BIOMEDICAL ENGINEERING

mccormick.northwestern.edu/biomedical

Biomedical engineers solve problems in the life sciences and clinical medicine by applying engineering and mathematical techniques. This approach has been fruitful where a descriptive approach is no longer adequate for studying complex systems involved in the body's transport, regulation, and information processing. Equally important has been the development of devices used inside or outside the body to replace or supplement physiological functions and to enhance the quality of diagnosis and care.

The interplay among the physical sciences, engineering, biology, and the medical sciences takes many forms. The traditional study of complex systems—whether for power transmission, communications, or the operation and control of industrial processes—provided engineers with a number of concepts and techniques that proved valuable in analysis and design. These principles expressed in mathematical form are applicable to a wide range of phenomena, including those in biological processes. Information theory, statistics, and computer technology have opened new areas for exploration of sensory and central nervous activity as well as patient handling and diagnosis. Theories for feedback controls, transport processes, materials science, and mechanics have provided new insight into homeostatic physiological processes. Analysis of heat transfer, fluid flow, and chemical-process control in living organisms requires competence in both engineering and the life sciences. Current studies further understanding of many physiological processes, which in turn leads to improvements in clinical practice, diagnosis, and patient care.

Northwestern was among the first schools to recognize the value of a biomedical engineering background. Today the Department of Biomedical Engineering offers one of the largest and broadest programs in the country at both the undergraduate and graduate levels. Most students interested in the field follow its program, but other engineering departments also offer biomedical options.

The biomedical engineering program provides biomedical training that is quantitative, emphasizes problem solving, and treats phenomena from the molecular to the systems levels. The curriculum prepares students for careers in dentistry, medicine, or research or with healthcare corporations. Required courses in mathematics, engineering, and science establish a strong foundation on which the student builds a self-selected area of specialization.

A minimum of 21 course units in engineering design and engineering science, as well as substantial training in design, are required for a biomedical engineering degree.

Those seeking admission to dental or medical school should be familiar with the entrance requirements of schools to which they intend to apply. Many professional schools require courses in physics, organic, and/or physical chemistry and laboratory biology, in addition to courses required by the biomedical engineering program. These requirements may be satisfied by judicious use of electives.

Biomedical Engineering Electives

Students seeking depth in one particular area of biomedical engineering may choose to focus their electives in one of the following three areas:

- Bioelectronics and Biosensors
- Biomaterials and regenerative medicine
- Biomechanics and rehabilitation
- Data Science
- Imaging and biophotonics

Alternately, students may choose a broader approach to the curriculum, selecting electives from all of these areas.

Programs of Study

- Biomedical Engineering Degree (https://catalogs.northwestern.edu/undergraduate/engineering-applied-science/biomedical-engineering/biomedical-engineering-degree/)

BMD_ENG 101-0 Introduction to Biomedical Engineering (0 Unit) Information to 1) help students determine if BME is the right major for them and 2) learn how to make the most of their undergraduate experience. The field of biomedical engineering, career and research opportunities, ethics.

BMD_ENG 207-0 BME Lab: Experimental Design (0.5 Unit) A laboratory course focusing on quantitative physiological measurements and analyses, instrument characterization, statistical design of experiments, and training in preparation and organization of laboratory notes and reports. Prerequisite: BMD_ENG 220-0 or IEMS 303-0 or MECH_ENG 359-0.

BMD_ENG 220-0 Introduction to Biomedical Statistics (1 Unit) Basic statistical concepts presented with emphasis on their relevance to biological and medical investigations.

BMD_ENG 250-0 Thermodynamics (1 Unit) Physical and chemical principles as applied to biological systems and medical devices. Topics include material balances, thermodynamics, solution chemistry, electrochemistry, surface chemistry, transport, and kinetics. Prerequisites: MATH 228-1; CHEM 132-0, CHEM 152-0, or CHEM 172-0.

BMD_ENG 270-0 Fluid Mechanics (1 Unit) Fundamentals of fluid mechanics and their applications to biological systems. Prerequisites: BMD_ENG 271-0, GEN_ENG 205-4 and MATH 228-2.

BMD_ENG 271-0 Introduction to Biomechanics (1 Unit) Analysis of stresses and deformations in solids. Problems in biomechanics, with emphasis on assumptions appropriate to modeling biological materials including bone, skin, muscle, and cell membranes. Prerequisite: GEN_ENG 205-2.

BMD_ENG 304-0 Quantitative Systems Physiology (1 Unit) Cardiovascular, respiratory, and immune systems, including physiology and pathophysiology. Case studies and a design team project. Integrated lab activities; no separate section.
Prerequisite: Students must have taken PHYSICS 135-2; junior standing recommended.

BMD_ENG 305-0 Quantitative Systems Physiology (1 Unit) Cellular mechanisms of and quantitative systems' approach to human renal, digestive, endocrine, and metabolic physiology. Integrated lab activities; no separate section.
Prerequisite: junior standing recommended.

BMD_ENG 306-0 Quantitative Systems Physiology (1 Unit) Functional/structural aspects of vertebrate nervous system. Neural biophysics. Integrated lab activities; no separate section.
Prerequisite: PHYSICS 135-2; junior standing recommended.

BMD_ENG 308-0 Biomedical Signals and Circuits (1.25 Units) Time and frequency domain analysis: convolution representation, Fourier series, Fourier transforms, frequency response, filtering, sampling. Prerequisite:

PHYSICS 135-2 or consent of instructor; BMD_ENG 207-0 (can be taken concurrently).

BMD_ENG 309-0 Biomedical Systems Analysis (1.25 Units) Introduction to linear systems analysis. Time and frequency domain techniques for analyzing linear systems, emphasizing their applications to biomedical systems. Python-based problem sets and a summative instrumentation and analysis lab project illustrate topics covered in class. Prerequisites: BMD_ENG 207-0; BMD_ENG 308-0; BMD_ENG 220-0; GEN_ENG 205-4.

BMD_ENG 311-0 Computational Genomics (1 Unit)
The course introduces state-of-the-art genomic sequencing technologies and computational modeling of high-throughput sequencing datasets. Through the course, students will learn how to apply these experimental and computational genomics technologies to study gene expression regulation underlying various biological processes, such as oncogenesis. Students will also apply computational and statistical skills, using linux and R/Matlab/Python.
Prerequisites: BMD_ENG 220-0; BIOL_SCI 201-0 or BIOL_SCI 202-0.

BMD_ENG 312-0 Biomedical Applications in Machine Learning (1 Unit)
Supervised learning tasks such as regression and classification, Convolutional Neural Networks and image analysis techniques and hidden Markov models, unsupervised learning approaches such as clustering and dimensionality reduction will be applied to both structured (numerical) and image data. All models will be implemented in Python, either from scratch or using high-level libraries.
Prerequisites: BMD_ENG 220-0, GEN_ENG 205-1, MATH 220-1, MATH 220-2.

BMD_ENG 313-0 Wearable Devices: From Sensing to Biomedical Inference (1 Unit)
This course will review the challenges and opportunities associated with using wearable devices to infer biomedical information about individuals and populations. It will cover techniques from signal processing, machine learning, and artificial intelligence relevant to this objective. Content will be taught using a series of projects relevant to the quantification of human movement and rehabilitation medicine.
Prerequisites: BMD_ENG 207-0 and BMD_ENG 220-0.

BMD_ENG 317-0 Biochemical Sensors (1 Unit)
Theory, design, and applications of biochemical sensors used in medical diagnosis, biomedical research, and patient monitoring. Detection of biomolecules with optical, electrochemical, mass spectrometry and other sensors. Start-up translation of sensor technology.
Prerequisites: BIOL_SCI 201-0; CHEM 215-1.

BMD_ENG 323-0 Visual Engineering Science (1 Unit)
Mammalian visual system. Physiological optics. Visual image representation and interpretation. Visual adaptation. Motion. Color vision.
Prerequisite: PHYSICS 135-2.

BMD_ENG 325-0 Introduction to Medical Imaging (1 Unit)
Diagnostic X-rays; X-ray film and radiographic image; computed tomography; ultrasound. Prerequisites: Undergraduate students must have completed PHYSICS 135-3 and BMD_ENG 309 (or equivalent course covering Fourier transform and other Signals concepts) to enroll in this course.
Prerequisites: Students must have completed PHYSICS 135-3 and knowledge of Fourier concepts.

BMD_ENG 327-0 Magnetic Resonance Imaging (1 Unit)
Nuclear magnetic resonance; two-dimensional Fourier transform, spinecho and gradientecho imaging; gradient and RF hardware.
Prerequisite: PHYSICS 135-3.

BMD_ENG 333-0 Modern Optical Microscopy & Imaging (1 Unit)
Rigorous introduction to principles, current trends, emerging technologies, and biomedical applications of modern optical microscopy.
Prerequisites: BMD_ENG 220-0, GEN_ENG 205-4, PHYSICS 135-3.

BMD_ENG 340-0 Pharmaceutical Engineering: From Discovery to Therapeutics (1 Unit)
This course will take students through the process of drug development from initial innovative concept and identified medical need, to proof of efficacy, clinical trials, and translation to 'big pharma'. Professor Moskal will draw upon his experience from academia and industry to chart out each critical step of drug development; additional industry experts will present guest lectures.
Prerequisites: CHEM 215-1 or be BME MS/PhD student to enroll in this class.

BMD_ENG 343-0 Biomaterials and Medical Devices (1 Unit)
Structure-property relationships for biomaterials. Metal, ceramic, and polymeric implant materials and their implant applications. Interactions of materials with the body.
Prerequisites: BIOL_SCI 201-0, BIOL_SCI 202-0 (can be taken concurrently), CHEM 215-1, MAT_SCI 201-0.

BMD_ENG 344-0 Biological Performance of Materials (1 Unit)
Structure-property relationships of materials, physical chemistry of surfaces and interfaces, materials-tissue interactions, applications to the selection and design of materials for medical implants and devices.
Prerequisites: BIOL_SCI 201-0, BIOL_SCI 202-0 (can be taken concurrently), CHEM 215-1, MAT_SCI 201-0.

BMD_ENG 346-0 Tissue Engineering (1 Unit)
In vivo molecular, cellular, and organ engineering, with emphasis on the foundations, techniques, experiments, and clinical applications of tissue engineering.
Prerequisites: BIOL_SCI 201-0, BIOL_SCI 202-0 (can be taken concurrently), CHEM 215-1.

BMD_ENG 347-0 Foundations of Regenerative Engineering (1 Unit)
Embryonic development, stem cell engineering, somatic regeneration, genome and transcriptome modifications, cell and tissue-level regenerative engineering.
Prerequisites: BIOL_SCI 201-0 or BIOL_SCI 202-0.

BMD_ENG 348-0 Applications of Regenerative Engineering (1 Unit)
Mechanisms of human disease, development and application of molecular, cellular, and tissue-level regenerative engineering strategies to selected human disorders, including neurodegenerative disorders, stroke, cystic fibrosis, cirrhosis, diabetes, muscular degenerative disorders, and skin injury.
Prerequisite: BIOL_SCI 201-0 or BIOL_SCI 202-0.

BMD_ENG 353-0 Bioelectronics (1 Unit)
Development and design of sensors, stimulators, and their medical devices for biointegrated electronics. Materials design and fabrication of passive and active components for sensitive, multimodal, and robust wearable and implantable devices.

BMD_ENG 354-0 Bioelectronics Lab (1 Unit)
Laboratories focused on the practical implementation, instrumentation, and fabrication of wearables and skinsensing. Applications range from vital sign monitoring to rehabilitation.
Prerequisites: BMD_ENG 353 or MAT_SCI 353. Concurrent enrollment is acceptable.

BMD_ENG 365-0 Control of Human Limbs and Their Artificial Replacements (1 Unit)

Human movement, biomechanics, skeletal and muscular anatomy, comparative anatomy, muscle physiology, and locomotion. Engineering design of artificial limbs.
Prerequisite: senior standing with engineering or physical science background.

BMD_ENG 366-0 Biomechanics of Movement (1 Unit)
Engineering mechanics applied to analyze human movement, including models of muscle and tendon, kinematics of joints, and dynamics of multi-joint movement. Applications in sports, rehabilitation, and orthopedics.
Prerequisite: BMD_ENG 271-0.

BMD_ENG 371-0 Mechanics of Biological Tissue (1 Unit)
Stress and strain for small and large deformations. Nonlinear elastic, viscoelastic, pseudo-elastic, and biphasic models.
Prerequisites: BMD_ENG 271-0; GEN_ENG 205-3; GEN_ENG 205-4.

BMD_ENG 377-0 Intermediate Fluid Mechanics (1 Unit)
Fundamental concepts of fluid dynamics. Kinematics, mass and momentum balances, constitutive relations. Navier-Stokes equations and methods of solution. Sealing techniques.
Prerequisite: BMD_ENG 270-0 or consent of instructor.

BMD_ENG 378-0 Transport Fundamentals (1 Unit) Fundamental and biomedical applications of diffusive and convective heat and mass transfer. Prerequisites: BMD_ENG 270-0; MATH 228-1; BMD_ENG 377-0 recommended.

BMD_ENG 380-0 Medical Devices, Disease & Global Health (1 Unit)
Health systems and technologies to address health problems of the world's underserved populations, with special emphasis on developing countries.

BMD_ENG 388-SA Health Systems Engineering (1 Unit)
Introduction to health systems in the context of disease burden with special emphasis in developing countries. We examine healthcare systems, financing, data and analytics. The course focuses primarily on health-related issues confronting South Africa and the associated social and economic impact.
Prerequisite: consent of instructor.

BMD_ENG 389-SA Health Technology Management (1 Unit)
This course provides an introduction to formal concepts and methodologies used in support of health technology planning, assessment and adoption - and related decision making - as part of cost-effective healthcare delivery. Open to participants in the Global Health Technologies Program only.

BMD_ENG 390-1 Biomedical Engineering Design (1 Unit) Open-ended team-designed projects in the medical devices arena. Systems approach requiring design strategy and concepts, including reliability, safety, ethics, economic analysis, marketing, FDA regulations, and patents. Written and oral reports. Pre-Requisites: BMD_ENG 207-0, BMD_ENG 220-0, BMD_ENG 270-0, BMD_ENG 308-0, BMD_ENG 309-0, COMP_SCI 150 and two of the following: BMD_ENG 250-0, BMD_ENG 271-0, MAT_SCI 201-0.

BMD_ENG 390-2 Biomedical Engineering Design (1 Unit) Development of a design project initiated during the previous quarter. Prerequisite: BMD_ENG 390-1.

BMD_ENG 390-3 Biomedical Engineering Design (1 Unit)
Continuation of a design project; independent study. May not be repeated for credit.
Prerequisites: BMD_ENG 390-1 or BMD_ENG 390-2; consent of instructor.

BMD_ENG 391-SA HealthCare Techology Innovation and Design (1 Unit)
Principles and practice of medical device design for the developing world. Evaluation of user needs in the environment of under-resourced segments of South African health care system. Validation and verification of engineering design solutions. Open to participants in the Global Health Technologies Program only.

BMD_ENG 395-0 Topics in Biomedical Engineering (1 Unit) Special Topics in Biomedical Engineering.

BMD_ENG 396-0 Special Topics (0.5 Unit)
Special Topics in Biomedical Engineering, Laboratory emphasis.

BMD_ENG 397-0 Special Topics in Biomedical Engineering (0.5-1 Unit)
Special Topics in Biomedical Engineering, Laboratory emphasis.

BMD_ENG 398-0 Special Topics in Biomedical Engineering (0.34 Unit)
Special Topics in Biomedical Engineering, Laboratory emphasis.

BMD_ENG 399-0 Projects (1 Unit) SEE DEPT FOR SECTION AND PERMISSION NUMBERS.