Program Description

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

The Doctor of Philosophy (PhD) degree in BME is a researc h degree that is intended to provide the graduate with the breadth and depth of knowledge in one area of specialization wit hin BME, as well as the scientific research training need ed for successful careers in academia, biomedical industry, or government. 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 vario us eng ineering, physical science, or life science disciplines or eq uivalent a re eligible for admission to the joint MU-MCW PhD Program in BME.

Students who do no t ha ve an engineering degree are admitted into the PhD program on a c onditional status based on successfu l 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 completio n of the PhD degree in BME. See the Handbook of MU -MCW PhD Program in BME for details.

Credits Required to Graduate
60 c redits minimum

Program Credit Requirements

Upon enrolling in t he doctoral program in BME, a student selects his or her a rea of specialization. Faculty designs a c urriculum and research program to address the specific goals of ea ch student. Program inc ludes course work in engineering, biology, mathematics, and medicine, all of which are integrated with research laboratory experience.

The Doctoral Qualifying Examination (DQE) consist V of both written and oral components. Students ent ering the doctoral program with a master's degree are recommended to take the DQE at or before the completio n 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 complete the PhD degree in BME. For someone ent ering with a BS degree, this constitutes 36 credits in didactic coursework, 9 credits in dissertation, and a m inimum 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 m inimum 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 5esearch credits can be earned by registering and attending a seminar series, workshop, conference, journal club, or simply c arrying 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 dissertatio n 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 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.

<u>Biomedical Sciences (3 credits required)</u>

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](#) .

<u>Applied Mathematics (3 credits)</u>
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