

BIOMEDICAL ENGINEERING

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Chair

John G. Georgiadis

Faculty with Research Interests

For more information regarding BME programs, faculty and research visit the Department of Biomedical Engineering website.

The Department of Biomedical Engineering confers a doctoral degree in biomedical engineering (Ph.D. in Biomedical Engineering). Currently, ten faculty members hold tenured or tenure track positions, and two faculty members hold teaching positions in the department. Several other university units contribute courses to the BME graduate program:

- Biology
- Chemistry
- Physics
- Chemical and Biological Engineering
- Computer Science
- Electrical and Computer Engineering
- Mechanical, Materials, and Aerospace Engineering
- Psychology
- Center for Ethics in the Professions

Research Areas

- Cell and tissue engineering
- Medical imaging
- Neural engineering

Admission Requirements

Minimum Cumulative Undergraduate GPA

3.2/4.0

Minimum GRE Scores

1800 (combined), 1200 (quantitative + verbal), 3.0 (analytical writing)

Meeting the minimum admission standards for GPA and GRE scores does not guarantee admission. Test scores and GPA are just two of several important factors considered. The admissions committee will also consider recommendations from three college faculty members acquainted with the character, research ability, potential, qualifications, and motivation of the applicant, and the needs of the departmental faculty. Entering graduate students are assigned a temporary academic adviser who will provide initial guidance. As their research and other academic interests become defined, students select a permanent research adviser who will also guide them through their academic studies.

Degrees Offered

- Master of Computational Engineering, Biomedicine Track
- Master of Engineering in Biomedical Engineering
- Master of Science in Biomedical Data Science and Modeling
- Master of Science in Biomedical Engineering
- Master of Science in Medical Devices and Biomaterials
- Doctor of Philosophy in Biomedical Engineering

Course Descriptions

BME 500

Introduction to Biomedical Engineering

Introduction to the concepts and research in biomedical engineering. Provides an overview of current biomedical engineering research areas, emphasis on application of an engineering approach to medicine and physiology signals. The focus is on connecting theory with practice: students are expected to critically analyze research manuscripts and perform corresponding analysis on relevant biomedical data.

Lecture: 2 Lab: 0 Credits: 2

BME 501

Communication Skills in BME

Students will be taught to communicate biomedical engineering research findings through written, poster, and oral presentation formats. Masters of Science with Thesis and PhD program students will be required to present their own research annually at the BME Seminar while enrolled in their thesis program.

Lecture: 1 Lab: 0 Credits: 1

BME 502

Introduction to Regulatory Science for Engineers

Engineers must be equipped to answer the growing demands for new medical technologies. Introduction to Regulatory Science teaches engineers how the regulated environment impacts the design, testing, and delivery of medical devices. It will equip students with the essential skills and tools critical to the practice of engineering in the medical device industry. In this course, students will be exposed to the core concepts, processes, and tools surrounding the global medical device regulatory framework, and will gain foundational knowledge for the practical application of regulations throughout the product development lifecycle. From knowledge gained in the class, students will be expected to work in teams and use critical thinking, data analysis and interpretation skills to research, evaluate, and present a scientific, technical, and legally justifiable approach for the global introduction of a new medical device.

Lecture: 3 Lab: 0 Credits: 3

BME 503

Mathematical and Statistical Methods for Neuroscience I

This quarter introduces mathematical ideas and techniques in a neuroscience context. Topics will include some coverage of matrices and complex variables; eigen value problems, spectral methods and Greens functions for differential equations; and some discussion of both deterministic and probabilistic modeling in the neurosciences. Instructor permission required.

Lecture: 2 Lab: 0 Credits: 2

BME 504

Neurobiology

This course is concerned with the structure and function of systems of neurons, and how these are related to behavior. Common patterns of organization are described from the anatomical, physiological, and behavioral perspectives of analysis. The comparative approach is emphasized throughout. Laboratories include exposure to instrumentation and electronics, and involve work with live animals. A central goal of the laboratory is to expose students to in vivo extracellular electrophysiology in vertebrate preparations. Laboratories will be attended only on one day a week but may run well beyond the canonical period. Instructor permission required.

Lecture: 2 Lab: 0 Credits: 2

BME 505

Mathematical and Statistical Methods for Neuroscience II

This quarter treats statistical methods important in understanding nervous system function. It includes basic concepts of mathematical probability; information theory, discrete Markov processes, and time series. Instructor permission required.

Prerequisite(s): BME 503 with min. grade of C

Lecture: 2 Lab: 0 Credits: 2

BME 506

Computational Neuroscience II: Vision

This course considers computational approaches to vision. It discusses the basic anatomy and physiology of the retina and central visual pathways, and then examines computational approaches to vision based on linear and non-linear systems theory, and algorithms derived from computer vision.

Lecture: 3 Lab: 0 Credits: 3

BME 507

Cognitive Neuroscience

This course is concerned with the relationship of the nervous system to higher order behaviors such as perception and encoding, action, attention and learning and memory. Modern methods of imaging neural activity are introduced, and information theoretic methods for studying neural coding in individual neurons and populations of neurons are discussed. Instructor permission required.

Lecture: 2 Lab: 0 Credits: 2

BME 508

Mathematics and Statistics for Neuroscience III

This course covers more advanced topics including perturbation and bifurcation methods for the study of dynamical systems, symmetry methods, and some group theory. A variety of applications to neuroscience will be described. Instructor permission required.

Prerequisite(s): BME 505 with min. grade of C and BME 503 with min. grade of C

Lecture: 2 Lab: 0 Credits: 2

BME 509**Vertebrate Neural Systems**

This lab-centered course teaches students the fundamental principles of mammalian neuroanatomy. Students learn the major structures and the basic circuitry of the CNS and PNS. Students become practiced at recognizing the nuclear organization and cellular architecture of many regions in animal brain models. This course is taught at the University of Chicago. Instructor permission required.

Lecture: 3 Lab: 0 Credits: 3

BME 510**Neurobiology of Disease I**

This seminar course is devoted to basic clinical and pathological features and pathogenic mechanisms of neurological diseases. The first semester is devoted to a broad set of disorders ranging from developmental to acquired disorders of the central and peripheral nervous system. Weekly seminars are given by experts in the clinical and scientific aspects of the disease under discussion. For each lecture, students are given a brief description of clinical and pathological features of a given set of neurological diseases followed by a more detailed description of the current status of knowledge of several of the prototypic pathogenic mechanisms.

Lecture: 2 Lab: 0 Credits: 2

BME 511**Extracellular Matrices: Chemistry and Biology**

Advanced topics dealing with the biology and chemistry of the extracellular matrix, cell-matrix interactions, and current methodologies for engineering these interfaces.

Lecture: 2 Lab: 0 Credits: 2

BME 512**Behavioral Neurosciences**

This course is concerned with the structure and function of systems of neurons and how these are related to behavior. Common patterns of organization are described from the anatomical, physiological, and behavioral perspectives of analysis. The comparative approach is emphasized throughout. Laboratories include exposure to instrumentation and electronics and work involvement with live animals.

Lecture: 2 Lab: 0 Credits: 2

BME 513**Methods of Computational Neuroscience: Single Neurons**

Topics include, but are not limited to, Hodgkin-Huxley equations, cable theory, single neuron models, information theory, signal detection theory, reverse correlation, relating neural responses to behavior, and rate versus temporal codes. Instructor permission is required.

Lecture: 3 Lab: 0 Credits: 3

BME 516**Biotechnology for Engineers**

This course will provide students opportunity to learn about the field of biotechnology and how to apply engineering principles to biological systems and living organisms for betterment of medicines as well as agricultural products. The course covers the introduction to biotechnology with information about cell and molecular biology, the role of enzyme and growth kinetics, media preparations for cell culture and various chromatographic techniques, and antibiotics and its role in secondary metabolic production. Biological effluent treatment and regulatory issues to obtain FDA will be taught. Instructor permission is required.

Lecture: 3 Lab: 0 Credits: 3

BME 517**Technologies for Treatment of Diabetes**

Study of physiological control systems and engineering of external control of biological systems by focusing on an endocrine system disorder – diabetes. The effects of type 1 diabetes on glucose homeostasis and various treatment technologies for regulation of glucose concentration. Development of mathematical models describing the dynamics of glucose and insulin concentration variations, blood glucose concentration measurement and inference techniques, insulin pumps, and artificial pancreas systems.

Lecture: 3 Lab: 0 Credits: 3

BME 518**Reaction Kinetics for Biomedical Engineering**

This course is an introduction to the fundamentals of chemical kinetics. Analysis of rate data; single and multiple reaction schemes. Biomedical topics include biological systems, enzymatic pathways, enzyme and receptor-ligand kinetics, pharmacokinetics, heterogeneous reactions, microbial cell growth and product formation, and the design and analysis of biological reactors.

Corequisite(s): BME 482

Prerequisite(s): BME 301 and MATH 252 and BME 335

Lecture: 3 Lab: 0 Credits: 3

BME 519**Cardiovascular Fluid Mechanics**

Anatomy of the cardiovascular system. Scaling principles. Lumped parameter, one-dimensional linear and nonlinear wave propagation, and three-dimensional modeling techniques applied to simulate blood flow in the cardiovascular system. Steady and pulsatile flow in rigid and elastic tubes. Form and function of blood, blood vessels, and the heart from an engineering perspective. Sensing, feedback, and control of the circulation. Includes a student project.

Lecture: 3 Lab: 0 Credits: 3

BME 521**Medical Imaging**

Study of modern technology for medical imaging. Theory and operation of CAT, SPECT, PET, MRI, X-ray and echo imaging modalities.

Lecture: 3 Lab: 0 Credits: 3

BME 522**Mathematical Methods in Biomedical Engineering**

Graduate standing in BME or consent of instructor This course is an introductory graduate level course that integrates mathematical and computational tools that address directly the needs of biomedical engineers. The topics covered include the mathematics of diffusion, pharmacokinetic models, biological fluid mechanics, and biosignal representations and analysis. The use of MATLAB will be emphasized for numerically solving problems of practical relevance.

Lecture: 3 Lab: 0 Credits: 3

BME 523**Cell Biomechanics: Principles and Biological Processes**

This course will provide students an opportunity to learn about mechanical forces that develop in the human body and how they can influence cell functions in a range of biological processes from embryogenesis, wound healing, and regenerative medicine to pathological conditions such as cancer invasion. Examples of research methods for investigating cell biomechanics in various biological systems will be discussed. Permission of instructor is required.

Lecture: 3 Lab: 0 Credits: 3

BME 524**Quantitative Aspects of Cell and Tissue Engineering**

This course is designed to cover fundamentals of cell and tissue engineering from a quantitative perspective. Topics addressed include elements of tissue development, cell growth and differentiation, cell adhesion, migration, molecular and cellular transport in tissues and polymeric hydrogels for tissue engineering and drug delivery applications.

Lecture: 3 Lab: 0 Credits: 3

BME 525**Introduction to Medical Devices, BioMEMS and Microfluidics**

This course will present fundamentals and applications of medical devices, BioMEMS, and microfluidic technologies for applications in the broad health and biomedical engineering. It will provide a broad view of the general field and a knowledge of relevant fabrication methods and analysis techniques. Fabrication and analytical techniques, interfacing with biological materials, and techniques for analyte detection will be emphasized. The course will include individual projects and critical paper reviews in which each student will be encouraged to master basic concepts in design and fabrication for devices for specific applications.

Lecture: 3 Lab: 0 Credits: 3

BME 526**Advanced Biomedical Engineering Design**

This course aims to educate students on project definition, and on the design, development, and technology transfer of potential biomedical products in the context of the student's major capstone project. Students will learn best practices for designing a marketable medical device, including the design process from the clinical problem definition through prototype and clinical testing to market readiness. Permission from instructor is required.

Lecture: 3 Lab: 0 Credits: 3

BME 527**Extracellular Matrix Biology**

This course is the same as the BME 427 Extracellular Matrix Biology course that has been approved for banner listing for Summer 2020. BME527 is the same class to extend this course to graduate students. The Extra Cellular Matrix (ECM) is that which connects cells in tissues and provides much of the organization and support in almost every tissue and or organ system of the body. Thus the aim of this course is to give students insights into ECM biology and its relevance to modern medicine and biomedical (tissue) engineering. A significant portion of working population is suffering from ECM-related maladies, and the focus of research has shifted into creating ECM implants. The ECM implant market is growing rapidly. For instance, the collagen meniscus implant market was reported to be at \$308.6 million in 2018. Understanding the implications of the molecular biology of ECM to feed into this research is highly relevant for students considering careers (academic and industry) in life sciences in industry, academia and healthcare. Extracellular Matrix (ECM) is a highly complex system in mammalian biology responsible for structural support and functional (biochemical) signals for physiology. Specific amino acid sequences on the various ECM elements are responsible to trigger intra- and extracellular cascades leading to cell division, proliferation, tissue regeneration, wound healing and inflammation. This course will focus on the following key concepts: a) Gene expression, structure and function of various ECM proteins and complexes and the physiological processes. b) Etiology and the molecular progression of diseases caused by abnormalities to ECM proteins. c) Mechanobiology of various ECM proteins. d) Structure function and mechanical function of ECM interfaces with other tissues (muscle, bone, skin etc.) e) Implications for tissue engineering and development of novel biomimetic and biological ECM implants.

Lecture: 3 Lab: 0 Credits: 3

BME 528**Engineering World Health**

This course covers the major types of medical equipment, including the principles of operation, the physiology underlying the measurement, the major functional (system) pieces for each instrument, and typical problems/applications of each instrument. Special focus is placed on making reliable and safe repairs in a low resource setting: Troubleshooting, creative problem solving, calibration and testing. Laboratory sessions will focus on learning hands on and technical knowledge required for completing basic electronic and mechanical repairs. Basic electronics through simple power supply design will be covered. Over the course of the semester, the class will travel to a hospital or training laboratory to troubleshoot and repair medical equipment as a group.

Prerequisite(s): MATH 152 and PHYS 221

Lecture: 3 Lab: 0 Credits: 3

BME 530**Inverse Problems in Biomedical Imaging**

This course will introduce graduate students to the mathematical theory of inverse problems. Concept from functional analysis will be applied for understanding and characterizing mathematical properties of inverse problems. This will permit for the analysis of the stability and resolution of image reconstruction algorithms for various existing and novel biomedical imaging systems. The singular value decomposition (SVD) is introduced and applied for understanding fundamental properties of imaging systems and reconstruction algorithms. Instructor permission required.

Lecture: 3 Lab: 0 Credits: 3

BME 532**Medical Imaging Science**

This course is an introduction to basic concepts in medical imaging, such as: receiver operating characteristics, the rose model, point spread function and transfer function, covariance and auto covariance, noise, filters, sampling, aliasing, interpolation, and image registration. Instructor permission required.

Lecture: 3 Lab: 0 Credits: 3

BME 533**Biostatistics**

This course is designed to cover the tools and techniques of modern statistics with specific applications to biomedical and clinical research. Both parametric and nonparametric analysis will be presented. Descriptive statistics will be discussed although emphasis is on inferential statistics and experimental design.

Lecture: 3 Lab: 0 Credits: 3

BME 535**Magnetic Resonance Imaging**

This is an introduction to the Physics and technology of magnetic resonance imaging (MRI). The topics that are covered include: basic MR physics, source of signal, signal acquisition, pulse sequences, hardware, artifacts, spectroscopy, and advanced imaging techniques. Instructor permission required.

Lecture: 3 Lab: 0 Credits: 3

BME 537**Introduction to Molecular Imaging**

This course provides an overview of molecular imaging, a subcategory of medical imaging that focuses on noninvasively imaging molecular pathways in living organisms. Topics include imaging systems, contrast agents, reporter genes and proteins, tracer kinetic modeling. Preclinical and clinical applications will also be discussed with an emphasis on cancer and the central nervous system.

Lecture: 3 Lab: 0 Credits: 3

BME 538**Neuroimaging**

This course describes the use of different imaging modalities to study brain function and connectivity. The first part of the course deals with brain function. It includes an introduction to energy metabolism in the brain, cerebral blood flow, and brain activation. It continues with an introduction to magnetic resonance imaging (MRI), perfusion-based fMRI, Bold fMRI, fMRI paradigm design and statistical analysis, introduction to positron emission tomography, (PET) and studying brain function with PET, introduction to magneto encephalography (MEG) and studying brain function with MEG. The second part of the deals with brain connectivity. It includes an introduction to diffusion tensor MRI, explanation of the relationship between the diffusion properties of tissue its structural characteristics, and white matter fiber tractography techniques. Instructor permission required.

Lecture: 3 Lab: 0 Credits: 3

BME 539**Advanced Medical Imaging**

This course introduces advanced clinical imaging modalities, research imaging techniques, and concepts from image science and image perception. The first part of the course introduces the perception of image data by human observers and the visualization of brain structure and function. It includes an introduction to magnetic resonance imaging (MRI) and a survey of neurological imaging via functional MRI (fMRI). The second part of the course covers image science, clinical imaging applications, and novel research imaging techniques. It includes an introduction to radiation detection and image quality evaluation, a survey of clinical cases, and an overview of new imaging methods.

Lecture: 3 Lab: 0 Credits: 3

BME 540**Wave Physics and Applied Optics for Imaging Scientists**

This course will introduce students to fundamental concepts in wave physics and the analysis of optical wave fields. These principles will be utilized for understanding existing and novel imaging methods that employ coherent radiation. Solutions to inverse scattering and inverse source problems will be derived and algorithmic realizations of the solutions will be developed. Phase contrast imaging techniques and X-ray imaging systems that employ coherent radiation will be studied. Instructor permission required.

Lecture: 3 Lab: 0 Credits: 3

BME 542**Advanced Concepts in Image Science**

This graduate level course introduces students to fundamental concepts in image science that are related to the optimization and evaluation of biomedical imaging systems. Topics covered include: deterministic descriptions of imaging systems, stochastic descriptions of imaging systems, statistical decision theory, and objective assessment of image quality.

Prerequisite(s): BME 532 with min. grade of C and BME 530 with min. grade of C

Lecture: 3 Lab: 0 Credits: 3

BME 543**Bioinstrumentation and Electronics**

Principles of circuit analysis are applied to typical transducer and signal recording situations found in biomedical engineering. Basic electrical and electronic circuit theory is reviewed with an emphasis on biomedical measurement applications. A special topic is individually studied by the student and presented to the class electrical physics class or basic circuits.

Lecture: 3 Lab: 0 Credits: 3

BME 545**Quantitative Neural Function**

Computational approach to basic neural modeling and function, including cable theory, ion channels, presynaptic potentials, stimulation thresholds, and nerve blocking techniques. Synaptic function is examined at the fundamental level.

Prerequisite(s): BME 453 with min. grade of C or BME 553* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

BME 551**Physiological Signal Processing and Control Theory**

This is the first of a 2 part course co-taught at IIT and the University of Chicago. essential elements of signal processing and control theory as it is applied to physiological systems will be covered. Part I will cover data acquisition and sampling, Laplace and Fourier transforms, filtering, time and frequency domains, system descriptions and lumped vs. distributed parameters. Students will use Mat lab to test concepts presented in class.

Lecture: 2 Lab: 0 Credits: 2

BME 552**Control Systems for Biomedical Engineers**

Control systems design and analysis in biomedical engineering. Time and frequency domain analysis, impulse vs. step response, open vs. closed loop response, stability, adaptive control, system modeling. Emphasis is on understanding physiological control systems and the engineering of external control of biological systems.

Lecture: 3 Lab: 0 Credits: 3

BME 553**Advanced Quantitative Physiology**

The main systems that control the human body functions will be reviewed to enable the students to understand the individual role of each major functional system as well as the need for the integration or coordination of the activities of the various systems.

Lecture: 3 Lab: 0 Credits: 3

BME 560**Methods in Biomedical Data Science**

The course provides an overview of predictive and descriptive statistical modeling methods for large biomedical datasets. Building on undergraduate-level knowledge of statistics, the course introduces Bayes and information theory, develops from these modeling algorithms and provides a series of biomedical application areas. Methods include meta-analytic techniques, linear and non-linear dimensionality reduction, traditional "non-deep" predictive tools (e.g. perceptron, support vector machines, logistic regression, decision trees, boosting, etc.), and some applications of deep neural networks. Application areas may include medical imaging (e.g. image segmentation), EEG and ECG signal analysis (e.g. anomaly detection), genetics (e.g. imputation methods, polygenic risk score computation, cell-free DNA analysis, etc.). Each course module involves analysis of real data using existing modeling libraries and students' own implementation. The predictive results may be compared to the state-of-the-art for each example dataset to assess the usefulness of the models. (3-0-3)

Prerequisite(s): (MATH 225 or BME 433 or CHE 426) and (MATH 332 or MATH 333)

Lecture: 3 Lab: 0 Credits: 3

BME 575**Neuromechanics of Human Movement**

This course will explore how we control movement of our extremities, with concepts drawn from mechanics and neurophysiology. The progression from neurological signals to muscle activation and resulting movement of the hand or foot will be modeled, starting at the periphery and moving back toward the central nervous system. Biomechanics of the limbs will be modeled using dynamic simulation software (Working Model) which will be driven by a neural controller, implemented in MATLAB. Issues related to sensory feedback and redundancy will be addresses.

Lecture: 3 Lab: 0 Credits: 3

BME 581**Fluid Mechanics for Biomedical Engineers**

This course is primarily focused on the development of theoretical and experimental principles necessary for the delineation of fluid flow in various in vitro chambers and the cardiovascular system. Its content will primarily deal with the basic concepts of flow in various geometries, the heterogeneous nature of blood and the application of such principles in flow chambers designed to expose blood elements to defined flow conditions. The relationship to flow in the normal and diseased vascular system will also be considered. A basic Fluid Dynamics Course is recommended. Instructor permission required.

Prerequisite(s): BME 500 with min. grade of C

Lecture: 3 Lab: 0 Credits: 3

BME 582**Advanced Mass Transport for Biomedical Engineers**

This course is primarily focused on the development of theoretical and mathematical principles necessary for the delineation of mass transport processes in biological & medical systems. The content includes heterogeneous reactions that occur at or in the vicinity of cells or vascular structures under applied laminar flow and transport across cell membranes and within tissues.

Lecture: 3 Lab: 0 Credits: 3

BME 585**Computational Models of the Human Cardiovascular System**

This course will focus on the use of computational fluid dynamics for the modeling and analysis of the human cardiovascular system. The course will cover both computational methods for fluid dynamics and biomedical aspects of the human cardiovascular system. Computer models for the simulation and analysis of hemodynamic phenomena will be developed. Requires an Introductory fluid dynamics.

Lecture: 3 Lab: 0 Credits: 3

BME 591**Research and Thesis for Master of Science Degree**

Research and thesis for master of science degree students. Instructor permission required.

Credit: Variable

BME 594**Special Projects**

Special projects.

Credit: Variable

BME 595**Seminar in Biomedical Engineering**

Current research and development topics in biomedical engineering as presented by outside speakers, faculty and advanced students.

Lecture: 0 Lab: 1 Credits: 1

BME 597**Special Problems**

Special problems.

Credit: Variable

BME 691**Research and Thesis PHD**

Research and Thesis for PhD degree. (variable credit)

Credit: Variable

ENGR 502**Medical Device Regulations and Commercialization**

This course helps prepare students for commercializing medical devices within a highly-regulated environment. Concepts include protecting intellectual property, the structure and scope of the Federal Drug Administration (FDA), developing, testing, producing and marketing medical devices under FDA regulations, total product lifecycle, and quality management.

Lecture: 3 Lab: 0 Credits: 3

ENGR 510**Strategic Engineering Management**

This course will review technology-based enterprises and the driving forces that impact corporate strategy. Students will learn how to apply engineering knowledge to determine technology/product direction and make/buy/partnering decisions. Relationships between research and development, operations, finance, marketing, and other functions within engineering-based organizations that drive strategic decisions will be examined. Strategy development and competitive analysis will be included. Case studies from the industry relevant to the student's engineering track will be reviewed.

Lecture: 3 Lab: 0 Credits: 3

ENGR 520**Best Practices in Engineering Project Management**

Many engineering projects suffer due to weak business cases, schedule slippages, and cost overruns. This course presents commonly used tools and techniques and best practices to build an effective business case, develop a realistic schedule and budget, and successfully execute and complete a project. Students are introduced to a generic project management life cycle model, review basic project management principles, tools, and techniques, and learn engineering-tailored best practices used by high performing, project-centric organizations. Students have an opportunity to apply selected tools in the form of short classroom exercises.

Lecture: 3 Lab: 0 Credits: 3

ENGR 521**Risk Management in Engineering Projects**

In project management, a risk is considered an uncertain event that may have a positive or a negative impact on project objectives. Managing identified threats individually through customized strategies is key to project success. Similarly, opportunities must be leveraged for better project outcomes. Implementation of an effective risk management process is imperative for today's complex projects. This course presents a five-step process to manage project threats as well as opportunities. On every project, students will be able to identify and analyze risks and develop response strategies for each identified risk and take proper response action to manage the risks. Industry best practices and quantitative tools and simulations are used to analyze risk.

Lecture: 3 Lab: 0 Credits: 3

ENGR 531**Urban Systems Engineering Design**

ENGR 531 is a project-based course where students will explore integrated designs of urban systems. Each project will apply the students' engineering disciplines (such as structures, transportation, building science, construction engineering and management, environmental engineering) in a comprehensive analysis that considers the economic, human, and environmental issues associated with the project.

Lecture: 3 Lab: 0 Credits: 3

ENGR 532**Urban Systems Engineering Seminar**

ENGR 532 is an active seminar course that emphasizes current topics in urban systems engineering. Invited speakers will include researchers and representatives from current practice, such as municipal and regional planners and consultants. Appropriate readings will be assigned in advance of each speaker to guide students in preparation for active discussion with each speaker. Each student will also write a term paper on an urban systems engineering topic of their choice, connecting material from the assigned reading, the speakers, and additional references selected by the student.

Lecture: 3 Lab: 0 Credits: 3

ENGR 534**Product Design and Innovation**

This course covers all aspects of planning new products or services that are commercially viable and add to a company's suite of offerings. It includes such topics as user research, market analysis, need/problem identification, creative thinking, ideation, concepting, competitive benchmarking, human factors, prototyping, evaluation, and testing. The course includes creative, analytical, and technical skills in a balanced approach using such teaching methods as case studies, individual exercises, and group projects.

Lecture: 3 Lab: 0 Credits: 3

ENGR 539**Robotic Motion Planning**

Configuration space. Path planning techniques including potential field functions, roadmaps, cell decomposition, and sampling-based algorithms. Kalman filtering. Probabilistic localization techniques using Bayesian methods. Trajectory planning.

Lecture: 3 Lab: 0 Credits: 3

ENGR 572**Construction Cost Accounting and Control**

Review of basic accounting principles and techniques – purchasing, accounts payable, invoicing, accounts receivable, general ledger, payrolls, and indirect costs. Job costing and budgeting. Recording and reporting procedures in construction projects – invoices, subcontractor applications for payment, labor time cards, unit completion reports, change orders. Cost coding systems for construction activities. Variance reporting procedures. Project closeout. Class exercise using computer program.

Lecture: 3 Lab: 0 Credits: 3

ENGR 573**Construction Contract Administration**

Characteristics of the construction industry. Project delivery systems. Duties and liabilities of the parties at the pre-contract stage. Bidding. Contract administration including duties and liabilities of the parties regarding payments, retainage, substantial and final completion, scheduling and time extensions, change orders, changed conditions, suspension of work, contract termination, and resolution of disputes. Contract bonds. Managing the construction company. Labor law and labor relations.

Lecture: 3 Lab: 0 Credits: 3

ENGR 574**Economic Decision Analysis in Civil Engineering**

Basic economic concepts including interest calculations, economic comparison of alternatives, replacement decisions, depreciation and depletion, tax considerations, and sensitivity analysis. Evaluation of public projects, the effect of inflation, decision making under risk and/or uncertainty, economic decision models. Case studies from the construction industry.

Lecture: 3 Lab: 0 Credits: 3

ENGR 575**Systems Analysis in Engineering**

Management and system concepts, linear programming, graphical methods, Simplex, two-phase Simplex, the transportation problem, the assignment problem, integer programming, and sensitivity analysis. System modeling by activity networks; maximal-low flow, longest-path and shortest-path analyses, flow graphs, decision-tree analysis, stochastic-network modeling, queuing systems, and analysis of inventory systems. Case studies from the construction industry.

Lecture: 3 Lab: 0 Credits: 3

ENGR 576**Nano Manufacturing**

This course covers the general methods used for micro- and nano-fabrication and assembly, including photolithography techniques, physical and chemical deposition methods, masking, etching, and bulk micromachining as well as self-assembly techniques. It also covers nanotubes, nanowires, nanoparticles, and the devices that use them, including both electronic and mechanical-electronic systems, as well as nano-structural materials and composites. Focus is on commercially available current processes as well as emerging technologies and evolving research areas. Sensing and instrumentation as well as nano-positioning and actuation are covered briefly.

Lecture: 3 Lab: 0 Credits: 3

ENGR 587**Introduction to Digital Manufacturing**

This course is about the digital revolution taking place in the world of manufacturing and how students, workers, managers, and business owners can benefit from the sweeping technological changes taking place. It is about the change from paper-based processes to digital-based processes all through the design/manufacturing/deliver enterprise, and across the global supply chain. It touches on digital design, digital manufacturing engineering, digital production, digital quality assurance, and digital contracting, from large companies to small. There is also a significant focus on cyber security and the new types of threats that manufacturers face in the new digital world. Other topics covered include intelligent machines, connectivity, the digital thread, big data, and the Industrial Internet of Things (IIoT).

Lecture: 3 Lab: 0 Credits: 3

ENGR 588**Additive Manufacturing**

This course examines the fundamentals of a variety of additive manufacturing processes as well as design for additive manufacturing, materials available, and properties and limitations of materials and designs. It also examines the economics of additive manufacturing as compared to traditional subtractive manufacturing and other traditional techniques. Additive techniques discussed include 3D printing, selective laser sintering, stereo lithography, multi-jet modeling, laminated object manufacturing, and others. Advantages and limitations of all current additive technologies are examined as well as criteria for process selection. Processes for metals, polymers, and ceramics are covered. Other topics include software tools and connections between design and production, direct tooling, and direct manufacturing. Current research trends are discussed.

Lecture: 3 Lab: 0 Credits: 3

ENGR 592**Engineering Management Capstone Experience**

Students apply the knowledge they have acquired in the Engineering Management program to a specific problem or case study. Projects will be identified and mentored in conjunction with faculty and industrial partners. A final report or business plan is required that reflects the focus of the capstone project.

Lecture: 3 Lab: 0 Credits: 3

ENGR 595**Product Development for Entrepreneurs**

Elements of product development (mechanical and electrical), manufacturing and production planning, supply chain, marketing, product research, and entrepreneurship concepts are taught in this class. In this course, student teams will be required to create a compelling product that has potential to be sold in today's marketplace. They will be required to create functional prototypes of their product for people to use and critique. If successful, students will be allowed to put their product on Kickstarter.com and take orders for delivery after the class is complete while potentially fostering their own business as a result of this course.

Lecture: 3 Lab: 0 Credits: 3

ENGR 596**Practical Engineering Training**

This course is a mentored, immersive practical engineering training. Students learn under the direction of professional engineers and practicing engineers by working on real engineering projects. The student will perform hands-on engineering, including learning and developing/applying engineering principles and concepts to complete the project assigned to the student. The student will apply engineering ethics and safety during their practical engineering training. Students will communicate the results of their work in written and oral communications. Students will receive assignments of varying complexity consistent with their graduate standing.

Lecture: 0 Lab: 9 Credits: 3

ENGR 598**Graduate Research Immersion: Team Project**

This course provides a faculty-mentored immersive team-based research experience. Research topics are determined by the faculty mentor's area of research. In addition to the mentored research, students participate in seminars, prepare a written report of their research findings, and present their research findings at a poster expo.

Lecture: 3 Lab: 0 Credits: 3

ENGR 599**Graduate Research Immersion: Individual**

This course provides a faculty-mentored immersive research experience. Research topics are determined by the faculty mentor's area of research. In addition to the mentored research, students participate in seminars, prepare a written report of their research findings, and present their research findings at a poster expo.

Lecture: 3 Lab: 0 Credits: 3