or simply c arrying dissertation-related a ctivities. A student can register for up to 9 c redits of reading and research per semester during fall and spring semesters and up to 6 c redits d uring the summer. Students should register for dissertatio n credits in the semester they intend to d efend 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 I ntegrity 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 a pply 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. Bioethic s 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,

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,

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.
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 var iable 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 statist ical models. The course will cover likelihood inference, properties of likelihood, exponential

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

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 biol ogical 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 biologic al 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 minim